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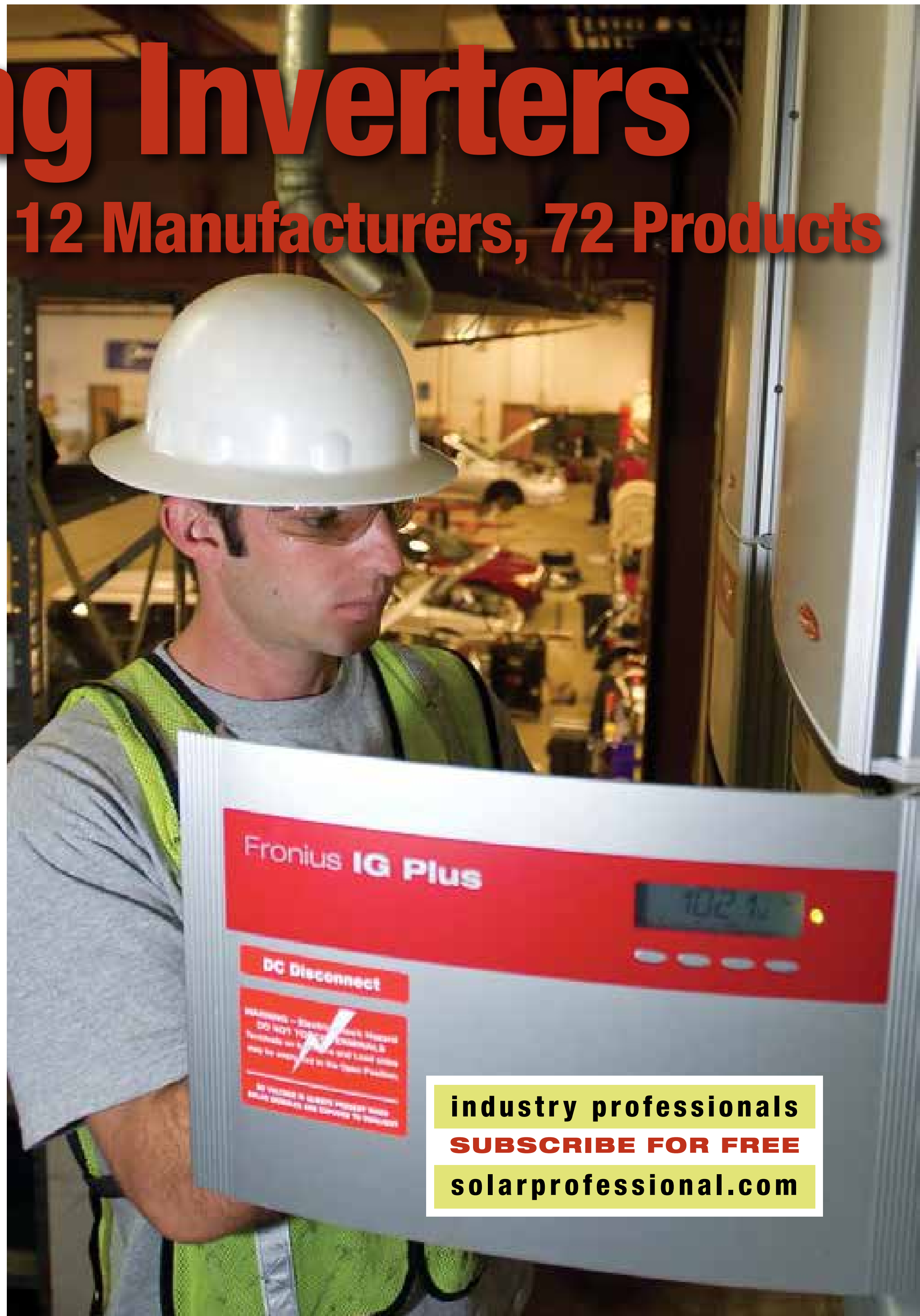

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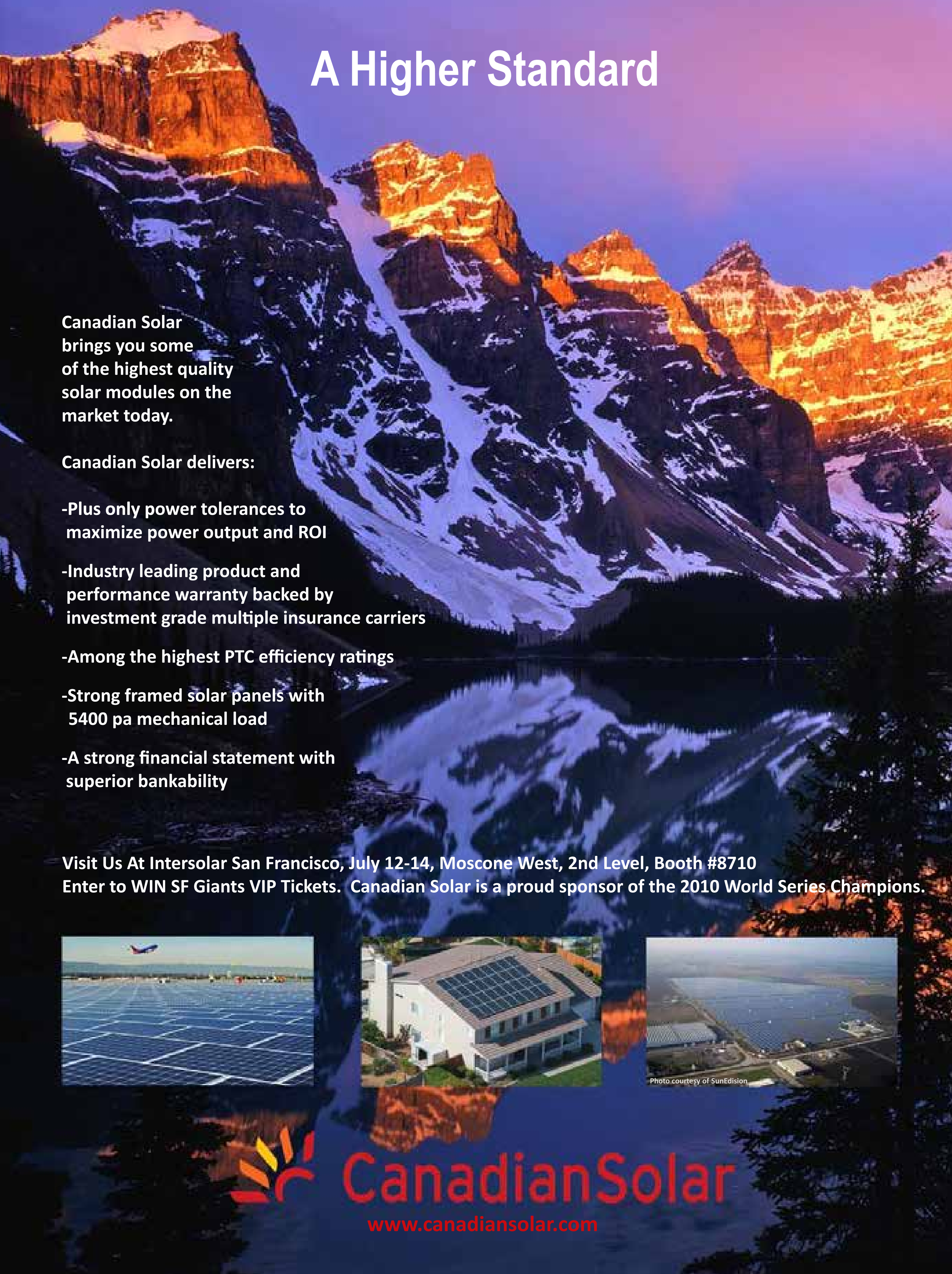

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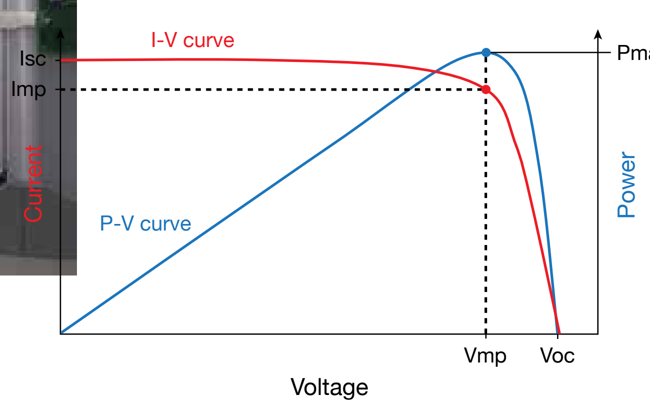

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ON THE COVER Five 11.4 kW Fronius IG Plus inverters process the PV power at Pickering's Auto Service Center in Lakewood, CO. The 55.5 kW system was designed and installed by Golden, Colorado-based Cascade Solar USA. The roof-mounted array utilizes 248 Sharp modules installed on IronRidge racking.
Photo by Topher Donahue


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Kohl Christensen, Oahu, Hawaii
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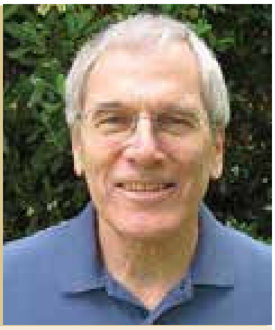
Contributors

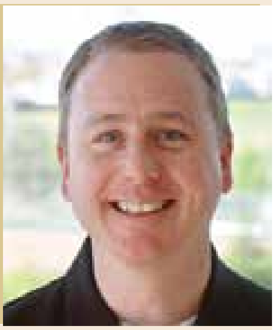
Experience + Expertise

Paul Hernday is an applications engineer with Solmetric, where he focuses on PV array performance testing and troubleshooting. He developed electrical test equipment with HP and Agilent Technologies for 33 years, and gained a year of PV field experience with North Bay Solar Electric before joining Solmetric. Paul instructs on PV topics at industry workshops and train-the-trainer events, as well as community events in Northern California.



Ethan Lipman started his solar career atop a commercial roof in 2006 with Borrego Solar Systems. Since then, he has been designing and permitting PV systems from residential to megawatt scale and creating tools to make the design process more efficient. Since going freelance, Ethan has branched out into policy issues, working to streamline permitting with Vote Solar's Project: Permit. He holds a BS in mechanical engineering from UC Davis and is a NABCEP Certified Solar PV Installer.

Greg Smith is a technical trainer at SMA America, the US-based subsidiary of global SMA Solar Technology AG, headquartered in Germany. He develops, designs and maintains curricula for SMA's state-of-the-art Solar Academy, where attendees of all skill levels—from novice to expert—can learn about SMA products, code compliance and installation best practices. Prior to joining SMA, Greg spent 20 years in the US Navy, most recently as a certified master training specialist.



PV Design Engineer **Mat Taylor** has been in the solar industry since the early 1990s. He is the lead PV designer for utility-scale projects at Quanta Renewable Energy Services, where he provides analysis and compliance methods for performance guarantees. Mat holds MS degrees in engineering and architecture.

David Williams is the CEO of dissigno, an international solar asset management services firm. He has managed the technical development, installation and operations of 42 MW of solar at more than 50 plants across the US, working with dozens of equipment manufacturers, integrators and investors. David has also worked on renewable projects in the Czech Republic, Tanzania, Morocco, South Africa and Australia.

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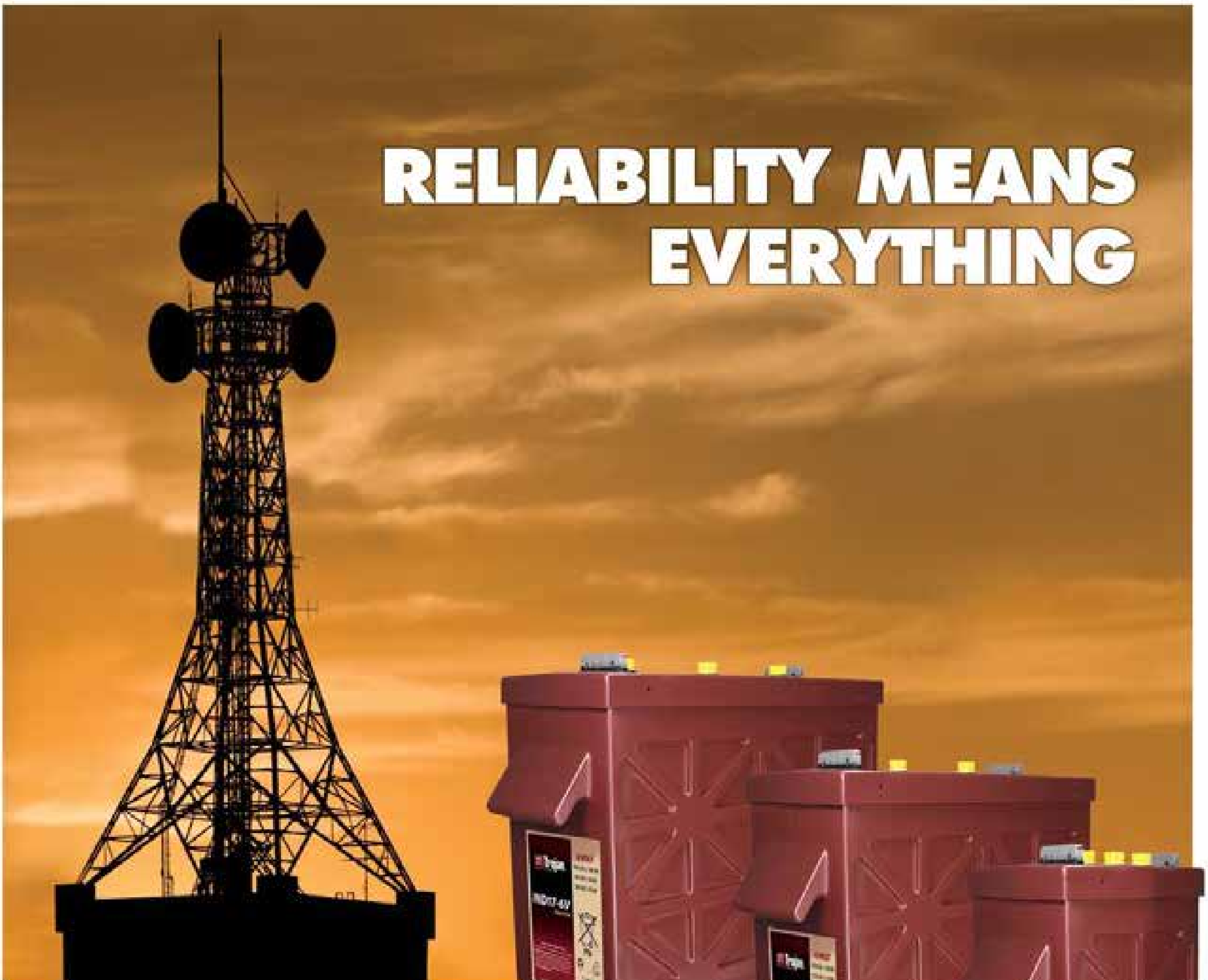

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Two Takes on Training

High-quality, ongoing training is a core component of improving productivity and maintaining high-functioning integration teams. Here, we present two perspectives on developing and executing successful training programs. First, Greg Smith, a technical trainer for SMA Solar Academy, details the process of developing a training program. Next, Blake Gleason, director of engineering for Sun Light & Power, shares an integrator's perspective on staff training.

Creating Quality Training Programs

According to the Solar Energy Industries Association, the solar market grew last year by 67%. This growth created an increase in jobs, installations and megawatt-hours injected into the grid. The resulting new workforce needs training to ensure efficient, effective and—most important—safe installation practices. Topics covered can include site surveying, electrical safety, *National Electrical Code* compliance, permitting, product knowledge and system design.

If you are looking for a training program, you have many resources at your disposal. If you are the one standing in the front of the room, you face several challenges. These include ensuring that the course content is appropriate for the intended audience, utilizing the applicable classroom equipment and learning materials, and speaking confidently during the presentation. However, these challenges can be met through a systematic approach to course development.

Course Development

This article focuses on a modified analysis, design, development, implementation and evaluation (ADDIE) method that adds a planning phase. The following course development phases can be applied to any training program to help ensure its success.

Phase 1: Plan. As the saying goes, no one plans to fail, but many fail to plan. During the planning phase, you should identify your resources. To effectively teach a class, how many demonstration inverters, modules, multimeters, ladders, calculators, wire strippers and so on do you need to have available? How large is your training room, and what is your maximum class size? Is the room properly lit? Where should the projector be located? The first step in your course planning is to address basic questions such as these.

Phase 2: Analyze. Who is your target audience? Are they your own employees, people who buy and install your product, or individuals new to the industry? You must determine why training is needed by doing a job task analysis, whereby you describe and record the tasks of the job that you are training on and specify the skills and requirements necessary to perform them. For instance, if you have noticed an increase in the number of accidents on the job site, how can you design a safety program to prevent more from happening? Careful analysis provides key factors that determine your curriculum.

Phase 3: Design. The design phase is perhaps the most important. If this phase fails, your training program will eventually fail. As you design the course, you will need to meet with subject-matter experts to CONTINUED ON PAGE 18

Microsoft PowerPoint is the preferred medium for most instructor-led lessons in our industry. Unfortunately, instructors often abuse PowerPoint, either by emphasizing style over substance with too many flashy animations and transitions, by using slides covered entirely by text, or by reading slides word-for-word while facing the screen. These practices can lead to bored attendees who are anxious to leave. Avoiding these mistakes helps to make your presentation more effective and engaging.

determine the content, such as *NEC* requirements, electrical safety, the use of shade analysis tools and how an inverter works. The end product of any brainstorming sessions should be a list of goals or objectives that are not only realistic, attainable and measureable but are also targeted to a specific course design.

Knowledge-based and task-based course design each use their own set of learning goals. (See Diagram 1.) Knowledge-based design focuses on theory and concepts, and utilizes course and topic learning objectives. Course learning objectives (CLOs) are broad learning goals for the entire course. CLOs are driven by topic learning objectives (TLOs), which are more specific goals that accomplish the criteria set forth in the CLOs. TLOs are derived from the job task analysis performed in Phase 2 and are the basic knowledge requirements of the entire course. Task-based design focuses on skill sets and hands-on lessons using terminal objectives and enabling objectives, which follow the same guidelines as CLOs and TLOs, respectively.

Think of an outline that starts with the broad goals defined in the CLOs and then becomes more specific as you move down toward the terminal objectives. Each goal must have a behavior, condition and assumed standard, and should follow this preamble: "Upon successful completion of this training program, you will be able to...."

The description of each behavior should include a very specific verb. Behavioral verbs include *connect, demonstrate, label, describe, evaluate, interpret, measure* and *solve.* Verbs such as *understand* and *know* are too vague and difficult to measure. Next, the condition describes how a behavior is to be achieved. Finally, the assumed standard is 100% or some other specified standard.

For example, an installer attending a class on the *NEC* might be given this

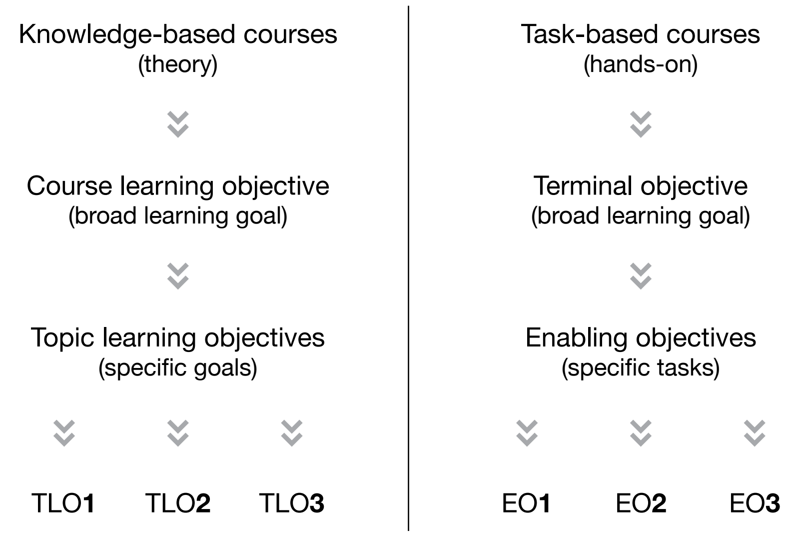

Diagram 1 Both knowledge-based classroom training and hands-on training should be driven by clearly defined learning goals and the specific skills necessary to achieve those goals.

goal: "Upon successful completion of this lesson, you will be able to describe the *NEC* Articles on grounding related to a PV installation from memory with 100% accuracy." The behavior is to describe the *NEC* Articles on grounding related to a PV installation. The condition is to describe them from memory. The assumed standard is to describe them with 100% accuracy.

If you plan to register the course with the North American Board of Certified Energy Practitioners (NABCEP), then it is very important to implement the NABCEP standards in the design phase. Note that people are NABCEP certified, while courses are NABCEP registered.

Phase 4: Develop. Deliverables in Phase 4 include instructor guides (lesson plans), trainee guides, instructional materials (charts, videos, *NEC* handbooks and so on), software, handouts (diagrams, schematics, outlines, wiring exercises and so on) and testing plans.

The final element of Phase 4 is a pilot course in which you practice with volunteers, including subject-matter experts. Practice delivery of every element of the course and refine the presentation. For example, can you get through all 600 slides in 3 hours? Do you need more time for attendees to mount the modules? Are there enough scheduled breaks? Are there enough electrical outlets?

Phase 5: Implement. Once you have tested the course through the pilot program in Phase 4 and you are satisfied with the curriculum, there is only one thing left to do: start teaching!

Phase 6: Evaluate. Congratulations on finally starting your course—but your work is not over. Course evaluation continues for the lifetime of your training program. It is crucial to consistently monitor, review and revise course content to ensure fresh, up-to-date material. Nothing erodes your credibility faster than referencing an article in the 2005 *NEC* when the AHJ uses the 2011 *NEC.* Did you remember to add that new fastener option or software program? What about that new product launched just last month?

The best way to keep your courses relevant is to keep them maintained. Course maintenance relies heavily on two forms of feedback: internal and external. Internal feedback comes from in-house appraisals, while external feedback is from CONTINUED ON PAGE 20

outside your organization, such as feedback from course attendees.

Regardless of the audience, prepare a feedback form with meaningful, targeted questions. It is important to budget time into your course for evaluation purposes. Feedback forms are generally passed out at the end of the day, when attendees are tired, hungry or in a rush to beat traffic. Including an evaluation period within the agenda sets an appropriate time expectation with the class.

Ask only a few questions, and require the reader to rate something on a scale from 1 to 5 or from "poor" to "excellent" so the form is not overly time-consuming. In addition, questions that ask for short, concise responses yield a higher response rate and provide the instructor and course designers with meaningful feedback with which to adjust the course.

You should always welcome feedback, including the negative kind. Do not shred the feedback forms that have less-than-desirable comments, as those are often the most helpful. For example, if you notice that one or two attendees per class mention the poor room lighting or awful food, then perhaps those items should be addressed. Although these comments have nothing to do with the course content, they might have kept your students from paying attention to your presentation.

Testing is another way to gauge training effectiveness. Test analysis can help identify areas of the course that need to be addressed. Does everyone miss question number six? You should confirm that it is appropriately covered in the presentation.

Testing is a complex subject. I recommend taking advantage of the many online resources that show step-by-step guides on how to develop proper testing programs. One such resource is the Interstate Renewable Energy Council (irecusa.org), which evaluates programs and trainers to ensure quality in renewable energy instruction and course content.

Take into Account the Human Element

The final piece of a training program is the instructor. It is challenging to find the right mix of traits that blend with the course material and resonate with your audience. In my experience, most salespeople are great for a features and benefits training program, but they tend to lack the requisite knowledge to successfully execute in-depth technical training. Conversely, some technical trainers have an impressive amount of knowledge, but they can put the class to sleep with an uninteresting presentation style.

These are sweeping generalizations, of course, but the good news is that both types of trainers (and those in between) can benefit from instructional training. A quick web search with the key words

Courtesy SMA America

Hands-on training Greg Smith gives trainees an overview of inverter topology during an SMA Solar Academy course.

"train the trainer" yields an extensive list of resources dedicated to making you the best instructor possible. Many programs cover adult learning theories and how to effectively target the many ways and styles of learning.

Additional Tips

In addition to following a systematic approach for course design, it is helpful to have a short list of tips to use in everyday training. Here are mine, based on lessons I have learned over the years from developing, designing and executing various training programs.

1. Tell your audience what you are going to teach, teach them and then tell them what you taught them.
2. You do not know everything! Never try to fake it—your students will call your bluff.
3. Keep your students engaged. Good teachers know how to keep the class stimulated and involved, even if the content is dry.
4 Keep up-to-date on your own training. Attend workshops, online courses or even college classes that directly contribute to your professional knowledge.
5. Keep records of all classes and attendees.
6. You are the instructor and presenter. You have achieved a level of credibility just by standing behind that podium. It is not necessary to provide an overabundance of trivia just to impress your audience.
7. Teach for no longer than 75 minutes without a break. People need to relax, visit the restroom and get some coffee.
8. Do not use verbal connectors such as "uh," "um" and "er." They do not necessarily correlate to nervousness or anxiety. Most of the time, the connector slips out because the brain is being taxed with something else besides talking. While these slips can be

eliminated with a little practice, it usually takes someone else pointing them out first.

Finally, have fun and be passionate about your subject matter. Enthusiasm is contagious.

—Greg Smith / SMA America / Rocklin, CA / sma-america.com

Keeping Up with Staff Training

At Sun Light & Power, a design/build solar integrator, we take training seriously. We have a variety of job positions that require specialized knowledge and skills. As we grow and add positions, we need to train new team members. As the industry grows and new products and technologies appear—and as we develop better standards and best practices—we need to train and retrain current team members. Our design consultants, engineers, project managers and installers all need both general and focused training. In order to do our best as a company, we need to do a lot of training.

Some training is general and cross-departmental. All staff members should have enough background knowledge about solar technologies to understand how their work fits into the larger picture. To this end, we have recurring training programs called *PV University* (PVU) and *Solar Thermal University* (STU). These eight 2-hour sessions cover topics from basic solar design to basic electrical and structural design and installation, and they are open to all staff members. An engineer and a foreperson usually teach each session. We hold PVU and STU about once per year or as needed. We have a well-documented curriculum that allows new instructors to participate without having to reinvent the wheel each time. Teaching these basic materials is a great way for veterans to solidify and update their knowledge base.

Another successful training program is the *Foreperson Forum,* a biweekly one-hour meeting. All of the people directly in charge of field quality control share tips and agree on the details of our best practices. We started holding this meeting 6 or 7 years ago when we realized that our most experienced installers, once promoted to forepersons, would be running their own crews and no longer be working with the other forepersons. Rather than let standards and practices diverge, we try to bring everyone back to the same page and continue to learn from each other. In addition, all of our PV forepersons are NABCEP Certified Solar PV Installers, which helps ensure that they have the same basic knowledge foundation.

Courtesy Sun Light & Power

Focused crew training Sun Light & Power engineers and field crewmembers assemble a SunLink Roof Mount System during an in-house training session.

Naturally, we also offer some highly specialized training programs. For field crews, topics range from safety to electrical to equipment operation to manufacturer-specific installation methods. Each topic typically requires both classroom and hands-on training.

In-House or Outsourced?

Some training programs are more appropriate taught in-house; some are better outsourced. Some can be taught in large groups; others work with only a few people at a time. Some are best taught on the job; others require a formal, focused session at the office or warehouse. For example, within the electrical training category, specific topics include conduit bending (very hands-on with a combination of focused warehouse practice and on-the-job training), PV-specific *NEC* issues (mostly classroom and relatively large group sessions), and "Tugger Training" (a small-group in-house training program focusing on safe and effective setup of our particular equipment).

In contrast to electrical training, we have found that lift equipment training is best outsourced. Many rental yards have decent-quality, low-cost training programs for the equipment they rent. We have had success outsourcing training for scissor lifts, telescoping reach lifts, forklifts and boom lifts, for example. When we do not have a regular curriculum developed for a topic under consideration, and all of our potential trainers are plenty busy, outsourcing saves a lot of in-house time and resources.

In general, outsourced training seems to work best for certain circumstances. Training on product-specific installations, such as a ballasted racking system, is most CONTINUED ON PAGE 24

effectively turned over to the manufacturer, especially when the product is new or redesigned. When we lack in-house expertise on any given topic, we hire an expert trainer. When the topic requires significant equipment and space, or elaborate setups for hands-on teaching, we are glad to outsource to a dedicated training facility. When only a handful of people need the training, or people need the training on a rolling basis, we call on outside professionals. We find that outside trainers usually do not mind if we send a limited number of participants because they enroll people from other companies to get a critical mass. Also, anytime third-party certification is required, useful or respected—such as some OSHA training programs, first aid and CPR, or NABCEP continuing education credits—we look to outside professionals.

Courtesy Sun Light & Power

Taking safety seriously Members of the Sun Light & Power team receive training on the requirements of perimeter marking for controlled access zones.

However, outsourced training can have several downsides. It can be difficult to find excellent instructors. Not all professional trainers are expert, knowledgeable or even competent! There is little more frustrating than sending people to an all-day training session only to hear: "We couldn't wait to get out of there," "We could have taught the class," "He couldn't answer any of our questions" and "We *paid* for that?"

Cost is a definite consideration. In addition to the sometimes-large fees associated with third-party training, there are time and environmental costs for each trainee travelling to and from a training site.

When the expert knowledge required to hold an excellent training program is not contained or developed within our company, we may not have access to the outsourced expertise when questions arise or further refinements are required. Sometimes in-house training and certification is simply preferred, such as when covering topics for which we want to certify people to our specific curriculum of best practices or our specific processes.

We have had success combining outsourced with in-house training. This strategy works particularly well when an all-day outsourced training can be distilled into 15 minutes of useful information. For example, we might send a few people as test cases to evaluate an instructor and training program. Typically, we get one of three responses: "There was no value;" "That training was fantastic and everyone who can should attend next time;" or "Here are the three things I learned that I can easily share." In the last case, which is the most common, we then arrange to have the attendee give a short in-house training to communicate the relevant knowledge.

The Right Instructor and Schedule

After management has established the need and budget for a particular training program, instructors must be identified. Instructors are not necessarily the top experts in our company. Sometimes it is better to have someone knowledgeable about the topic, but often it is better to have an instructor the audience knows and trusts. Someone who is well respected, such as the lead foreperson, can be an excellent instructor for a group of installers. Even better, we like to have a team of instructors: one person who is close to the audience (lead instructor) and one who is a subject expert (sidekick instructor) who can answer detailed questions and provide backup to the lead instructor.

Deciding who makes the best instructor depends on the topic and its complexity. For strictly rules-based training, such as most safety topics, we lean toward the instructor who already has the respect of and a direct connection to the audience. For a topic like electrical theory, we pick an instructor who has expert knowledge about the topic and can cogently share that with the audience.

Finally, the training event itself must be planned. Especially for field crew training, the challenge is primarily one of scheduling. Therefore, we prefer to have the person who normally schedules the crews take charge of scheduling the training sessions. If possible, the sessions can be coordinated with other times when everyone is gathered, such as safety meetings, or at the beginning or end of the day. If topics and instructors are always ready to go, rainy days can work well. Naturally, they are a bit less predictable.

—Blake Gleason / Sun Light & Power / Berkeley, CA / sunlightandpower.com

QA

Geotagging Digital Photos

Digital photography is an important component of project development. When it comes time to visit a project site, a developer might return with hundreds of photographs documenting existing site conditions, proposed equipment locations and potential sources of shading. As preliminary designs are reworked into final plans, permits are obtained and construction crews complete the physical installation, many hundreds of site photos are captured along the way. After construction is completed, digital photography can be used to provide evidence of good workmanship and as-built conditions.

These project photos get stored on laptops, PCs, company servers and flash drives, which are easily lost. They get emailed around at high resolution, clogging up inboxes. The task of searching through 500 photos for a certain shot of a particular piece of switchgear is akin to looking for a needle in a haystack. Worst of all, it is difficult for people who have never been out to the jobsite to orient themselves while looking through a disorganized photo archive.

Picturing the Future

Fortunately, it does not have to be this way. We can make major productivity improvements simply by leveraging readily available equipment and software—like GPS-enabled digital cameras and cloud storage services—to capture and organize digital photographs. By using digital photography more effectively, we can improve communications and reduce IT headaches.

Geotagging. Just as a digital photograph includes metadata that identifies the date and time when the photo was taken, the file can also be tagged with data about its geographic location, a process known as *geotagging*. While automatically capturing these data points is only possible with a GPS-equipped camera or smartphone, these devices are more common than many people realize.

The Apple iPhone 3G was the first smartphone with integrated GPS to make geotagging simple. Subsequently, high-resolution cameras and GPS functionality have become standard features on all smartphones. Now, presumably in an effort to help retain market share, every major point-and-shoot digital camera manufacturer offers at least one GPS camera, often in the $300-or-less price range. Examples of common consumer cameras with GPS on-board available at press time include the award-winning Casio EX-H20G (pictured below), the Panasonic DMC-ZS7 and the Sony HX5V. The higher-priced Ricoh G700SE is targeted specifically at professional and industrial applications.

Project developers currently underutilize geotagging, but it is very useful. When enabled, GPS latitude and longitude coordinates are embedded into each photo. In many cases, a compass bearing that indicates the camera lens direction is also included. Taking geotagged photos means that you and your colleagues no longer have to search through a folder on the server full of JPEG files with cryptic names like IMG0189. Instead, you can look at a map of a job site with site photos layered on top of it, showing where the photographer was standing when each picture was taken. While a large construction or surveying firm might have geographic information system (GIS) software running on its desktops and servers with add-on software for incorporating photo geolocation, I have found that solar companies can accomplish the same general goal using free or low-cost consumer products and services, like Google's Picasa Web Albums.

Courtesy Casio

Hybrid-GPS camera The innovative Casio EX-H20G uses a combination of motion sensors and standard GPS to track your location, even when GPS satellite signals are unavailable.

While GPS coordinates for geotagged photos are not always perfect, I have found them to be accurate within 5 feet when I am standing on the rooftop of a building with nothing above me but blue sky. If a site is suitable for solar power, it also has an unobstructed view of GPS satellites. If a photo is tagged with an inaccurate location, you can easily correct the data using software like Google's Picasa. If you use an iPhone to take your pictures, you can even fine-tune the geolocation data for important photos while still on-site with an app called Geotag Editor. Soon, there may be no need to fine-tune recorded locations. The next generation of GPS satellites, which will be launched into orbit over the next couple of years, will be able to pinpoint locations with 10 times greater accuracy than current satellites.

Cloud storage. Companies like Apple and Google have already developed consumer software that addresses many of the pain points around organizing and sharing digital photographs. Many of us are familiar with photo management programs like iPhoto and Picasa, and photo sharing websites like Flickr and Picasa Web Albums. However, most people probably use these tools only for their personal photo collections. That is shortsighted.

There are clear advantages to using Google's Picasa Web Albums cloud storage service CONTINUED ON PAGE 28

QA

for managing project photos. Employees can access photos from any Internet-connected device. It is easy to share photos without clogging email with large attachments. It is simple to share an album securely with an external partner. People can even upload photos to Picasa Web Albums from their smartphone. One huge benefit of Picasa Web Albums is that it recognizes geolocation data embedded in photos.

Commercial- and utility-scale power plant development depends heavily on the wealth of aerial imagery found in Google Earth. Thanks to online satellite mapping, we can learn an enormous amount about a project site without leaving the office. Project developers can easily measure parcels of land, evaluate topography and drop in location-specific site notes without ever touching a CAD program. When it comes time to visit a project site to validate assumptions made from afar, Google Earth becomes even more valuable when geotagged project photos are layered right on top of satellite imagery that includes markups and site notes. Saving and sending KML files from Google Earth also provides an incredibly lightweight way to communicate all

Courtesy Ethan Lipman (2)

Photos in context This screen capture illustrates how geotagged project photos stored online using Google's Picasa Web Albums can be visualized in the context of Google Earth satellite data. The red pins on the aerial map on the right indicate the approximate location from which each photograph was taken during the site walk.

Fine-tuning If the geolocation for a digital photo is not precise enough, simply fine-tune it in Picasa, as shown here.

this location-specific information. (Web exclusive: visit solarprofessional.com to download a sample KML file.)

Since most solar power plants are expected to operate for more than 25 years, installation companies are wise to document their work with photographic proof of equipment installed correctly. Once Google Earth's aerial views are updated to include the completed solar power installation, geotagged photos layer right on top of the satellite view, indicating where the work was performed. You now have evidence of what the wiring in Combiner Box #32 looks like, along with its location within the context of an aerial photograph.

Google is not the only game in town for storing and sharing photos in ways that leverage GPS data. However, the company does currently have the most comprehensive suite of hosted products, some of which your company may have already adopted. While good enterprise software is also available as an alternative to the Google-verse, most solar companies are not large enough to be in the market for these products. If your company is an exception to the rule and already running GIS desktop and server software solutions from Esri, consider exploring add-on applications—like GPS PhotoMapper from alta4, GPS-Photo Link from GeoSpatial Experts and PSI:Capture from PSIGEN—for organizing photos around geolocation.

—Ethan Lipman / consultant / San Francisco, CA / ethanlipman@asme.org

Optimizing Collector-Loop Design Temperatures

To meet the increased demand for commercial-scale solar water heating systems, designers and installers familiar with the residential solar thermal market require an expanded knowledge base. This includes awareness of new equipment and a firm understanding of the design subtleties associated with larger commercial systems. One notable area of design that can have a significant impact on system energy production is collector-loop temperature and flow rates.

An installer recently asked a question that serves as a good example of this impact. With input from the collector manufacturer, he had installed a 14-collector system designed to heat an indoor swimming pool located near St. Louis, Missouri. The glazed, flat-plate 4-by-8-foot collectors were plumbed in a single row in parallel. The system included a collector-loop pump, a pool pump and a stainless steel plate heat exchanger. After the system was commissioned, the temperature differential between the pool water going to the heat exchanger and the outlet temperature of the collectors was as high as 65°–70°F. As designed, this system is not optimized for maximum efficiency.

Collector-Loop Temperature

Excessive collector-loop temperatures indicate lost energy production. The higher the collector temperature, the more heat is lost to the outside air and the lower the system's efficiency. This is particularly true of flat-plate collector systems. Evacuated-tube systems are negatively impacted by high collector temperatures, but to a lesser degree than flat-plate units because of the superior insulation of the evacuated collectors' vacuum tube construction.

In the system under consideration, a more ideal temperature differential between the cold side of the heat exchanger and the collector outlet would be approximately 30°F when the system is exposed to full sun. This lower temperature differential would indicate that the system is operating efficiently, without excessive heat loss to the environment. A 30°F differential also indicates that the system's flow rate is sufficient, but not high enough to cause short cycling of the control during cloudy weather. In addition—and most importantly—a system that is operating with a 30°F differential produces thousands more Btu per day than a similar system running at a 65°–70°F differential.

Excessive collector-loop temperatures indicate lost energy production. The higher the collector temperature, the more heat is lost to the outside air and the lower the system's efficiency.

The corresponding heat gain associated with lower collector temperatures is illustrated and quantified by the Btu production output matrix of the Solar Rating and Certification Corporation (SRCC)-certified collector shown in Figure 1. Although the SRCC constructs its matrixes using the difference in the inlet temperature and the ambient temperature (not the inlet and outlet temperatures), the concept is the same. For reference, a 4-by-10-foot flat-plate collector with a differential of 36°F produces approximately 13,000 more Btu per day on a mildly cloudy day (1,500 Btu/sq. ft. per day insolation) than if it was operating with a differential of 90°F.

COLLECTOR THERMAL PERFORMANCE RATING							
Megajoules Per Panel Per Day				Thousands of Btu Per Panel Per Day			
CATEGORY (Ti-Ta)	CLEAR DAY	MILDLY CLOUDY	CLOUDY DAY	CATEGORY (Ti-Ta)	CLEAR DAY	MILDLY CLOUDY	CLOUDY DAY
A (-5°C)	60.8	45.9	31.2	A (-9°F)	57.6	43.5	29.5
B (5°C)	55.3	40.5	25.7	B (9°F)	52.4	38.4	24.4
C (20°C)	47.1	32.6	18.2	C (36°F)	44.7	30.9	17.2
D (50°C)	32.4	18.7	6.1	D (90°F)	30.7	17.7	5.7
E (80°C)	19.2	7.4	0.0	E (144°F)	18.2	7.0	0.0

Courtesy SRCC

Figure 1 Note the drop in Btu production when comparing a 4-by-10-foot flat-plate collector operating at an inlet temperature of 36°F above the ambient temperature and the same collector operating at a temperature of 90°F above.

Low Collector-Loop Flow Rate

Excessive collector-loop temperatures are usually caused by lower-than-optimal flow rates through the loop's piping. Specified flow meters should be installed in all solar water heating systems according to collector manufacturer's instructions. Without flow meters, suboptimal flow rates can be detected only by monitoring the system's temperature differentials. Several factors may contribute to non-optimal flow rates and each illustrates a design best practice.

Pressure drop. As additional collectors are plumbed in parallel in a single row, pressure drop within and between collectors increases. I suspect the CONTINUED ON PAGE 32

number of collectors plumbed in a single row is the likely cause of the excessive temperature differential in the example system. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ashrae.org) *Active Solar Heating Design Manual* recommends a maximum of eight collectors in a single row. Although this standard varies based on the collector and the collector header sizes, I would never recommend installing more than ten 4-by-10-foot collectors with 1-inch headers in a single row.

Some manufacturers may approve a design with more than 10 collectors in a row, but they do so at the peril of system production. The flow in any set of collectors is always greater with fewer of them plumbed in parallel. The example system would have a better flow rate if it was configured as two rows of seven collectors. The resulting increased flow rate would bring down the collector-loop operating temperature and significantly increase annual production.

Pump capacity. A pump without sufficient capacity (based on the desired flow rate and system head pressure) could be the problem. If the collector manufacturer approved the pump models during its design review, pump capacity is not likely to be the cause of the example system's excessive temperatures. However, if the pool pump was installed and in service prior to the solar thermal installation, its condition should be verified. An older pump may have diminished capacity due to a worn or damaged impeller or partially clogged impeller housing. Depending on the condition of the pump, this could reduce flow rates and elevate collector-loop temperatures.

Piping diameter. The pipes to and from the collectors should be of sufficient size to avoid impeding the system's flow rates due to excessive frictional head losses. While ½-inch tubing may be suitable for small, two-collector systems, ¾-inch pipe is better. This is particularly true for drainback systems because the larger pipe diameter enables more rapid and thorough system draining. A good standard for systems with six to ten 4-by-8-foot collectors is 1-inch piping. Larger systems require corresponding increases in pipe diameter. In addition, these pipe sizes all require upsizing if long runs are required to and from the collectors.

Heat exchangers. Fluid restrictions caused by a system's heat exchanger can also result in elevated collector-loop temperatures. Heat exchangers with fluid passages that are significantly smaller than the cross-sectional area of the collector-loop piping can cause large system temperature differentials and unnecessary heat loss. An example would be reducing a system's ¾-inch piping down to a heat exchanger with a single ¼-inch tubular fluid passage. Assuming the heat exchanger's tubing length is appropriate for a specific system, the ¼-inch tube has a good surface-to-volume ratio and may have enough exchange area to be effective. However, the cross-sectional area reduction results in increased frictional head loss and consequently higher collector-loop operating temperatures. For reference, the piping areas in this example are 0.078 square inches for ¼-inch tubing and 0.484 square inches for ¾-inch tubing (source: *Copper Tube Handbook*, copper.org).

The heat exchanger can also cause excessive collector-loop temperatures if the exchanger is too small, has too little surface area to volume or—in the case of a double-wall exchanger—poor bonding of the double wall. A good example of an undersized heat exchanger is illustrated in the above photo. The single-wall copper tube-in-tube exchanger was in service for a few years on an indoor pool system similar to the example system. The owner complained that the collectors did not heat the pool beyond about 70°F. After we replaced the exchanger with the stainless steel plate exchanger shown, the solar collectors kept the pool in the 80°F range through the next winter. The plate exchanger has a larger surface area and a higher wetted surface area (good surface to volume). The relatively poor exchange in the tube-in-tube exchanger caused excessive collector-loop temperatures and unnecessary heat loss.

—Chuck Marken / SolarPro magazine / Ashland, OR / solarprofessional.com

Courtesy AAA Solar

Exchange area The larger single-wall copper tube-in-tube exchanger shown here was replaced with a smaller stainless steel plate exchanger. The modification resulted in lower system temperature differentials and an increase in pool water temperature of approximately 10°F during the winter months.

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the WIRE Industry Currents

SPI 2011 Moves to Texas

[Washington, D.C.] From October 17 to 20, 2011, North America's largest solar power trade show and conference will promote new opportunities in emerging solar markets by moving out of California and into Dallas, Texas. Regardless of the relocation, Solar Power International (SPI) is expected to continue to draw nearly 24,000 professionals from more than 125 countries. More than 1,100 companies representing the entire solar industry spectrum will exhibit on 1 million square feet of space. Exhibits will highlight the latest in PV cells and modules, balance of systems, material and equipment suppliers, distributors, integrators, installers and solar service providers, thermal solar technologies, solar thermal electric and concentrating PV. The Solar Energy Industries Association (SEIA) and Solar Electric Power Association (SEPA) annually organize SPI. All proceeds support the expansion of the US solar market through SEIA's and SEPA's year-round research and educational activities, as well as SEIA's advocacy.

Solar Electric Power Association / 202.857.0898 / solarelectricpower.org
Solar Energy Industries Association / 202.682.0556 / seia.org
Solar Power International 2011 / solarpowerinternational.com

Trojan Expands AGM Line of Batteries

[Santa Fe Springs, CA] The deep-cycle absorbed glass mat (AGM) batteries from Trojan Battery are designed for renewable energy systems that require a reduced-maintenance battery. The AGM line is low-temperature tolerant, shock and vibration resistant, and features low internal resistance that results in higher charging and discharging efficiencies. Trojan Battery has introduced two new models in this line, the 12-volt U1-AGM and the 22-AGM, which are rated at 33 and 50 amp-hours, respectively.

Trojan Battery / 800.423.6569 / www. trojanbatteryre.com

Enphase Releases Next-Generation Micro

[Petaluma, CA] With the release of the M215 microinverter, Enphase Energy can match its product line with higher-power modules currently on the market. The new inverter is designed to work with 60-cell crystalline modules, has a CEC efficiency of 96% and comes standard with a 25-year warranty. Enphase also released the new Engage System, which simplifies the microinverter installation process. The system includes the Engage Cable that can be bought to match modules mounted in either portrait or landscape orientation and cut to length to meet custom requirements for each job. The increased wire gauge in the cabling allows up to 4 kW on a single branch circuit, helping to reduce the overall number of wiring connections. In addition, the new Engage Port ACM microinverter port was announced. This device is designed to replace the traditional dc junction box, allowing module manufacturers to integrate Enphase microinverters directly into their product portfolio.

Enphase Energy / 877.797.4743 / enphase.com

Satcon Adds to Equinox Inverter Line

[Boston, MA] Earlier this year, Satcon began shipping the 625 kW Equinox inverter. The inverter is built on the same platform as the 500 kW Equinox and allows integrators greater flexibility in sizing large-scale projects. The overall unit is housed in a NEMA 3R enclosure with the electronics housed in a NEMA 4 enclosure for additional protection. The inverter's standard communications allow for integration with SCADA monitoring systems, and it includes an integrated dc disconnect for system maintenance. When placed in utility-scale applications, the inverter provides remote control of real and reactive power, low voltage ride through and power factor control.

Satcon / 617.897.2400 / satcon.com

SolarNexus Provider Networks Established

[Berkeley, CA] SolarNexus, a provider of web-based solar business management software, has launched two new online tools that help solar integrators increase operational efficiencies. In April, it announced the SolarNexus Supplier Network, which enables integrators to connect and collaborate with subcontractors. The network's platform helps integrators deal with surges in demand and outsource specific tasks on a regular basis, resulting in direct collaboration with the industry's leading service providers, making it easy to buy qualified leads, outsource permit packages, create 3-line diagrams, hire stand-ins for inspectors and get help troubleshooting distant service problems. The company has also released the SolarNexus Hardware Supplier Network. This allows contractors to order their hardware electronically from leading equipment providers, reducing overhead in tracking catalog numbers, creating orders and managing pricing information.

SolarNexus / 510.842.7875 / solarnexus.com

Quick Mount PV Offers New Flashing Solutions

[Concord, CA] Three new products from Quick Mount PV provide additional solutions for both pitched residential and commercial roofs. The New Roof Composition Mount is designed to be installed before the roofing material. It uses a post standoff and flashing that is installed by a roofing contractor as part of the overall roof installation, allowing the roofer to seal all the posts. The Universal Tile Mount is a similar product for use on existing or new tile roofs. This double-flashed option replaces the existing Curved Tile Mount. The Low Slope Mount can integrate into existing or new single-ply membrane and built-up asphalt commercial roofs. All three products utilize the company's new Qbase for the roof attachment points. The aluminum-cast base holds standoffs as tall as 9 inches, while attaching to the roofing substrate or structure with either two or four attachments.

Quick Mount PV / 925.687.6686 / quickmountpv.com

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The Strength to Deliver

DPW Solar Releases New Power Rail Product

[Albuquerque, NM] DPW Solar has introduced a line of fully ballasted mounting options that utilize a top-down mounting rail to reduce installation time. The system has undergone full wind tunnel testing and requires no penetrations for most locations. Attachment options are available if roof penetrations are required for a particular site. The ballast pans are secured between the supporting rails and eliminate the need to measure between rails during installation. The racking system requires just one tool for installation and uses DPW Solar's RAD (Random Access D-shaped) fastener, which is designed for drop-in placement anywhere along the rail. A protective EPDM layer is factory installed, eliminating the need for additional roof protection. The rails are compatible with WEEB grounding clips.

DPW Solar / 800.260.3792 / dpwsolar.com

Unirac Offers Mobile Apps

[Albuquerque, NM] Unirac has introduced a new digital inclinometer application developed specifically for the PV industry. The U-Clinometer app, designed for use on Apple iPhones and iPod touch devices, can be downloaded for free from the Apple App Store. Support for additional mobile devices is planned for later in 2011. The U-Clinometer app enables the

measurement of both roof pitch and PV array angles. Unirac has also developed a QR-Code reader that provides a direct digital link to installation guidelines, blueprints and other product support documentation. In addition, Unirac recently launched a redesigned website that is optimized for viewing on mobile devices, making it more convenient for installers to navigate the company's online content from the field.

Unirac / 505.242.6411 / unirac.com

SolarWorld Adds Poly

[Hillsboro, OR] SolarWorld is now manufacturing 60-cell polycrystalline modules at its Oregon facility. The modules are available in outputs ranging from 220 W to 245 W. All modules are available with SolarWorld's version 2.0 or 2.5 frame. The 2.0 frame is compatible only with top-down mounting clips. The equipment-grounding conductor can mount to any corner. The 2.5 frame is for use with either top-down or bottom-up mounting. It can have a grounding conductor attached to any corner and four additional points along the frame edge.

SolarWorld / 503.844.3400 / solarworld-usa.com

PanelClaw Announces UL 2703 Certification

[North Andover, MA] The racking system manufacturer PanelClaw declared its compliance with a new standard for racking: UL 2703, Rack-Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels. The standard covers rack-mounted systems and clamping devices for modules listed to UL 1703, up to 1,000 V. To pass UL 2703, the racking system and modules undergo temperature and humidity cycling tests, followed by bonding path resistance tests to prove durable electrical bonding in outdoor environments. With the PanelClaw system, integrators can now bond multiple strings of modules with a single grounding lug when used with appropriate modules. Modules must undergo conductivity and load testing with specific mounting products prior to being approved for use under the new UL 2703 standard.

PanelClaw / 978.688.4900 / panelclaw.com

Schneider Introduces 1,000 Vdc Disconnect

[Burnaby, BC] Schneider Electric released the solar industry's first 1,000 Vdc heavy-duty disconnect. The Square D REHU disconnects are housed in white NEMA 3 enclosures and have an operating temperature range from -37°C to 50°C. For grounded PV arrays, the three-pole disconnect comes preconfigured with all three poles wired in series. Ungrounded PV arrays utilize the four-pole disconnect and have two poles wired in series, resulting in a switch that can disconnect both hot conductors simultaneously. The disconnects are available in 100 A and 200 A ratings.

Schneider Electric / 847.397.2600 / schneider-electric.com

Pictometry Offers Aerial Images Online

[Rochester, NY] Pictometry International has developed Pictometry Online, a web-based service offering a vast library of high-resolution aerial images. The tool is designed to enable integrators to quickly and accurately calculate exact characteristics of roof surfaces—pitch, orientation, square footage and roof obstructions. With the Pictometry Online service, users can visualize potential shading issues external to the roof surface. Views are available from all directions, as well as top-down. Images can be saved and used to collaborate with coworkers and other contractors on-site to facilitate coordination.

Pictometry / 888.771.9714 / pictometry.com

String Inverters

Single-Phase Solutions *for the* North American Market

By David Brearley and Joe Schwartz

While utility-scale PV plants utilizing high-power central inverters make up the fastest growing solar market sector globally, many *SolarPro* readers may be surprised by the fact that low-power string inverters accounted for the majority of inverter capacity sold worldwide in 2010. Ash Sharma, a member of IMS Research, a UK-based market research firm, presented some compelling numbers at PHOTON's PV Inverter Conference in Berlin, Germany, in April 2011—compelling numbers for string inverters, that is. Globally, 21 GW of inverters were sold in 2010. Low-power string inverters represented 57% of this total sales capacity. High-power central inverters accounted for 42% of the sales, with microinverters rounding out the field at 1%. While most leading inverter manufacturers design and produce both string and central inverters, based on the current market share percentages, it is a safe bet to assume that manufacturers are devoting significant resources to the advancement of their string inverter products.

While data that represents string inverter market share in the US in its entirety is not publicly available, the regularly updated California Solar Initiative (CSI) database provides insight into inverter manufacturers' share of the California market and serves as a general reference point for the US market for these products as a whole. SunCentric, a solar consulting firm based in California and Oregon, generated the data included in Figures 1 and 2 for publication in *SolarPro.* (SunCentric's recently released 2011 CSI program analysis can be downloaded from the company's website at suncentricinc.com.) The data included in the two charts was sourced directly from the raw CSI data in CONTINUED ON PAGE 44

Courtesy SunSense

Courtesy CSI and SunCentric (2)

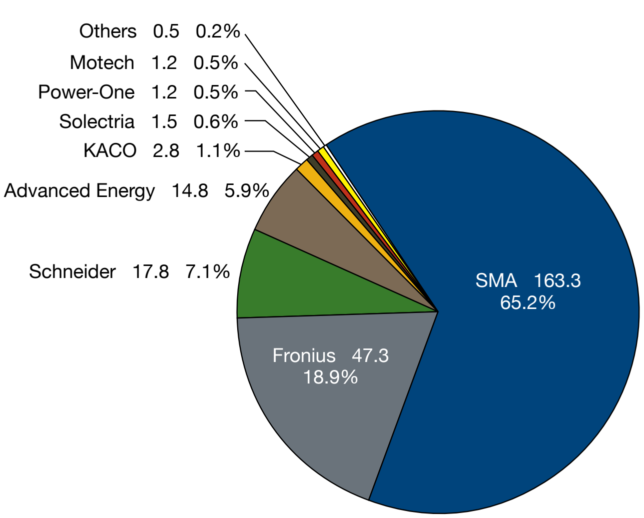

Figure 1 This chart represents deployed single-phase string inverters from the CSI database as completed residential and nonresidential systems from January 2007 through mid-May 2011. MWdc and the percent of market share are presented according to inverter manufacturer, with 250 MWdc total installed capacity.

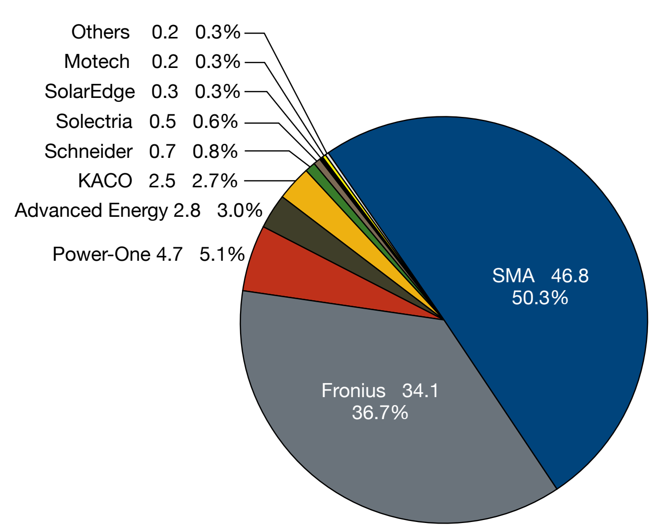

Figure 2 This chart represents single-phase string inverters from the CSI database as in-process residential and nonresidential systems as of mid-May 2011. MWdc and the percent of market share are presented according to inverter manufacturer, with 93 MWdc total capacity in process.

mid-May 2011, and was filtered to present a clear snapshot of inverter market share among string inverter manufacturers. Residential and nonresidential projects using single-phase string inverters comprised the dataset. Only systems utilizing grid-direct, single-phase string inverters were included. Private-label inverters from companies including SunPower and Yes! Solar were allocated to the original equipment manufacturer. It is interesting to note that the shift in market share between SMA and Fronius appears to be driven in part by SunPower purchasing and branding. SunCentric reported that SunPower has approximately 10.8 MW of Fronius string inverters in process compared to 8.4 MW of branded SMA products.

2011 SINGLE-PHASE STRING INVERTER SPECIFICATIONS

As the application space for string inverters grows, manufacturers of these products have been positioning themselves to capture North American market share through expanded product lines and manufacturing capacities, strategic acquisitions and an increased presence in North America in both sales and support services. As a point of reference, *SolarPro's* 2010 string inverter specification table lists 48 inverter models from eight manufacturers. The updated accompanying table (see pp. 60–66) includes 72 string inverter models from 12 manufacturers. Several existing string inverter manufacturers have added models to their product lines and four additional major manufacturers have released equipment for the US market.

To create a clear differentiation between product classes, only single-phase string inverters are listed in this year's string inverter specifications table. With the exceptions of a few models that are pending CSI eligibility, all of the inverter products included in the table are listed to UL 1741 and are currently eligible for the CSI program. The decision to make CSI eligibility the criteria for inclusion is based on our perspective that if inverter manufacturers are serious about delivering and supporting products in the US, they are surely eager to meet the incentive eligibility requirements for California, the country's largest solar market.

STRING INVERTER MANUFACTURERS

While seasoned integrators working in North America are familiar with the system design, installation and performance subtleties of major string inverter brands, the companies behind the products and the evolution of the product lines are less well known. The following profiles present detailed information about the companies behind the products, in an effort to shed some light on exactly who is manufacturing the products you are installing. Information included in the company profiles was sourced from interviews conducted by *SolarPro* staff with company representatives and from information published directly by these manufacturers in investor profiles, earnings reports, company histories and corporate press releases. It should be noted that the depth and thoroughness of the information provided by the various manufacturers during our interview process varied considerably, as did the availability of company-specific information that was sourced during the online research phase of each profile's development. CONTINUED ON PAGE 46

Advanced Energy The PV Powered inverter line from Advanced Energy includes nine models ranging from 2 kW to 5.2 kW. The inverters are manufactured in the US in Bend, Oregon, and feature a split-chassis design that allows the inverter to be easily separated from the wiring compartment. The inverters include a dc/ac disconnect that is listed to the UL 98 standard.

Courtesy Namaste Solar

Advanced Energy. Headquartered in Fort Collins, Colorado, Advanced Energy (AE) was founded in 1981. The publicly traded company (NASDAQ: AEIS) reported revenues of $459.4M for the 2010 fiscal year. AE currently has more than 1,600 employees working across a relatively diverse product and services portfolio that, as of January 2011, comprises two primary business units: AE Thin Films and AE Renewables. AE Thin Films develops and manufactures power conversion and control systems for technology markets that include semiconductor, solar, glass and flat-panel displays. AE Renewables develops and manufactures utility- and commercial-scale central inverters, as well as a full line of string inverters for small commercial and residential markets.

AE's line of Solaron central inverters has been a leading brand in the utility and large commercial application space since the introduction of the Solaron 333 kW central inverter in 2007. With the acquisition of PV Powered in May 2010, AE added several central inverters to its product portfolio, as well as nine string inverter models. PV Powered was founded in 2003 and is located in Bend, Oregon. AE's line of PV Powered string inverters is manufactured at the Oregon plant to supply the US market. In addition, the company shipped its first units from an Ontario manufacturing partner, Celestica, in December 2010, to serve the Ontario feed-in tariff (FIT) market.

AE's *Corporate Fact Sheet for the Second Quarter 2011* reported that the company achieved a 22% US solar inverter market share for the first 9 months of 2010 with its Solaron and PV Powered inverter models combined. PV inverters represent 23% of the company's overall revenue, and the company projects its inverter manufacturing capacity (including string commercial and utility-scale products) to reach approximately 2 GW annually by the end of 2011. While AE does not publicly share manufacturing capacity by market segment, in the press release announcing the acquisition of PV Powered, the company projected the sales of PV Powered inverters would contribute $40–$50M to AE's 2010 revenue, with $30–$35M from sales in the commercial market and $10–15M from the residential market.

Casey Miller, AE's director of string inverters and site solutions, comments on the ongoing improvements in reliability of the PV Powered line of inverters. "PV Powered string inverters have been on the market in the US since 2003," Miller says. "The product has undergone three design revisions, all focused on reliability and installability improvements based on real-word, under-the-sun performance." He notes that the company has a clear focus on product design details that make the equipment installer-friendly. According to Miller: "We do the little things right to make installation easy. UL 98 listed dc/ac disconnect, ample wire bending and working space, and plug-and-play monitoring save time and money on the job site."

In addition, Miller highlighted the company's focus on advances in system monitoring: "We believe that system owners should take an active role in understanding how their system is performing. Adhering to this philosophy, we offer a very low-cost data monitoring card that, through MyPVPower.com, allows system owners to monitor their inverter anywhere in the world. MyPVPower.com is a service that is totally free for the life of the inverter and is simple, intuitive and easy to use, yet includes powerful features such as data export and reporting for incentive programs. The optional PVM1010 data monitoring card is installed internally to the inverter and does not require additional external enclosures or power outlets."

AE's PV Powered string inverter line includes 2 kW to 5.2 kW units with model-specific output voltage options of 208 Vac and 240 Vac. The inverters are passively cooled and include an integrated dc/ac disconnect listed to the UL 98 standard. The inverters feature a split-chassis design with the disconnect housed within an *NEC*-compliant raceway that facilitates manufacturer-approved, flush side-by-side mounting of multiple inverters.

Delta Energy Systems
A new entrant to the North American solar market, Delta Energy Systems recently released its SOLIVIA string inverter line in the US. The US inverter line is manufactured in Thailand and includes four models with rated outputs that range from 2.5 kW to 5 kW.

Courtesy Delta Energy Systems

Delta Energy Systems. While Delta's string inverter products are new to the North American market, the company itself is well established. Delta was founded in 1971 and is a $6.6B company with 80,000 employees worldwide. It is also the number one manufacturer of switch-mode power supplies globally. Delta is one example of a power systems technology corporation that has recently directed its sights on the North American solar marketplace. In 2002, Delta acquired the advanced power supply division of the Swiss group ASCOM Energy Systems (formerly FRAKO, a German power supply manufacturer founded in 1928). The division was renamed Delta Energy Systems. A subsidiary of the global Delta family, Delta Energy Systems manufactures power supply products for computer, telecommunication, medical and industrial industries, as well as products for PV applications.

According to Andreas Schmitt, head of marketing for Delta Energy Systems, Delta began investing in the research and development of solar inverter products at its Teningen, Germany, location in 1999. Delta's first solar inverter product was a microinverter that was developed for a Belgian OEM customer and released in 1999. Over 30,000 microinverter units were sold up to 2003. In 2002, development and production of string inverters for OEM customers began. In 2005, Delta launched OEM string inverters for the US market. Three years later, it introduced Delta solar inverters for the European market at the annual Intersolar conference in Munich, Germany. In 2010, Delta Energy Systems launched the SOLIVIA brand solar inverters and shipped the first SOLIVIA EU models. Also in 2010, Delta released a 100 kW central inverter, as well as 15 kW and 20 kW transformerless string inverters for European projects.

In 2010 Delta strategically decided to enter the US market with its own SOLIVIA TR String Inverter brand and began building US sales and support. This year, Delta Energy Systems is launching four models of SOLIVIA string inverters for the US and Asian-Pacific markets and a PV monitoring system that is compatible with all the single-phase SOLIVIA string inverters available worldwide. Delta Energy Systems' design R&D headquarters is located in Teningen, Germany. The SOLIVIA line of inverters is manufactured in Dubnica nad Váhom, Slovakia, and Bangkok, Thailand. The Slovakia factory was opened in May 2007, and has a current production capacity of 600 MW, which the company projects will grow to 2 GW by 2015. Inverters destined for the US and Asia-Pacific markets are manufactured in the Thailand factory that was opened in 2010 with a production capacity of 600 MW. Currently, central inverter solutions represent 10% of Delta Energy Systems' total inverter revenue, with string inverters accounting for 90% of the company's inverter revenue.

"There is stability offered in the $6.6 B company behind our products," says Schmitt. "The PV business, while appearing to be quite mature to many, is just in its early stages. We believe local installers are the most influential group determining what solutions end-users choose, so we continue to focus on working with installers and trying to make their job easier."

Delta Energy Systems' current SOLIVIA TR string inverter line for the US market includes four units with rated power specifications ranging from 2.5 kW to 5 kW. The 4.4 kW and 5 kW units were pending CSI eligibility at the time of publication. The inverters are field configurable for 208/240 Vac output and feature NEMA 4X enclosures, a fused string combiner and array dc disconnect standard.

Exeltech. Exeltech is a privately held company headquartered in Fort Worth, Texas. While grid-connected inverters have only recently been added to the company's product portfolio, Exeltech has been manufacturing inverters for stand-alone, battery-based applications for the telecomm and renewable energy industries since the company was founded in 1990. Veteran installers who were working in the off-grid marketplace in the early 1990s likely remember integrating Exeltech's SI Series inverters, the first high-frequency pulse width modulation sine wave inverter available on the market, into systems outfitted with (now largely defunct) modified square wave inverters. At the time, it was a technical revelation to have the option of specifying a true sine wave inverter to run sensitive electronic loads in off grid applications. Exeltech also pioneered the redundant, hot-swappable stage inverter concept with its MX Series battery-based inverter product line.

Exeltech recently entered the grid-tied string inverter market CONTINUED ON PAGE 50

Courtesy Exeltech

Exeltech With a 20-year history in developing and manufacturing battery-based inverters for the telecomm and renewable energy industries, Exeltech has introduced a transformerless inverter for grid-direct applications. The 1.8 kW XLGT inverter is manufactured in Fort Worth, Texas.

with the introduction of its transformerless XLGT18A60 inverter, which received ETL listing to UL 1741 in February 2011. At 14 pounds, the 1.8 kW 120 Vac unit is the lightest inverter listed in the accompanying specifications table. All of Exeltech's inverters, including all circuit boards, transformers and enclosures, are manufactured at its Fort Worth facilities.

While the XLGT's transformerless topology is new to Exeltech, senior engineer Dan Lepinski points to Exeltech's track record of reliability building battery-based inverters for the telecomm industry. He says, "Exeltech has been manufacturing power inverters for over 20 years and markets its products to applications where high-reliability is paramount. This same philosophy went into the design and manufacture of our grid-tied inverters. While it has become accepted in the solar energy industry that inverters may have to be replaced every 8–10 years, Exeltech took the approach that you buy it and install it once. That's it."

Fronius. A privately held firm, Fronius was founded by Günter Fronius in Pettenbach, Austria, in 1945. The company's initial products included battery chargers and welding transformers. Today, these fields make up two of the three Fronius business divisions. Its third and most recent business division is solar electronics. In 1995, Fronius entered the solar market with the Sunrise grid-direct inverter. According to a 2011 report published by GTM Research, Fronius is currently the fourth-largest global supplier of inverters. Since the company added light commercial central inverters to its product mix only recently, this substantial market share is built primarily on its offering of string inverters. The company currently employs approximately 3,000 people. It has sales representatives in more than 60 countries and 17 foreign subsidiaries. While solar inverter production had been centralized at the company's Sattledt location in Austria, which opened in 2007, Fronius recently opened a Canadian subsidiary with an initial annual production capacity of 250 MW.

The Fronius IG-series of inverters was first launched in Europe in 2001. Two years later, the company released the Fronius IG 40 and IG 60, its first multiple power stage inverters. By using intelligent control of multiple power stages, Fronius is able to divide, balance and otherwise optimize the operation of individual inverter power stages. The company refers to this as its *MIX concept*. In addition to the obvious manufacturing efficiencies of having a standard power stage, Fronius touts improved operational efficiency across all power ranges and increased component lifespan as benefits of a multiple power stage inverter design. MIX technology is

Courtesy Electron Connection

Fronius USA Seven single-phase and two 3-phase models make up the Fronius IG Plus line. Rated power output for the single-phase units ranges from 3 kW to 11.4 kW. The higher-power inverter models in the lineup utilize the company's MIX technology, which balances and optimizes the multiple power stages that make up a single inverter unit.

now ubiquitous across all Fronius product lines, including its light commercial CL inverters.

The first UL-listed multistage Fronius IG string inverters were released to the North American market in 2004. Four years later, the company released updated IG Plus inverters to the US and Canada. This product line currently includes seven single-phase string inverter models, ranging in capacity from 3 kW to 11.4 kW, capable of interconnecting to the grid at 208, 240 or 277 Vac. The UL-listed IG Plus product line also features a pair of 3-phase inverters, rated at 11.4 kW (for 208 or 240

Courtesy Ingeteam

Ingeteam Spanish inverter manufacturer Ingeteam is also a new entrant to the North American PV market. The company has announced the availability of two 5 kW inverter models, one of which is transformerless.

delta services only) and 12 kW (for 277 wye service only). IG Plus inverters are housed in NEMA 3R enclosures and actively cooled using variable-speed fans. Source-circuit fuseholders are provided for the ungrounded dc input conductors, as is an inverter-integrated dc disconnect. Fronius uses a high-frequency, transformer-based inverter topology, which means that its products are not as heavy as comparably sized 60 Hz transformer-based inverters.

In reference to increasing the company's North American market share, Gord Petroski from Fronius USA, reports: "We are proactive with our efforts in the US market, with very aggressive pricing and products in stock and ready for immediate shipping." He also points out that the company's product line is both proven and well suited to the market. "Our IG Plus series has a consistently wide MPPT voltage window for maximum energy harvest in diverse weather conditions," he explains. "This feature is needed in a market that is as varied as the US and Canada."

Ingeteam. Headquartered in Zamudio, Spain, Ingeteam brings more than 30 years of experience in the power electronics design and manufacturing sector. It began developing products for the renewable energy industry in the 1990s. The company is privately held, with a network of sales offices that includes locations in Brazil, China, the Czech Republic, France, Germany, Italy, Mexico, Spain, and the US. Ingeteam's global business structure includes six primary units: energy, industry, shipbuilding, railway traction, basic technologies and services. In 1990, Ingeteam Energy, S.A. was founded to develop electrical and control systems for industrial-scale wind power and PV technologies. The 1990s also marked the beginning of the Spanish company's international expansion. Today, Ingeteam has more than 3,500 employees worldwide and offers a wide range of grid-connected and stand-alone PV inverters, marketed under the Ingecon Sun brand, with rated capacities from 2.5 kW to 625 kW. Manufacturing facilities are located in Spain and the US. String inverters represent approximately 15% of the company's overall revenue from inverter sales.

Ingeteam first introduced a 2.5 kW transformer-based, single-phase string inverter model for the European market in 2000. A 6 kW transformerless string inverter, also destined for the European market, was released in 2005. More recently, Ingeteam developed a new family of 3-phase transformerless string inverters with power outputs from 10 kW to 18 kW, again for the European market. The company's first string inverter models developed for the US, the transformer-based Ingecon Sun Lite 5 U and transformerless Ingecon Sun Lite 5 TL U, have been listed to UL 1741. CEC eligibility is pending. The two Ingecon Sun Lite inverter models became available to North American customers in July of this year.

Ingeteam solidified its commitment to the US market with the announcement of a new 100,000-square-foot combined production facility and office complex in Milwaukee, Wisconsin, with completion set for some time this summer. The company expects the facility to employ approximately 275 workers by 2015 and is projected to achieve an annual production capacity of 300 MW. In addition, Ingeteam has a business office in Santa Clara, California, focused on developing the company's presence in the North American PV market.

KACO new energy. Founded under the name Kupfer-Asbest-Company Gustav Bach in 1914, KACO has evolved from a manufacturer of ring gaskets for use in the automotive industry to the third-largest inverter manufacturer worldwide in 2010. The firm is privately held, is based in Neckarsulm, Germany, and currently has 700 employees CONTINUED ON PAGE 54

Courtesy KACO new energy

KACO new energy The 02xi series currently includes four models with rated power outputs of 1.5 kW to 5 kW. The company recently announced the availability of its first transformerless inverters for the US, the 6400xi and 7600xi.

worldwide. KACO pioneered the development of electromechanical choppers (predecessors of modern inverters) in the 1940s during World War II in response to the destruction of large segments of Germany's electrical grid. In 1994, the company began developing inverter technology for PV applications. Today, KACO offers a full line of inverters for residential, commercial and utility-scale applications and has produced more than 3 GW of PV inverters since 1999. A secondary business unit is dedicated to the manufacture of power supply systems for rail and industrial applications. More than 15,000 KACO battery-coupled power supply systems have been employed in rail vehicles worldwide. The company was reorganized in 2009 as KACO new energy GmbH.

While the German PV market has traditionally been the primary focus of KACO's product distribution, international exports currently represent 35% of the company's inverter sales. KACO has branch offices in locations that include Canada, China, France, Greece, Israel, Italy, South Korea, Spain and the US. The company's North American headquarters is located in San Francisco. KACO is actively working to increase its presence in the North American market. KACO new energy began producing 60 MW of string inverters at its San Jose, California, facility in January 2011. The 1502xi and 2502xi models manufactured at this location have been available since Q1 2011, and the 3502xi and the 5002xi models assembled there will be available this summer. The revised nameplate for these inverters will make it clear that the products are assembled in the US. According to Svea Jeske, KACO marketing and event manager, the company's motivation to manufacture in San Jose is twofold: "California remains one of the strongest and most promising US markets for PV. In addition, San Jose's proximity to major national distribution will make this production development strategically beneficial for the solar market in California and beyond." In May 2011, KACO announced the opening of a new North American manufacturing facility in London, Ontario, Canada. The plant has more than 30,000 square feet of manufacturing and warehouse space and will produce a projected 1 GW of PV inverters for the Canadian market in 2011. The company plans to employ more than 100 full-time employees at the facility.

In 2006, KACO released its first string inverters in the US, which included the 1501xi, 2901xi and 3601xi models. The first-generation model line was replaced in 2009 with the current 02xi series. The redesigned model line is comprised of 1.5 kW to 5 kW units. The products come CONTINUED ON PAGE 56

standard with an integrated connection box that houses a dc/ac disconnect. The split-architecture design allows the inverter to be separated from the wiring/switch enclosure to simplify maintenance or repair work. Output can be configured for 208 Vac, 220 Vac (Mexico) and 240 Vac services. The 1.5 kW, 2.5 kW and 3.5 kW models feature passive cooling. Integrators should note that the 5 kW unit's cooling approach combines passive cooling with internal fan assist. Web-based system monitoring can be enabled via KACO's optional watchDOG communication card, and KACO offers blueplanet web, a free web-hosted monitoring service for residential systems of up to 10 kW in capacity.

Immediately prior to this issue's publication date, KACO formally announced the availability of two new transformerless inverter models that are competitively priced for the US market. These models were originally announced in 2010. Both of these inverters are listed to UL 1741 and are eligible for the CSI program. The 6400xi and 7600xi inverters have achieved a CEC efficiency rating of 96.5% and are 94% efficient at 10% of rated output power. The introduction of the new transformerless models is a forward-looking move for KACO and a chance to gain early market share in the rapidly evolving transformerless string inverter space in the US.

Motech Industries. Headquartered in Tainan, Taiwan, Motech Industries is a publicly traded company listed on the Taiwan Stock Exchange. Motech was founded in 1981 and has evolved from a test and measurement instruments designer and manufacturer to a full-service global solar company. Motech's solar division was established in 1997, and the production of photovoltaic cells commenced in 2000. In 2009, Motech acquired GE Energy's former solar module assembly operation located in Newark, Delaware. In 2010, Motech reported its position as one of the 10 largest solar cell producers worldwide.

Motech embarked on the development of solar inverters in 2004 and began shipping inverters into the European marketplace in 2006. In 2008, Motech inverters received UL 1741 listing for use in the US and began shipping to the North American market via a distribution agreement with groSolar, a US-based solar solutions provider and equipment wholesaler. Motech's current PVMate inverter line includes six models with power outputs that range from 2.7 kW to 7.5 kW and feature an integrated dc/ac disconnect. The inverter can be physically separated from the lower wiring box that houses the disconnect, if servicing is required.

Power-One. Headquartered in Camarillo, California, with design, manufacturing, sales and service operations in Asia, Europe and throughout the Americas, Power-One is currently the world's second largest designer and manufacturer of solar inverters. Over the past 40 years, the company has evolved from a family-owned power supply manufacturing business that was incorporated as Power CA in 1973 to a publicly traded company

Courtesy Power-One

Power-One Transformerless topology and dual, independent MPPT channels are two product highlights of Power-One's Aurora string inverter line. The single-phase line includes seven models. In addition, Power-One has introduced two 3-phase string inverter models with rated outputs of 10 kW and 12 kW for commercial applications.

(NASDAQ: PWER) with net revenues of $1,074M for its fiscal year ending January 2011. Power-One currently has approximately 3,400 employees at facilities worldwide.

Power-One's initial public offering took place in 1997, raising more than $80M. In 2006, the company acquired the Power Electronics Group of Magnetek for a purchase price of approximately $69.4M, according to Power-One's most recent annual report. The Power Electronics Group included operations in China, Hungary, Italy and the US, with approximately 500,000 square feet of manufacturing facilities and 1,200 employees. This transaction included dc-to-dc converter products and power supplies and, notably, the Aurora line of PV and small wind inverters with capacities ranging from 3 kW to 6 kW. Power-One's more recent purchase of Fat Spaniel Technologies in 2010 was another notable acquisition.

In 2010, the company was reorganized into two business units: Renewable Energy Solutions and Power Solutions. The Renewable Energy division designs and manufactures power conversion products for both PV and wind power applications. The Power division is focused on power management solutions used in computer servers, data storage, networking, telecomm and industrial applications.

Power-One has been capturing global inverter market share at an unmatched pace, moving from the number nine position in 2009 to the number two position in 2010. Power-One reports inverter shipments reached 2.6 GW in 2010, and more than 4 GW of inverter capacity has been installed globally to date. Manufacturing facilities are located in Valdarno, Italy, for Africa, Europe and the Middle East (4 GW); Gongming, China, for Asia-Pacific (1 GW); Phoenix, Arizona, for North America (1 GW); and Scarborough, Ontario, for Canada (500 MW).

According to Kent Sheldon, vice president of sales, Renewable Energy Solutions, North America: “The Aurora product family of 2 kW to 6 kW transformerless inverters has been continuously developed in Europe over the past 6 years, as well as in North America over the past 3 years. Our string inverters have evolved into our third generation of TL inverters that have improved features, reliability and price with each update.”

Power-One’s current lineup for the US market includes seven single-phase models. Product highlights include a transformerless topology; dual, isolated MPPT stages that allow different string configurations, lengths and orientations; the widest PV voltage input range specification listed in the accompanying table; and fan-free passive cooling. Later in 2011, Power-One will be launching a redesigned full line of inverter products in North America, to include microinverters, dc optimizers, string inverters, and commercial and utility-scale inverters for PV and wind power applications.

Schneider Electric. Founded in 1836 and incorporated in 1981, Schneider Electric is a global leader in active energy management solutions headquartered in Rueil-Malmaison, France. The company has more than 110,000 employees in more than 100 countries. Publicly traded on Euronext, a pan-European stock exchange, the company reported sales revenues of 19.6B euros for 2010, 24% of which were generated in North America. Schneider Electric acquired Square D, a leading US electrical equipment manufacturer, in 1991. Since 2011, activities at Schneider Electric have been organized into five operating segments: power, energy, buildings, industry and IT. Renewable energy solutions and services are grouped within Schneider Electric’s power portfolio. In 2010, this operating segment of the company accounted for 53% of total revenue, or 10.3B euros. According to the company’s annual report, Schneider Electric’s power business is currently number one in the world in low-voltage markets and number two worldwide in installation and control systems. The report also describes renewable energy as a “lever for growth” within this operating segment. It notes: “Solutions and services (in the power business) are seeing growth again thanks to renewable energy solutions.”

Emphasis on the renewable energy sector is part of a transformation stratagem initiated at Schneider Electric in 2002. Strategic acquisitions in the 1980s and 1990s helped the company transition from being a family-owned steel business to a publicly traded world leader in electrical products. Management at Schneider Electric has recently sought to diversify and enhance its portfolio of solutions to anticipate changing energy requirements in the future. In July 2008, as part of this strategic realignment, the company acquired Xantrex Technology in an all-cash transaction valued at approximately $500M. In addition to portable power products for mobile applications, the Xantrex product

SMA America With 14 grid-direct string inverter models available in the US, SMA America's product lineup is the most extensive in the industry. In 2010 SMA introduced the TL-US series of 8 kW to 10 kW transformerless inverters. The company operates a 1 GW manufacturing facility in Denver, Colorado.

Courtesy Meridian Solar

portfolio includes battery-backup and grid-direct inverters for residential applications, as well as an extensive line of commercial and industrial inverters.

It is worth noting that Xantrex, which was founded in 1983, had its own history of strategic acquisitions in renewable energy and power conversion technology. Over a 2-year period, starting in 1999, Xantrex acquired three inverter companies: Heart, Statpower and Trace Engineering. While Xantrex used the products and technologies acquired from Heart and Statpower primarily in mobile and consumer electronic solutions, the assets acquired from Trace were used in both grid-direct and utility-interactive battery-backup solutions. Xantrex's early grid-tied experiences using Trace technology were not without challenges. The Trace Sun Tie inverter, Xantrex's only residential grid-direct inverter when it was released in July 2001, suffered from multiple problems with its MPPT algorithm, which the company was slow to address until these issues became well publicized. Around the same time, in November 2001, Xantrex received notification that UL was decertifying its battery-based Trace SW series inverters for utility-interactive operation. While Xantrex fixed this problem relatively quickly with the release of an add-on grid-tied interface, the company's responsiveness was once again called into question.

Given the rapid rate of change in the solar industry, these decade-old bumps in the road for Xantrex were ancient history—until January 18, 2011, when Schneider Electric announced a recall of approximately 25,000 Xantrex GT series and private-labeled inverters. Whatever memories this announcement may have brought back for industry veterans, Schneider Electric's management of the Xantrex recall is a marked departure from the past. First, it was the company's own quality control processes and procedures that identified the potential problem—prior to any reports of injury or property damage. Second, in initiating a voluntary recall, the company was adhering to its own internal quality control standards. The Schneider Electric annual report states: "Despite its testing and quality control procedures, the company's products might not operate properly or might contain design faults or defects, which could give rise to disputes in respect to its liability as a seller or manufacturer.... To prevent or limit these risks, the company recalls products if there are any doubts whatsoever that a product or one of its components is not 100% safe in respect of people and/or equipment."

"Schneider Electric takes product safety and quality very seriously," explains Ron Catanzaro, vice president of marketing. "We identified a potential safety issue in the North American single-phase Xantrex GT series grid-tied inverter related to a component on the circuit board. We reported this to the Consumer Product Safety Commission and agreed to a voluntary field repair upgrade, which involved a kit to replace the component and further strengthen the enclosure. As the solar industry matures, Schneider CONTINUED ON PAGE 68

Less Guts, More Glory

the new KACO blueplanet 00xi transformerless inverter series

KACO has worked closely with installers all over the US to provide them with the most reliable and efficient products and technology. Now KACO plans to usher in a new era of solar. KACO has launched a **transformerless inverter** series like you've never seen.

These inverters **produce more kWhs** than ever before. They **enhance efficiency numbers** by using a single stage DC conversion process. The **low component** count makes this inverter series the **most reliable and lightest** in the world.

Best Performance

KACO transformerless inverters have a maximum efficiency of 97.2% and are already 90% efficient at 35 watts of input power

Newest generation IGBTs provide accurate and reliable operation

Highest quality chokes and microcontrollers ensure maximum performance and longevity

Highest Reliability

Sealed outdoor enclosure protects power electronics from insects, dust, humidity and ocean air

Redundant high quality power capacitors increase lifetime

3.3 GW of KACO PV inverters are in operation around the world - These are the most reliable inverters you can find

Easiest Installation

Minimize mounting time to approximately 15 minutes with the ***easy***install T-bracket

Up to 50% lighter than comparably sized inverters

DC Disconnect housing includes a code compliant string combiner with four fused DC inputs

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2011 Grid-Direct String Inverter Specifications

		Input Data (dc)						Output Data (ac)			
Manufacturer	Model	Maximum recommended PV power at STC (W)	Maximum open-circuit voltage	PV start voltage	Maximum power point tracking voltage range	Maximum usable input current	Maximum short-circuit current	CEC rated power (W)	Nominal output voltage	Maximum output current	Maximum ac OCPD rating (A)
Advanced Energy	PVP2000	2,500	500	130	115–450	18.5	26.0	2,000	240	8.5	20
Advanced Energy	PVP2500	3,130	500	155	140–450	19.0	26.0	2,500	240	10.5	20
Advanced Energy	PVP2800	3,500	500	195	180–450	16.5	26.0	2,800	208	13.5	20
Advanced Energy	PVP3000	3,750	500	185	170–450	19.0	26.0	3,000	240	12.5	20
Advanced Energy	PVP3500	4,308	500	215	200–450	18.5	26.0	3,500	240	15.0	20
Advanced Energy	PVP4600	5,750	500	220	205–450	24.0	48.0	4,600	208	22.5	30
Advanced Energy	PVP4800	6,000	500	215	200–450	25.5	48.0	4,800	240	20.5	30
Advanced Energy	PVP5000 [3]	6,000	500	215	200–450	26.5	48.0	N/A	240	21.0	30
Advanced Energy	PVP5200	6,500	500	255	240–450	23.0	48.0	5,200	240	22.0	30
Delta Energy	SOLIVIA 2.5 TR	3,200	600	150	150–500	8.6	19.0	2,500	208/240	11.0/12.0	15
Delta Energy	SOLIVIA 3.3 TR	4,000	600	150	150–500	13.0	24.0	3,300	208/240	16.0/14.5	20
Delta Energy	SOLIVIA 4.4 TR	5,200	600	150	150–500	15.1	31.0	4,400	208/240	24.0/19.5	30
Delta Energy	SOLIVIA 5.0 TR	6,000	600	150	150–500	17.2	37.0	5,000	208/240	24.0/22.0	30
Exeltech	XLGT18A60	2,450	600	235	200–600	9.5	10.0	1,800	120	15.0	20
Fronius USA	IG Plus V 3.0-1$_{\text{UNI}}$	3,450	600	245	230–500	14.0	18.0	3,000	208/240/277	14.4/12.5/10.8	20/20/15
Fronius USA	IG Plus V 3.8-1$_{\text{UNI}}$	4,400	600	245	230–500	17.8	22.0	3,800	208/240/277	18.3/15.8/13.7	25/20/20
Fronius USA	IG Plus V 5.0-1$_{\text{UNI}}$	5,750	600	245	230–500	23.4	29.0	5,000	208/240/277	24.0/20.8/18.1	30/30/25
Fronius USA	IG Plus V 6.0-1$_{\text{UNI}}$	6,900	600	245	230–500	28.1	35.0	6,000	208/240/277	28.8/25.0/21.7	40/35/30
Fronius USA	IG Plus V 7.5-1$_{\text{UNI}}$	8,600	600	245	230–500	35.1	44.0	7,500	208/240/277	36.1/31.3/27.1	45/40/35
Fronius USA	IG Plus V 10.0-1$_{\text{UNI}}$	11,500	600	245	230–500	46.7	58.0	9,995	208/240/277	48.1/41.7/36.1	60/60/45
Fronius USA	IG Plus V 11.4-1$_{\text{UNI}}$	13,100	600	245	230–500	53.3	67.0	11,400	208/240/277	54.8/47.5/41.2	70/60/60
Ingeteam	IngeconSun 5 U	6,500	550	150	200–450	30.0	30.0	5,000	208/240/277	25.0	32
Ingeteam	IngeconSun 5TL U	6,500	550	150	200–450	30.0	30.0	5,000	208/240/277	25.0	32
KACO new energy	1502xi	2,000	550	125	125–400	14.3	21.5	1,500	208/240	8.0/8.0	15
KACO new energy	2502xi	3,000	550	200	200–450	13.5	21.5	2,500	208/240	12.5/12.5	20
KACO new energy	3502xi	4,000	600	200	200–510	18.5	28.0	3,500	208/240	16.0/17.0	25
KACO new energy	5002xi	6,000	600	200	200–510	26.5	40.0	5,000	208/240	24.0/24.0	30
KACO new energy	6400xi	DNR	550	DNR	320–550/365–550	21.0	36.0	6,400	208/240	31.0/27.0	50
KACO new energy	7600xi	DNR	550	DNR	320–550/365–550	24.0	36.0	7,600	208/240	37.0/32.0	50
Motech	PVMate 2900U	3,600	600	235	200–550	16.0	24.0	2,700/2,900	208/240	13.0	20
Motech	PVMate 3840U	4,900	600	235	200–550	20.0	24.0	3,330/3,840	208/240	16.0	20
Motech	PVMate 4900U	6,200	600	235	200–550	25.0	30.0	4,300/4,900	208/240	20.7	30
Motech	PVMate 5300U	6,700	600	235	200–550	25.0	30.0	4,600/5,300	208/240	22.1	30
Motech	PVMate 6500U	7,000	600	260	230–500	35.0	44.0	6,500	208/240/277	23.5/27.1/31.3	55
Motech	PVMate 7500U	8,000	600	260	230–500	35.0	44.0	7,500	208/240/277	27.1/31.3/36.1	55
Power-One	PVI-3.0-OUTD-S-US	3,500	600	200	90–580	10.0 [5]	12.5 [5]	3,000	208/240/277	14.5/14.5/12.0	20/20/15
Power-One	PVI-3.6-OUTD-S-US	4,150	600	200	90–580	16.0 [5]	20.0 [5]	3,600	208/240/277	17.2/16.0/16.0	25/20/15
Power-One	PVI-3.8-I-OUTD-S-US	4,000	520	200	160–470 [4]	12.5 [5]	20.0 [5]	3300/3800/3800	208/240/277	16.0	20
Power-One	PVI-4.2-OUTD-S-US	4,820	600	200	90–580	16.0 [5]	20.0 [5]	4,200	208/240/277	20.0	25
Power-One	PVI-4.6-I-OUTD-S-US	4,800	520	200	170–470 [4]	14.0 [5]	20.0 [5]	4,600	208/240/277	22.5/20.0/20.0	30/25/25
Power-One	PVI-5000-OUTD-US	5,300	600	200	90–580	18.0 [5]	22.0 [5]	5,000	208/240/277	24.0/20.0/18.0	30
Power-One	PVI-6000-OUTD-US	6,400	600	200	90–580	18.0 [5]	22.0 [5]	6,000	208/240/277	29.0/25.0/21.6	30
Schneider Electric	Conext 2.8	3,100	600	160	195–550	14.9/15.4	24.0	2,700/2,800	208/240	13.0/11.7	20
Schneider Electric	Conext 3.3	3,500	600	160	200–400	16.5/17.5	24.0	3,100/3,300	208/240	14.9/13.8	20
Schneider Electric	Conext 3.8	3,600/4,200	600	160	195–550	19.5/20.8	24.0	3,500/3,800	208/240	16.8/15.8	25/20
Schneider Electric	Conext 5.0	4,800/5,400	600	160	240–550	20.0/22.0	24.0	4,500/5,000	208/240	22.0/21.0	30
SMA America	SB 700-US	875	250	150	125–200	7.0	18.0	700	120	6.6	15
		750	200	125	100–160	7.0	18.0	600	120	5.7	15
		575	150	95	77–120	7.0	18.0	460	120	4.4	15
SMA America	SB 2000HF-US	2,500	600	220	175–480	15.0	25.0	2,000	208/240	10.0/8.5	25
SMA America	SB 2500HF-US	3,125	600	220	220–480	15.0	25.0	2,500	208/240	12.0/10.4	25
SMA America	SB 3000HF-US	3,750	600	220	220–480	15.0	25.0	3,000	208/240	14.4/12.5	25
SMA America	SB 3000-US	3,750	500	228	175–400/200–400	17.0	24.0	3,000	208/240	15.0/13.0	30

Footnote Key

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[6] One input per MPPT channel
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[9] GEC not required (equipment ground only, 10–6 AWG)
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N/A = not applicable
DNR = did not report

Performance				Integrated Disconnects and Combiners				Termination Specifications			
Peak efficiency (%)	CEC weighted efficiency (%)	CEC night tare loss (W)	Ambient temperature range (ºF)	dc disconnect standard	ac disconnect standard	Disconnect amperage rating (dc/ac)	Fused combiner standard	Number of dc string inputs	dc terminal size range (AWG)	ac terminal size range (AWG)	GEC terminal size range (AWG)
93.5	92.0	3.60	-13–104	yes	yes	48/40	no	3	12–6	12–6	14–4
95.8	94.5	3.90	-13–104	yes	yes	48/40	no	3	12–6	12–6	14–4
93.1	92.0	3.85	-13–104	yes	yes	48/40	no	3	12–6	12–6	14–4
94.3	93.5	3.63	-13–104	yes	yes	48/40	no	3	12–6	12–6	14–4
96.7	95.5	3.86	-13–104	yes	yes	48/40	no	3	12–6	12–6	14–4
96.5	95.5	4.00	-13–104	yes	yes	48/40	no	3	12–6	12–6	14–4
97.2	96.0	4.10	-13–104	yes	yes	48/40	no	3	12–6	12–6	14–4
97.1	N/A	N/A	-13–104	yes	yes	48/40	no	3	12–6	12–6	14–4
97.0	96.0	4.00	-13–104	yes	yes	48/40	no	3	12–6	12–6	14–4
96.2	94.5/95	0.33/0.44	-13–158	yes	no	40	yes	3	14–6	14–6	14–6
96.2	95/95.5	0.33/0.44	-13–158	yes	no	40	yes	3	14–6	14–6	14–6
96.0	DNR	DNR	-13–158	yes	no	40	yes	3	14–6	14–6	14–6
95.6	DNR	DNR	-13–158	yes	no	40	yes	3	14–6	14–6	14–6
97.8	96.5	0.16	-4–104	yes	yes	20/20	N/A	1	16–12	14–12	14–4
96.2	95.0/95.5/96.0	0.62/0.83/1.10	-13–131	yes	no	40	yes	6	14–6	14–4	14–4
96.2	95.0/95.5/96.0	0.62/0.83/1.10	-13–131	yes	no	40	yes	6	14–6	14–4	14–4
96.2	95.5/95.5/96.0	0.71/0.76/1.02	-13–131	yes	no	60	yes	6	14–6	14–4	14–4
96.2	95.5/96.0/96.0	0.71/0.76/1.02	-13–131	yes	no	60	yes	6	14–6	14–4	14–4
96.2	95.0/95.5/96.0	0.71/0.76/1.02	-13–131	yes	no	60	yes	6	14–6	14–4	14–4
96.2	95.0/95.5/96.0	0.64/0.85/1.13	-13–131	yes	no	80	yes	6	14–6	14–4	14–4
96.2	95.0/95.5/96.0	0.64/0.85/1.13	-13–131	yes	no	80	yes	6	14–6	14–4	14–4
96.2	95.5	DNR	-4–149	yes	no	30	yes	4	6	6	6
97.0	96.0	DNR	-4–149	yes	no	30	yes	4	6	6	6
95.5/95.9	95.0/95.5	0.29/0.39	-4–140	yes	yes	40/36	no	3	12–4	12–4	12–4
95.6/95.9	95.0/95.5	0.29/0.39	-4–140	yes	yes	40/36	no	3	12–4	12–4	12–4
95.9/96.2	95.5/96.0/96.0	0.26/0.36	-13–140	yes	yes	40/36	no	3	12–4	12–4	12–4
96.0/96.3	95.0/95.5	0.26/0.36	-13–140	yes	yes	40/36	no	3	8–4	8–4	8–4
96.9/97.2	96.5	0.26/0.45	-4–140	yes	no	DNR	yes	4	10–6	10–6	10–6
97.0/97.1	96.5	0.26/0.36	-4–140	yes	no	DNR	yes	4	10–6	10–6	10–6
96.4/96.7	95.5/96.0	0.50/0.50	-13–130	yes	yes	30/30	yes	3	12–6	12–6	12–6
96.5/96.7	95.5/96.0	0.50/0.50	-13–130	yes	yes	30/30	yes	4	12–6	12–6	12–6
96.4/96.6	96.0/96.0	0.50/0.50	-13–130	yes	yes	30/30	yes	4	12–6	12–6	12–6
96.4/96.2	95.5/96.0	0.50/0.50	-13–130	yes	yes	30/30	yes	4	12–6	12–6	12–6
96/96.3/96.7	96.0/96.0	0.50/0.50/0.50	-13–149	yes	yes	40/40	yes	5	10–6	8–6	8–6
96.2/96.5/96.7	96.0/96.0	0.50/0.50/0.50	-13–149	yes	yes	40/40	yes	5	10–6	8–6	8–6
96.8	96.0	0.10/0.10/0.20	-13–140	yes	no	25	no	2[6]	10–4	10–4	10–4
96.8	96.0	0.10/0.10/0.20	-13–140	yes	no	25	no	2[6]	10–4	10–4	10–4
96.9	96/96.5/96.5	0.10/0.10/0.10	-13–140	yes	no	25	no	2	10-4	10-4	4
96.8	96.0	0.10/0.10/0.20	-13–140	yes	no	25	no	2[6]	10–4	10–4	10–4
96.9	96/96.5/96.5	0.10/0.10/0.10	-13–140	yes	no	25	no	2	10–4	8–4	4
97.0	96.0/96.5/96.5	0.18/0.24/0.32	-13–140	yes	no	25	no	2[6]	10–4	10–4	10–4
97.0	96.0/96.5/96.5	0.18/0.24/0.32	-13–140	yes	no	25	no	2[6]	10–4	10–4	10–4
94.6/95.0	93.5/94.0	1.00/1.00	-13–149	yes	yes	25/25	no	2	14–6	14–6	12–4
95.6/95.8	95.0/95.0	1.00/1.00	-13–149	yes	yes	25/25	no	2	14–6	14–6	12–4
95.6/95.9	95.0/95.0	1.00/1.00	-13–149	yes	yes	25/25	no	2	14–6	14–6	12–4
95.5/95.9	95.0/95.5	1.00/1.00	-13–149	yes	yes	25/25	no	3	14–6	14–6	12–4
93.6	91.5	0.10	-13–113	no	no	N/A	no	2	10–6	14–6	14–6
93.3											
92.4											
96.0	95.0	0.80	-13–113	yes	no	36	yes	3	10–6	10–6	10–6
96.0	95.0	0.80	-13–113	yes	no	36	yes	3	10–6	10–6	10–6
96.0	95.0	0.80	-13–113	yes	no	36	yes	3	10–6	10–6	10–6
96/96.5	95.0/95.5	0.10	-13–113	yes	no	36	yes	4	10–6	10–6	10–6

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2011 Grid-Direct String Inverter Specifications

		Mechanical						
Manufacturer	Model	Cooling method	Noise level @ 1 m (dB) [1]	Enclosure NEMA rating	Dimensions H x W x D (inches)	Weight (lbs)	Listing agency	Warranty standard/ extended (years)
Advanced Energy	PVP2000	passive	< 35	3R	30.4 x 15.6 x 8.1	93 [2]	ETL	10
Advanced Energy	PVP2500	passive	< 35	3R	30.4 x 15.6 x 8.1	107 [2]	ETL	10
Advanced Energy	PVP2800	passive	< 35	3R	30.4 x 15.6 x 8.1	107 [2]	ETL	10
Advanced Energy	PVP3000	passive	< 35	3R	30.4 x 15.6 x 8.1	107 [2]	ETL	10
Advanced Energy	PVP3500	passive	< 35	3R	30.4 x 15.6 x 8.1	121 [2]	ETL	10
Advanced Energy	PVP4600	passive	< 35	3R	35.0 x 18.1 x 8.6	162 [2]	ETL	10
Advanced Energy	PVP4800	passive	< 35	3R	35.0 x 18.1 x 8.6	162 [2]	ETL	10
Advanced Energy	PVP5000 [3]	passive	< 35	3R	35.0 x 18.1 x 8.6	162 [2]	ETL	10
Advanced Energy	PVP5200	passive	< 35	3R	35.0 x 18.1 x 8.6	162 [2]	ETL	10
Delta Energy	SOLIVIA 2.5 TR	passive	< 35	4X	25.6 x 16.8 x 9.1	58	ETL	10/15, 20
Delta Energy	SOLIVIA 3.3 TR	passive	< 35	4X	25.6 x 16.8 x 9.1	58	ETL	10/15, 20
Delta Energy	SOLIVIA 4.4 TR	passive	< 35	4X	29.3 x 16.8 x 9.1	82	ETL	10/15, 20
Delta Energy	SOLIVIA 5.0 TR	passive	< 35	4X	29.3 x 16.8 x 9.1	82	ETL	10/15, 20
Exeltech	XLGT18A60	passive	< 40	3R	17.2 x 9.5 x 5.8	14	ETL	5/10
Fronius USA	IG Plus V 3.0-1UNI	active	< 62	3R	17.1 x 26.5 x 9.9	55	CSA	10/15, 20
Fronius USA	IG Plus V 3.8-1UNI	active	< 62	3R	17.1 x 26.5 x 9.9	55	CSA	10/15, 20
Fronius USA	IG Plus V 5.0-1UNI	active	< 62	3R	17.1 x 38.1 x 9.9	81	CSA	10/15, 20
Fronius USA	IG Plus V 6.0-1UNI	active	< 62	3R	17.1 x 38.1 x 9.9	81	CSA	10/15, 20
Fronius USA	IG Plus V 7.5-1UNI	active	< 62	3R	17.1 x 38.1 x 9.9	81	CSA	10/15, 20
Fronius USA	IG Plus V 10.0-1UNI	active	< 64	3R	17.1 x 49.7 x 9.9	110	CSA	10/15, 20
Fronius USA	IG Plus V 11.4-1UNI	active	< 64	3R	17.1 x 49.7 x 9.9	110	CSA	10/15, 20
Ingeteam	IngeconSun 5 U	active	< 51	3R	27.4 x 14.2 x 13.3	168	UL	10/20
Ingeteam	IngeconSun 5TL U	active	< 51	3R	28.4 x 14.2 x 7.0	62	UL	10/20
KACO new energy	1502xi	passive	< 35	3R	30.0 x 14.0 x 8.3	42	TUV	10
KACO new energy	2502xi	passive	< 35	3R	32.0 x 14.0 x 8.3	52	TUV	10
KACO new energy	3502xi	passive	< 35	3R	36.0 x 14.0 x 9.3	69	TUV	10
KACO new energy	5002xi	active	< 45	3R	36.0 x 14.0 x 9.3	70	TUV	10
KACO new energy	6400xi	active	< 45	3R	44.2 x 14.0 x 8.9	95	TUV	10
KACO new energy	7600xi	active	< 45	3R	44.2 x 14.0 x 8.9	95	TUV	10
Motech	PVMate 2900U	passive	< 35	3R	28.8 x 17.9 x 6.9	51	UL	10
Motech	PVMate 3840U	active	< 55	3R	28.8 x 17.9 x 6.9	51	UL	10
Motech	PVMate 4900U	active	< 57	3R	28.8 x 17.9 x 8.3	62	UL	10
Motech	PVMate 5300U	active	< 57	3R	28.8 x 17.9 x 8.3	62	UL	10
Motech	PVMate 6500U	active	< 47	3R	28.8 x 17.2 x 8.2	90	UL	10
Motech	PVMate 7500U	active	< 47	3R	28.8 x 17.2 x 8.2	90	UL	10
Power-One	PVI-3.0-OUTD-S-US	passive	< 50	4X	33.7 x 12.8 x 8.3	46	CSA	10/15
Power-One	PVI-3.6-OUTD-S-US	passive	< 50	4X	33.7 x 12.8 x 8.3	46	CSA	10/15
Power-One	PVI-3.8-I-OUTD-S-US	passive	< 50	4X	34.6 x 12.8 x 8.3	61	CSA	10/15, 20
Power-One	PVI-4.2-OUTD-S-US	passive	< 50	4X	33.7 x 12.8 x 8.3	46	CSA	10/15
Power-One	PVI-4.6-I-OUTD-S-US	passive	< 50	4X	34.6 x 12.8 x 8.3	61	CSA	10/15, 20
Power-One	PVI-5000-OUTD-US	passive	< 50	4X	38.6 x 12.8 x 7.7	66	CSA	10/15
Power-One	PVI-6000-OUTD-US	passive	< 50	4X	38.6 x 12.8 x 7.7	66	CSA	10/15
Schneider Electric	Conext 2.8	passive	< 35	3R	35.4 x 16.0 x 7.3	67	CSA	10
Schneider Electric	Conext 3.3	passive	< 35	3R	35.4 x 16.0 x 7.3	70	CSA	10
Schneider Electric	Conext 3.8	passive	< 35	3R	38.9 x 16.0 x 7.3	80	CSA	10
Schneider Electric	Conext 5.0	passive	< 35	3R	38.9 x 16.0 x 7.3	84	CSA	10
SMA America	SB 700-US	passive	DNR	3X	13.0 x 11.0 x 7.0	51	UL	10/20
SMA America	SB 2000HF-US	active	< 38	3R	14.0 x 29.0 x 7.0	51	UL	10/20
SMA America	SB 2500HF-US	active	< 38	3R	15.0 x 29.0 x 7.0	51	UL	10/20
SMA America	SB 3000HF-US	active	< 38	3R	16.0 x 29.0 x 7.0	51	UL	10/20
SMA America	SB 3000-US	active	< 40	3R	18.0 x 14.0 x 9.0	84	UL	10/20

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2011 Grid-Direct String Inverter Specifications

		Input Data (dc)						Output Data (ac)			
Manufacturer	Model	Maximum recommended PV power at STC (W)	Maximum open-circuit voltage	PV start voltage	Maximum power point tracking voltage range	Maximum usable input current	Maximum short-circuit current	CEC rated power (W)	Nominal output voltage	Maximum output current	Maximum ac OCPD rating (A)
SMA America	SB 3800-US	4,750	600	285	250–480	18.0	25.0	3,800	240	16.0	30
SMA America	SB 4000-US	4,375/5,000	600	285	220–480/250–480	18.0	25.0	3,500/4,000	208/240	17.0	30
SMA America	SB 5000-US	6,250	600	300	250–480	21.0	36.0	5,000	208/240/277	24.0/21.0/18.0	50
SMA America	SB 6000-US	7,500	600	300	250–480	25.0	36.0	6,000	208/240/277	29.0/25.0/22.0	50
SMA America	SB 7000-US	8,750	600	300	250–480	30.0	36.0	7,000	208/240/277	34.0/29.0/25.0	50
SMA America	SB 8000-US	10,000	600	365	300–480	30.0	36.0	7,680/8,000	240/277	32.0/32.0	50
SMA America	SB 8000TL-US	10,000	600	360	300–480	28.0	45.0	8,000	208	40.0	60
SMA America	SB 9000TL-US	11,250	600	360	300–480	31.0	45.0	9,000	208	44.0	60
SMA America	SB 10000TL-US	12,500	600	360	300–480	35.0	45.0	10,000	208	48.0	60
SolarEdge	SE 3300 US	4,125	500	5 [7]	5–60 [7]	N/A [8]	30.0	3,300	208/240	16.0/14.0	40
SolarEdge	SE 3800 US	4,750	500	5 [7]	5–60 [7]	N/A [8]	30.0	3,800	208/240	18.5/16.0	40
SolarEdge	SE 5000 US	6,250	500	5 [7]	5–60 [7]	N/A [8]	30.0	5,000	208/240	24.0/21.0	40
SolarEdge	SE 6000 US	7,500	500	5 [7]	5–60 [7]	N/A [8]	30.0	5,200/6,000	208/240	25.0/25.0	40
Solectria Renewables	PVI 1800	2,200	400	150	125–350	11.0	13.0	1,800	208/240	8.7/7.5	15
Solectria Renewables	PVI 2500	3,200	400	150	125–350	15.0	18.0	2,500	208/240	12.0/10.4	15
Solectria Renewables	PVI 3000	3,600	600	235	200–550	16.0	24.0	2,700/2,900	208/240	13.0	20
Solectria Renewables	PVI 4000	4,900	600	235	200–550	20.0	24.0	3,400/3,900	208/240	16.3	25
Solectria Renewables	PVI 5000	6,200	600	235	200–550	25.0	30.0	4,300/4,900	208/240	20.7	30
Solectria Renewables	PVI 5300	6,700	600	235	200–550	25.0	30.0	4,600/5,300	208/240	22.1	30
Solectria Renewables	PVI 6500	8,100	600	260	230–500	35.0	55.0	6,500	208/240/277	31.3/27.1/23.5	40/35/30
Solectria Renewables	PVI 7500	9,300	600	260	230–500	35.0	55.0	7,500	208/240/277	36.1/31.3/27.1	50/40/35

Footnote Key

[1] With fans operating in actively cooled units
[2] With dc/ac disconnect enclosure
[3] Available in Canada only
[4] With parallel configuation for MPPT
[5] Per MPPT channel
[6] One input per MPPT channel
[7] Powerbox specification
[8] Controlled by power boxes
[9] GEC not required (equipment ground only, 10–6 AWG)
[10] Option on panel assemblies
N/A = not applicable
DNR = did not report

Performance				Integrated Disconnects and Combiners				Termination Specifications			
Peak efficiency (%)	CEC weighted efficiency (%)	CEC night tare loss (W)	Ambient temperature range (ºF)	dc disconnect standard	ac disconnect standard	Disconnect amperage rating (dc/ac)	Fused combiner standard	Number of dc string inputs	dc terminal size range (AWG)	ac terminal size range (AWG)	GEC terminal size range (AWG)
96.8	96.0	0.10	-13–113	yes	no	36	yes	4	10–6	10–6	10–6
96.5/96.8	95.5/96.0	0.10	-13–113	yes	no	36	yes	4	10–6	10–6	10–6
96.7/96.8/96.8	95.5	0.10	-13–113	yes	no	36	yes	4	10–6	10–6	10–6
96.9/96.8/97	95.5/95.5/96.0	0.10	-13–113	yes	no	36	yes	4	10–6	10–6	10–6
97.1/96.9/97	95.5/96.0/96.0	0.10	-13–113	yes	no	36	yes	4	10–6	10–6	10–6
96.3/96.5	96.0/96.0	0.10	-13–113	yes	no	36	yes	4	10–6	10–6	10–6
98.3	98.0	0.25	-13–113	yes	no	36	yes	6	10–6	10–6	10–6
98.3	98.0	0.25	-13–113	yes	no	36	yes	6	10–6	10–6	10–6
98.3	97.5	0.25	-13–113	yes	no	36	yes	6	10–6	10–6	10–6
97.6	97.0/97.5	< 2.50	-4–120	yes	yes	30/40	N/A	2	10–6	10–6	N/A [9]
97.6	97.0/97.5	< 2.50	-4–120	yes	yes	30/40	N/A	2	10–6	10–6	N/A [9]
97.6	97.0/97.5	< 2.50	-4–120	yes	yes	30/40	N/A	2	10–6	10–6	N/A [9]
97.6	97.0/97.5	< 2.50	-4–120	yes	yes	30/40	N/A	2	10–6	10–6	N/A [9]
94.5	92.5	0.26/0.14	-13–131	no [10]	no [10]	N/A [10]	no	1	10–6	10–6	10–6
94.5	92.0/93.0	0.10/0.32	-13–131	no [10]	no [10]	N/A [10]	no	1	10–6	10–6	10–6
96.4/96.7	95.5/96.0	0.50/0.50	-13–131	yes	yes	30/30	yes	3	10–6	10–6	10–6
96.5/96.7	95.5/96.0	0.50/0.50	-13–131	yes	yes	30/30	yes	4	10–6	10–6	10–6
96.4/96.7	96.0/96.0	0.50/0.50	-13–131	yes	yes	30/30	yes	4	10–6	10–6	10–6
96.2/96.4	95.5/96.0	0.50/0.50	-13–131	yes	yes	30/30	yes	4	10–6	10–6	10–6
96.0/96.3/96.7	95.5/96.0/96.0	0.50/0.50	-13–131	yes	yes	44/45	yes	5	10–6	8–6	10–6
96.2/96.5/96.7	95.5/96.0/96.0	0.50/0.50	-13–122	yes	yes	44/45	yes	5	10–6	8–6	10–6

Footnote Key

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[10] Option on panel assemblies
N/A = not applicable
DNR = did not report

2011 Grid-Direct String Inverter Specifications

		Mechanical						
Manufacturer	Model	Cooling method	Noise level @ 1 m (dB) [1]	Enclosure NEMA rating	Dimensions H x W x D (inches)	Weight (lbs)	Listing agency	Warranty standard/extended (years)
SMA America	SB 3800-US	active	< 42	3R	18.0 x 14.0 x 9.0	84	UL	10/20
SMA America	SB 4000-US	active	< 37	3R	18.0 x 14.0 x 9.0	84	UL	10/20
SMA America	SB 5000-US	active	< 44	3R	18.5 x 24.0 x 9.0	141	UL	10/20
SMA America	SB 6000-US	active	< 45	3R	18.5 x 24.0 x 9.0	141	UL	10/20
SMA America	SB 7000-US	active	< 46	3R	18.5 x 24.0 x 9.0	141	UL	10/20
SMA America	SB 8000-US	active	< 49	3R	18.5 x 24.0 x 9.0	145	UL	10/20
SMA America	SB 8000TL-US	active	< 46	3R	18.5 x 24.0 x 9.0	77	UL	10/20
SMA America	SB 9000TL-US	active	< 46	3R	18.5 x 24.0 x 9.0	77	UL	10/20
SMA America	SB 10000TL-US	active	< 46	3R	18.5 x 24.0 x 9.0	77	UL	10/20
SolarEdge	SE 3300 US	passive	DNR	3R	27.5 x 12.5 x 7.5	52	ETL	12/20
SolarEdge	SE 3800 US	passive	DNR	3R	27.5 x 12.5 x 7.5	52	ETL	12/20
SolarEdge	SE 5000 US	passive	DNR	3R	27.5 x 12.5 x 7.5	52	ETL	12/20
SolarEdge	SE 6000 US	passive	DNR	3R	27.5 x 12.5 x 7.5	52	ETL	12/20
Solectria Renewables	PVI 1800	passive	< 35	4X	18.5 x 13.1 x 5.6	34	UL	5/10
Solectria Renewables	PVI 2500	active	< 52	4X	23.6 x 13.1 x 5.6	36	UL	5/10
Solectria Renewables	PVI 3000	active	< 35	3R	28.8 x 17.9 x 6.9	47	ETL	10
Solectria Renewables	PVI 4000	active	< 55	3R	28.8 x 17.9 x 6.9	48	ETL	10
Solectria Renewables	PVI 5000	active	< 57	3R	28.8 x 17.9 x 8.3	59	ETL	10
Solectria Renewables	PVI 5300	active	< 57	3R	28.8 x 17.9 x 8.3	60	ETL	10
Solectria Renewables	PVI 6500	active	< 47	3R	28.8 x 17.3 x 8.2	89	ETL	10
Solectria Renewables	PVI 7500	active	< 47	3R	28.8 x 17.3 x 8.2	89	ETL	10

Electric and other global suppliers will support events like this with well-established processes, policies and actions that are commonplace in other industries."

This ability to leverage the backing of a 19.6B euro company—one that is also a leading supplier of electrical distribution equipment—is one of the things that sets Schneider Electric apart. Catanzaro notes: "We not only offer inverters, but also a full line of dc and ac circuit protection products and disconnects from Square D." While the company uses a mixture of in-house and contracted manufacturing plants in Asia and North America, its new single-phase line of Conext series inverters for North America will be produced in Bangalore, India, where a subsidiary, American Power Corporation, has manufacturing plants. Catanzaro explains: "This allows the product line to take advantage of world-class manufacturing and global supply chain capabilities within the Schneider Electric group."

The redesigned Conext series of string inverters from Schneider Electric consists of four models designed for 208 Vac or 240 Vac interconnection, ranging in capacity from 2.7 kW to 5 kW. The high-frequency, transformer-based inverters are housed in NEMA 3R enclosures. Each unit includes an integrated Square D disconnect that opens both the dc and ac inputs to the inverter. The inverters are passively cooled, which allows them to be installed side-by-side with no side clearance. The Conext series inverters feature Fast Sweep technology, a shade-tolerant MPPT algorithm. Schneider reports that performance is comparable to microinverter systems.

SMA. Founded in 1981 when it was spun off from the University of Kassel, SMA has been headquartered in Niestetal, Germany, since 1982. Since 2008, shares in SMA Solar Technology have been listed in both the Prime Standard of the Frankfurt Stock Exchange (S92) and the TecDAX. Sales of 1.9B euros were reported in 2010, making SMA the world market leader for solar inverters. The company currently employs approximately 5,000 people worldwide and has 17 foreign subsidiaries on four continents (Asia, Australia, Europe and North America), including four subsidiaries in the US and Canada. While SMA does not release subsidiary sales figures, David Wojciechowski, senior director of sales for SMA America and SMA Canada, reports: "About 80% of SMA's 2010 global sales were generated by its medium-power solutions, which include residential and light commercial inverters."

A longtime leader in residential inverter technology, SMA released its first solar inverter, the PV-WR, CONTINUED ON PAGE 70

to the European market in 1990. Subsequent European product releases include a long list of industry firsts: the first high-voltage string inverter (the Sunny Boy 700) in 1995; the first transformerless inverter (the Sunny Boy 1500) in 1998; and the first multistring inverter (the Sunny Boy 5000TL) in 2002. Similarly, the first high-voltage string inverters available to the North American market were a pair of UL-listed, 60 Hz transformer-based Sunny Boy string inverters—the SWR 1800 and SWR 2500—released in 2001.

SMA currently offers 14 grid-direct string inverters in North America, many of which operate at multiple output voltages. The original 60 Hz transformer-based inverter line has been updated and expanded over the past decade; the US series of Sunny Boy inverters currently includes eight models ranging in capacity from 700 W to 8,000 W. SMA also offers a series of three high-frequency string inverters, ranging in capacity from 2 kW to 3 kW; inverters in the HF-US series are designed to fit between studs, making them ideal for new construction or space-constrained retrofit applications. In 2010, SMA introduced its TL-US series of inverters in North America; ranging in capacity from 8 kW to 10 kW, these are the first transformerless inverters ever to receive UL certification.

SMA's annual manufacturing capacity is 11 GW, the highest of all solar inverter manufacturers; this includes 500 MW of capacity in Ontario, Canada, and 1 GW in Denver, Colorado, which is reportedly the western hemisphere's largest inverter assembly site. ARRA-compliant string inverter models being assembled in Denver include SB 3000-US, SB 4000-US, SB 5000-US, SB 6000-US, SB 7000-US and SB 8000-US. These same Sunny Boy models are also being assembled in Ontario, initially by Celestica, to meet the province's microFIT requirements for domestic content.

According to Wojciechowski, SMA's commitment to regional production sites is just one of the strategies that the company employs in order to protect its leadership position in the North American market. The other way is through continued innovation of its products and technology. "SMA's Sunny Boy TL-US series of transformerless inverters offers significant improvement in a range of key criteria when compared to traditional galvanically isolated PV inverters," he explains. "Eliminating the transformer has allowed SMA to improve the efficiency of the system and, therefore, energy yields. At the same time, weight has been reduced by nearly half, allowing for easier installation. Integrators have been quick to recognize the benefits of transformerless

Courtesy Green Apple Energy

SolarEdge A proprietary system that includes SolarEdge transformerless inverters and module-level dc-to-dc power optimizers was introduced to the US market in 2010. Four inverter models from 3.3 kW to 6 kW are available. The module-level optimization approach enables low power, module-level safety and fault monitoring.

inverters and have rapidly adopted these new models for their projects."

When asked about potential permitting or inspection obstacles, Wojciechowski reports that the company has experienced "little to no push-back." He credits the company's strong service, support and education programs for the smooth rollout. "SMA America took care to educate integrators, utilities, AHJs and other stakeholders," he notes. "SMA believes that the imperative to reduce PV system costs and improve energy yields will continue to drive manufacturers to introduce transformerless inverters to the US market."

SolarEdge Technologies. A group of professional technologists with experience in solar, semiconductor and mission-critical power systems established SolarEdge Technologies as a private company in 2006. Widely recognized for its technological innovation, the company's global investors include GE Energy Financial Services and several top-tier venture capital firms. With offices in Germany, Israel, Japan and the US, the company has more than 100 employees involved in R&D, marketing, sales, and technical and logistical support. Since early 2009, Flextronics, a global provider of electronics manufacturing services, has mass-manufactured SolarEdge products in Israel; in April 2011, the two companies announced the opening of a new production line for North America, located in Newmarket, Ontario, Canada. The scheduled production capacity in both plants is 250 MW for 2011, but this capacity can be doubled if needed to meet market demands.

The SolarEdge system consists of module-level, dc-to-dc power optimizers and proprietary transformerless inverters. The optimizer is available both as a module-embedded and a module add-on solution. The company's first products were released in 2009. In 2010, product shipments exceeded 50 MW and went primarily to the European market. Because its product line had to be adapted for North American requirements, SolarEdge did not begin its US and Canadian product rollout until August 2010. The company currently offers four single-phase string inverters in North America—ranging from 3.3 kW to 6 kW in capacity—that interconnect to the grid at either 208 Vac or 240 Vac. The company is currently shipping second-generation optimizers and inverters. Third-generation products, offering additional features and improved energy yield, are expected to begin shipping later this year.

The proprietary transformerless inverters from SolarEdge were developed in cooperation with the Franhoffer Institute in Germany. Recognized as a leader in inverter technology, Franhoffer currently holds the world record for PV inverter efficiency, with a 99% efficient 5 kW transformerless 3-phase inverter. The CEC efficiency rating for SolarEdge string inverters is 97.5% at 240 Vac and 97% at 208 Vac. SolarEdge believes that module-level optimization can further increase energy yield by 2% to 3% compared to an ideal unshaded array, with greater gains possible on shaded arrays.

In addition to improving energy yields, the main SolarEdge system differentiators, according to John Berdner, general manager for North America, are design flexibility and improved safety. "The combination of module-level optimizers coupled with our own transformerless inverters frees system designers from nearly all the constraints of traditional string inverters," he explains. "String lengths of eight to 25 modules are possible, regardless of temperature. Strings can be of dissimilar lengths, modules within the same string can be mounted in different orientations and different types of modules can be used in the same string."

Module-level optimization also means that the system includes module-level safety and fault monitoring. "During installation and service, the output voltage of individual power optimizers is reduced to a safety voltage of 1 Vdc," Berdner points out. "The system also automatically reverts to safety mode in response to any grid faults or array ground faults, or if an excessively high temperature is detected, such as during a fire. Fault messages are reported by email, and system performance is verified with web-based module-level monitoring that is included with every inverter."

Solectria Renewables. Headquartered in Lawrence, Massachusetts, Solectria Renewables is a privately held corporation that manufactures and supports a full range of inverter products for utility, commercial and residential projects. The US company has an interesting history. In 1989, James Worden and Anita Rajan Worden founded Solectria Corporation. At the time, their design and manufacturing focus was on energy management components for automotive, power generation and other industrial applications. From 1989 to 2005, Solectria Corporation manufactured over 4,000 electric vehicles that relied on the proprietary drive system technology it had developed. Solectria Corporation also manufactured power electronics and controls for high-power systems, including inverters, dc-to-dc converters, energy storage and related technologies. In 2005, Solectria Renewables was founded with the sole focus of developing PV inverters, and Solectria Corporation was sold to Azure Dynamics. Solectria Renewables went from EV to PV, carrying the inverter technology utilized in the Solectria Corporation's electric vehicles to the manufacture of PV inverters. CONTINUED ON PAGE 74

Courtesy Solectria Renewables

Solectria Renewables
Headquartered in Lawrence, Massachusetts, Solectria Renewables launched its first string inverter models in 2005. The current PVI inverter lineup includes 1.8 kW to 5.3 kW single-phase products. Two additional models, the PVI 6500 and PVI 7500 will be released this summer.


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NEW KIND OF INVERSION.
ADVANCED ENGINEERING IN.
MORE POWER OUT.

Today, Solectria Renewables' wide range of products includes 1.8 kW to 500 kW grid-tied inverters. Solectria Renewables' marketing manager, Natalie Wiener, reports that the company's current inverter sales revenue distribution is approximately 35% string inverters and 65% central inverters. In addition to PV inverters, Solectria Renewables also manufactures string combiners and offers a variety of online system monitoring options via its SolrenView web-based monitoring system.

Solectria Renewables launched its line of PVI 1.8 kW and 2.5 kW single-phase string inverters in 2005. In 2008, the company partnered with Taiwanese inverter manufacturer Motech to release the PVI 3000–5300 series string inverter line to the US market. Mike Kelly, engineering manager for Solectria Renewables, emphasizes the strength of the relationship as well as his company's ownership of the PVI inverter line. "The PVI 3000–5300 series is our inverter, and we treat it as such," Kelly says. "We're responsible for the product line's distribution, support and warranty. Our investment in the product is much deeper than simple branding." This summer, two additional PVI models, the PVI 6500 and PVI 7500, will be released. These inverters have been ETL listed to UL 1741 and are currently eligible for the CSI program. The new units can be field-configured for 277 Vac output for commercial applications and will fill out Solectria Renewables' overall inverter line. The company's commercial and utility-scale PV inverters are manufactured in the US and are ARRA compliant as well as Ontario FIT Content Compliant. Solectria's PVI 3000–5300 series Ontario FIT compliant single-phase string inverters are assembled in Ontario, Canada.

Solectria Renewables has been developing smart grid features for its high-power 3-phase inverters. While bringing these advanced capabilities to the string inverter product class is possible, Kelly does not feel that this transition will occur in the near future. He says, "There are no real technical obstacles to porting the smart grid features we have been developing for our large commercial and utility-scale inverters over to string inverter products. However, in most cases, string inverter systems do not tend to be aggregated to a degree that would justify advanced grid features like remote command and control or VAR support."

In March, Solectria Renewables completed an expansion at its manufacturing facility in Lawrence, Massachusetts. The company expanded its California sales office and opened new offices in Florida and Colorado to increase its presence in the US. Scott Bowden, business development manager for Solectria Renewables, commented: "Solectria Renewables' business is growing extremely quickly, and we see a need for regional support. We've strategically located our new offices in Florida and Colorado in part to serve existing customers, but also to reach the growing number of new customers. The expansion of our California facility is also very exciting. We've expanded our sales office to include customer service and application engineering. We are pleased to be well positioned to serve the PV market nationwide."

FUTURE STRING INVERTERS

When you consider that high-voltage string inverters were a new-to-market technology in the US in 2001, the product class has clearly experienced extraordinary growth and innovation. New products from manufacturers like Eltek Valere are on the immediate horizon, and we expect to see additional models from the current market leaders as well.

SolarEdge's Berdner believes that string inverter developments over the next few years will take three directions. First, he expects the US PV industry to transition to transformerless inverters, noting: "There is a growing acknowledgement that ungrounded arrays offer a number of safety benefits compared to grounded arrays." Second, he expects the adoption of module-level power electronics in rooftop systems to become more widespread. Third, Berdner expects more inverter systems to incorporate bidirectional communication and control. "Once some changes are made to the UL and IEEE standards, inverters can easily provide improved low voltage ride through and enable remote utility control of power level and power factor. In order to allow widespread adoption of PV, inverters will need to become better citizens of the grid."

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SolarEdge / 530.273.3096 / solaredge.com

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Field Applications for I-V Curve Tracers

By Paul Hernday

While indispensible to PV cell and module manufacturing processes, I-V curve tracers have historically held a limited role in the field. Now that the technology is more widely accessible, the role of curve tracers is expanding beyond the laboratory.

Courtesy Integrated Energy Systems, Pittsburg Unified School District, Sage Renewables, Solmetric, Stellar Energy Solutions

Silicon PV modules are highly reliable, but performance problems do arise, and the industry needs fast and accurate ways to detect them. The stakeholders in newly built systems want to verify that all the PV modules are of a consistent quality, that they were not damaged during shipment or assembly, and that the array is producing at the contracted capacity. These stakeholders would also like a permanent record of the as-built system performance, a benchmark for comparison as arrays age and degrade—particularly in cases where warranty negotiations are required. Later in the system's life cycle, operations and management (O&M) or asset management companies want to evaluate the health of older arrays and have the ability to efficiently locate an ailing module.

These are all potential applications for I-V curve tracers, which can provide both a qualitative visual representation and a quantitative measure of PV performance. Curve tracing equipment was developed for testing transistors and diodes in the semiconductor industry. Now it is a workhorse in PV R&D and manufacturing, for use with both individual cells and modules. It also has a long history of use in field testing of PV arrays, a use that is likely to increase in frequency as more affordable and user-friendly products become available.

In an effort to demystify I-V curve tracers, here I explain how these devices work and how they can be used to commission and troubleshoot PV arrays. The basic characteristics of a healthy I-V curve are described, as well as characteristics that indicate the most common classes of PV array performance impairments. I present rules of thumb for the successful use of I-V curve tracers in the field, which is inherently more challenging than taking measurements in controlled settings like a factory or laboratory. I also provide tips on how to avoid common measurement and data analysis mistakes. When properly attained and analyzed, I-V curve traces provide the most comprehensive measurement possible of PV module or array performance.

I-V Curve Measurements

I-V curves or *traces* are measured by sweeping the load on a PV source over a range of currents and voltages. Curve tracers accomplish this by loading a PV module or string at different points across its operating range between 0 V and Voc. At each point, the output current and voltage are measured simultaneously. The load presented by the curve tracer may be resistive, reactive (typically capacitive) or electronic. Field test gear uses resistive or capacitive loading, whereas reference I-V test systems at research facilities tend to use electronic loads. The I-V curve may be swept in either direction.

In field test equipment, the actual I-V measurement sweep typically requires less than a second. However, there is a sweep speed limit for certain cell types. High-efficiency cell technologies from Sanyo, SunPower and other manufacturers cannot be swept arbitrarily fast. Because these cells store considerably more charge, more time is required for the cells to reach steady-state operating conditions at each point in the curve. A rough guideline is that the sweep rate for high-efficiency cells should not exceed 10 V per second per cell.

I-V CURVE REFRESHER

I-V curves, which appear on every PV module datasheet, represent all of the combinations of current and voltage at which the module can be operated or loaded. Normally simple in shape, these curves actually provide the most complete measure of the health and capacity of a PV module or array, providing much more information than traditional electrical test methods.

A normal-shaped I-V curve is shown in Figure 1 (p. 78). The maximum power point (Pmp) of the I-V curve—the product of the maximum power current (Imp) and the

Courtesy Solmetric (3)

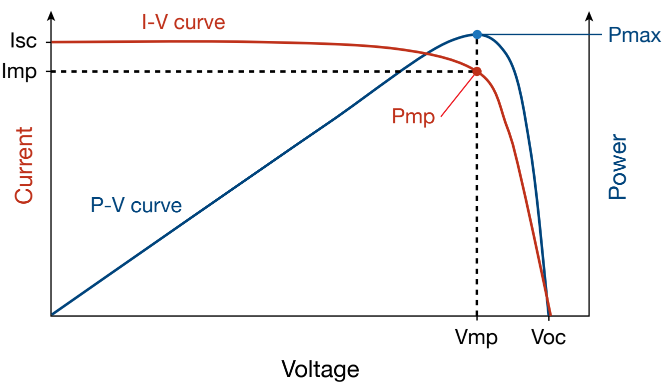


Figure 1 The normal I-V curve (red) and P-V curve (blue) shown here could represent any portion of a PV array—from a single cell, to a cell string or module, up through the array itself. The points making up this curve can be measured with a single connection and a single piece of equipment.

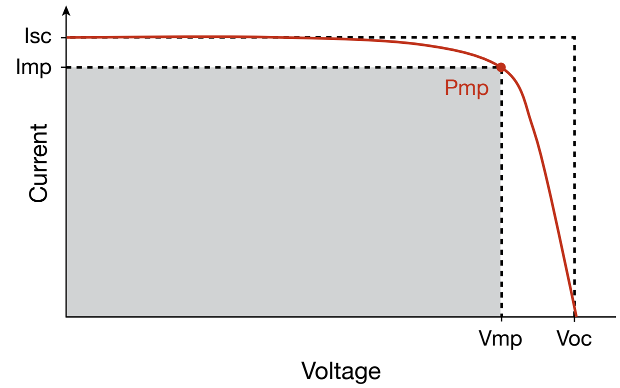


Figure 2 The outer rectangle represents an ideally square (but physically impossible) I-V curve; the shaded rectangle represents the actual measured I-V curve. The ratio of the smaller area to the larger area is the fill factor, a figure of merit for PV output capacity.

maximum power voltage (Vmp)—is located at the knee of the curve. At lower voltages, between the knee and the short-circuit current (Isc), the current is less dependent on voltage. At higher voltages, between the knee and open-circuit voltage (Voc), the current drops steeply with increasing voltage. The output current of a typical crystalline silicon PV module drops 65% in the upper 10% of its output voltage range. It is not uncommon for an I-V curve to be displayed with its associated power-voltage (P-V) curve, which is also shown in Figure 1. The value of power at each voltage point is calculated using the corresponding current from the I-V curve. The peak of the P-V curve (Pmax), of course, occurs at Vmp.

Fill factor. For given values of Isc and Voc, the power-generating capability of a PV module or array is related to the squareness of the I-V curve. The two rectangular areas in Figure 2 illustrate this relationship. The more square (or rectangular) the I-V curve, the closer Imp and Vmp approach Isc and Voc, and the higher the output power.

This relationship is also described by a figure of merit called the *fill factor,* expressed mathematically in Equation 1:

$$FF = (Imp \times Vmp) / (Isc \times Voc) \qquad (1)$$

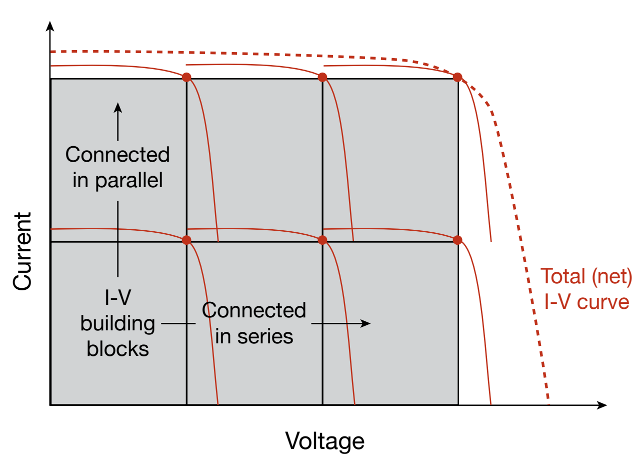
A fill factor of 1.0 represents a perfectly square I-V curve, a physical impossibility but a useful reference shape. The two areas in Figure 2, and the numerator and denominator of Equation 1, are all products of current and voltage, with units of electrical power. Any physical effect that reduces the fill factor also reduces the output power of the PV module or string.

Modules with a given PV module part number should have very similar fill factors under similar environmental conditions. Fill factor does vary across cell technologies, ranging from 0.75 to 0.85 in crystalline silicon cells and from 0.55 to 0.75 for most thin-film cells. Fill factor can be also be reduced by several classes of PV impairments, which are described later.

Scaling curves. The I-V curve of a given PV module can be scaled to represent a string or array by simply rescaling the voltage and current axes. A building block analogy, as shown in Figure 3, is useful in troubleshooting PV arrays. When modules are placed in series, the curves are stacked horizontally by adding voltages for each value of current. When modules are placed in parallel, their curves are stacked vertically by adding currents for each value of voltage. The resulting overall I-V curve and max power point are the horizontal and vertical sum of the individual building blocks.

The building blocks can also represent cell strings within PV modules. This view is helpful in CONTINUED ON PAGE 80

Figure 3 The I-V building blocks shown here could represent PV cells, cell strings or modules. The analogy of scaling up an I-V curve from more basic building blocks is useful when troubleshooting PV arrays.



troubleshooting situations because, although PV cells are the fundamental unit of production, string voltage tends to be lost in jumps that correspond to the loss of individual cell strings. A step down in an I-V curve may indicate the loss of a building block or at least a reduction in current of one of the building blocks. The width of the step is a clue to how many modules or cell strings are affected by shading, failed bypass diodes or other problems.

Benefits of Curve Tracing

The benefits of curve tracing are substantial. In addition to measuring Isc and Voc, curve tracing also captures all of the operating points in between these values, including the current and voltage of the MPP and thus the maximum power value itself. The overall shape of the I-V curve can be analyzed to give clues to performance issues in ways that traditional test methods cannot. Further, the maximum output-power rating for individual PV modules or strings can be obtained without an inverter or the attendant uncertainties of the individual inverter efficiency.

David King, PV consultant and founder of DK Solar Works, has extensive laboratory and field experience with I-V curve tracers. King worked for 31 years in the solar energy departments at Sandia National Laboratories, where he managed laboratories for testing PV cells, modules and high voltage arrays, as well as overseeing system performance characterization and modeling activities. Based on that experience, King concludes that I-V curve tracing is a fundamental, required measurement throughout the PV industry, both indoors in cell or module manufacturing environments, and outdoors for the testing of modules, module-strings and large arrays.

"I-V curve measurements provide direct performance characterization and verification, as well as a diagnostic tool for periodic PV system performance assessments," says King. "I-V curve tracing is the most informative measurement that can be performed on a PV module or array. The visual shape of the curve provides immediate diagnostic insight for a PV specialist. When coupled with the associated solar irradiance and temperature data, it provides a quantified comparison to expected performance."

Courtesy Daystar

Daystar DS-100C Designed for field use, this I-V curve tracer from Daystar is rugged and portable. It is capable of tracing subarrays of up to 50 kW in capacity.

Though no other diagnostic tool can provide as much relevant information about PV component or system health, today's commissioning agents and O&M technicians do not often use I-V curve tracers for their periodic performance assessments. According to Andrew Rosenthal, director of the Southwest Technology Development Institute (SWTDI) at New Mexico State University, the high cost of these tools has limited their use in the field.

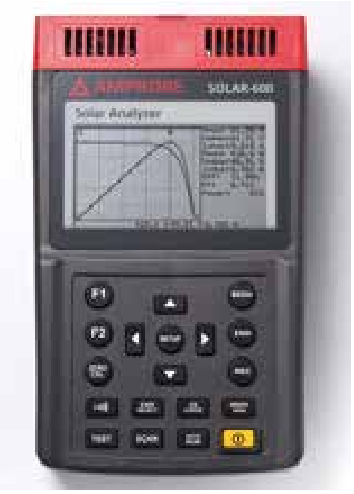
"Curve tracing has not been more widely used in the industry because of the prohibitively high cost of most curve tracers," Rosenthal says. He explains that one of the common field applications for curve tracing in R&D is to accurately determine the dc power rating for a PV system. "I-V curve tracing is a valuable tool when an accurate system rating is required," says Rosenthal. "It is also a valuable tool for system troubleshooting when string or array performance is less than expected."

Specialists engaged in PV system troubleshooting activities have long required access to I-V curve tracers, regardless of the cost. For example, Bill Brooks, principal at Brooks Engineering, first used an I-V curve tracer in 1988 and purchased a tracer of his own in the early 1990s. Brooks believes that the educational benefits of working with a curve tracer are hard to overstate. "I had the great fortune of learning about PV through the eyes of an I-V curve tracer," he says. "I consider that education a critical part of my success in understanding and troubleshooting how PV systems operate."

This educational component is one of the reasons Brooks is excited about the increasing availability of affordable and portable products. Companies like Amprobe, Daystar, EKO, HT-Italia and Solmetric all have curve tracers available in North America that are specifically intended for field-testing applications like PV system commissioning and troubleshooting; even more products are available in Europe.

"Now that these devices are so much more affordable, there is no good reason not to get one," says Brooks. "For example, the cost for the PVA-600 PV Analyzer from Solmetric is in a range that makes it attractive to any company with a dozen or more employees. Unlike a new truck that depreciates the second it is driven off the lot, a curve tracer is an investment that helps the employees of that company understand their trade better and eventually become experts in their field."

Isaac Opalinsky, technical trainer at SunPower, CONTINUED ON PAGE 82



Courtesy Amprobe

Amprobe Solar-600 This handheld solar analyzer from Amprobe is capable of tracing I-V curves for individual modules rated at up to 60 V and 12 A. The internal memory stores up to 99 measurements.

Courtesy Solmetric

Solmetric PVA-600 The PV analyzer from Solmetric, which has a measurement range of 600 V and 20 A, is designed specifically for field testing PV systems. An optional wireless sensor kit is also available.

has long used curve tracers in training programs as an educational tool to help students understand how real-world effects, such as temperature, irradiance, shading and mismatch, impact system performance.

"Recently, we have been able to measure some of the I-V curves that had previously only been modeled, including scenarios with multiple strings, shading and intentional mismatch, for instance multiple orientations," says Opalinsky. "It is satisfying for students to see how the things we discuss in the classroom are validated and replicated with real-world measurements. Even if the students are not the technicians who are likely to be performing O&M tasks in the field, an I-V curve tracer that can be used directly by the students can help create the 'ah-ha!' moments where abstract concepts are synthesized."

While it is possible for technicians in the field to get a basic snapshot of system performance and diagnose many field failures using affordable and widely available tools like digital multimeters and clamp meters, Opalinsky notes that I-V curve tracers have two unique advantages. First, I-V curve tracers make it easier and safer to take Isc measurements. Second, curve tracers can reveal what happens to an array under load.

"The four key measurements that can be performed with a digital multimeter (Voc, Vmp, Imp, Isc) are inadequate if we want to get a picture of how the PV system responds to a varying load," states Opalinsky. "Without disassembling an array, it can be difficult to determine if a perceived problem is just a function of varying environmental conditions, a single bypass diode that has failed or high resistance in a corroded connector."

"**As our industry matures,** we should not be selling PV as a 'maintenance-free' energy solution. At a minimum, we should be inspecting all PV systems on a regular basis. If using a digital multimeter is like measuring a patient's blood pressure and heart rhythm, using an I-V curve tracer is like administering an MRI. Rather than being EMTs responding to an emergency, we should be physicians helping to keep our patients healthy through preventative maintenance and regular screening."

—Isaac Opalinsky, SunPower

PV Array Performance Impairments

In order to identify potential problems using an I-V curve tracer, technicians need to be trained to understand the different classes of performance impairments, as well as the associated curve signature for each. There are five basic classes of PV array performance impairments: series losses, shunt losses, mismatch losses, reduced current and reduced voltage.

Series losses. Losses due to excess series resistance show up in the I-V curve as a decreased slope, or inward tilt, of the curve near Voc. An example is shown in Figure 4 (p. 84). Series resistance effects are equivalent to adding a single external resistor in series with the PV module. The voltage drop across this resistor increases linearly with output current, reducing the output voltage. Since the current change relative to voltage in the I-V curve is much CONTINUED ON PAGE 84

more pronounced near Voc, the decreased slope due to increased series resistance is most apparent at these higher voltages, near Voc.

Series resistance losses can be located internally, inside a PV module, or externally, in the array wiring and switchgear. Dr. Sarah Kurtz, principal scientist and reliability group manager at the National Renewable Energy Laboratory (NREL), notes that the most common cause of PV performance problems is probably increased series resistance. "This is often caused by internal interconnections beginning to crack or break entirely," she explains. "Most of today's modules have redundant wiring so that a single break doesn't stop the current flow, but it still increases the series resistance." Corroded or poorly connected array wiring can be an external cause of increased series resistance.

A solar module is typically divided into cell strings, each of which is shunted by a bypass diode. If series resistance in a module is very large, sufficient voltage can be developed across the series resistance so that the bypass diode turns on. An example of this effect can be observed when part of a module is shaded. In this case, the shaded cells are no longer predominantly current generators, but instead act as a dissipative resistive element. The bypass diode then shunts the current around the resistive cells, at the price of reduced string voltage and power in the partially shaded string.

Both series and shunt (or parallel) resistances degrade system efficiency by dissipating power. Since power dissipation can occur in a localized region, "hot spots" can develop. This can lead to thermal runaway where the high temperatures lead to greater power dissipation and, in some cases, damage to a PV module. If functioning properly, the bypass diodes help mitigate series resistance effects.

Shunt losses. Losses due to shunt resistance show up in the I-V curve as an increased slope, or downward tilt, of the curve near Isc. This is a region where the I-V curve is ordinarily very flat, if no shunt resistance is present. Shunt resistance effects are equivalent to connecting resistors across PV cells. As the cell voltage increases, the current through this shunt resistor also increases, reducing the module's output current and power correspondingly.

Shunt losses are located mostly within PV modules and are caused by resistive paths between the cell's front and back faces. Imperfections in cell material and faulty edge isolation can cause shunt losses. Cells that are cracked or damaged—sometimes when the metallization is added—can also cause leakage.

Mismatch losses. Substantial mismatch effects show up as notches or kinks in the I-V curve, as shown in Figure 5. More moderate effects show up as slope changes in the Isc leg of the I-V curve. The many possible causes include shading, uneven soiling, cracked PV cells, shorted bypass diodes and mismatched modules. Module mismatch can be due to differential aging effects, manufacturing tolerances or the mixing of different modules in the same string. It can also arise from one or more cell strings cutting out due to shading, bypass diode failure or the triggering of bypass diodes by other module level issues.

Reduced current. Reduction in the height of the I-V curve can be caused by uniform soiling, edge soiling (common in low-tilt, portrait-mode arrays), PV module degradation or weather conditions that reduce the input irradiance. Soiling directly impacts the height of the curve because it reduces the incident irradiance.

Figure 4 The I-V curve signature for a cell string with excess series resistance (in red) is compared here to the curve for a healthy cell string (in green).

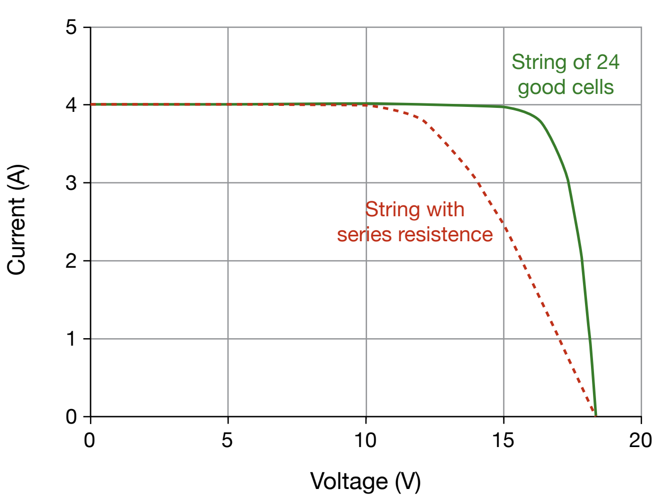
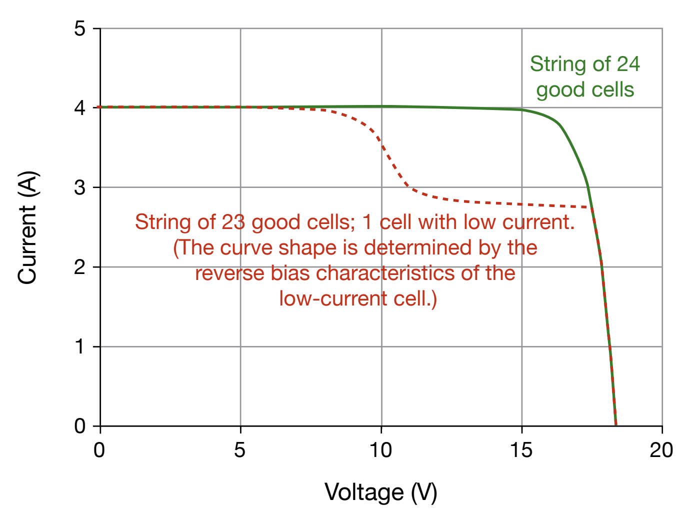


Figure 5 Reduced current from a single PV cell in a string of cells can produce the notched I-V curve signature (in red) typical of a PV source with mismatch losses.



Courtesy NREL (2)

Reduced voltage. The width of the I-V curve is affected by module temperature. Poor air circulation, for example, can raise the module temperature and substantially reduce Voc and Vmp. Module degradation, shorted bypass diodes and other system problems can also reduce Voc and Vmp. The width of the I-V curve is relatively insensitive to normal soiling.

IMPAIRMENT SIGNATURES

Each of the impairment classes described has a characteristic I-V curve signature, as summarized in Figure 6 (p. 86). The reduced current and reduced voltage impairment classes affect the height and width of the I-V curve. The other three impairment classes affect the overall shape of the I-V curve. Excess series resistance, decreased shunt resistance, and mismatch cannot be detected by simple open-circuit voltage measurements or clamp meter current measurements of individual strings. I-V curve tracers, however, provide a window into these failure modes that allows the PV technician to verify performance quickly and spot problems early.

"Some failure or degradation mechanisms cause internal changes to cells that cannot be seen with the naked eye," explains NREL's Kurtz. However, it may be possible to see the effects of these changes in I-V curve traces. She continues, "These changes may increase the series resistance, decrease the voltage and/or current, or may cause some shunting that makes the flat part of the I-V curve slope somewhat, decreasing the height of the knee, and, therefore, the output power."

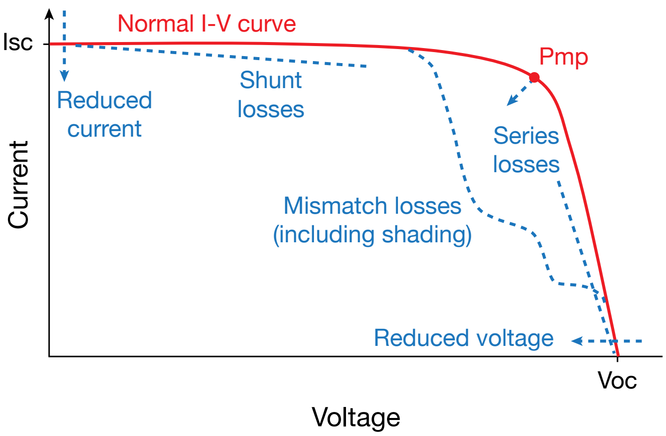
PV Performance Verification Process

Because field testing PV arrays requires working on or around energized circuits, personal protective equipment is required. It is also necessary to observe proper safety procedures, such as lockout-tagout. Read and follow NFPA-70E, *Electrical Safety in the Workplace,* for more information (See Resources).

The process of isolating circuits for measurement varies depending on the details and scale of the installation.

Residential systems. In residential systems, the PV output conductors may land on terminal blocks in an inverter-integrated disconnect switch or in the inverter itself. While curve tracers can be connected to live PV strings as long as the measurement process is disabled, lifting live PV circuit conductors can be dangerous. It is advisable that residential system designs always include either fuses or dc disconnects that enable the isolation of individual strings from the inverter and from each other. PV systems require checkups and servicing as they age, so it makes sense for system components to include the means for isolating and connecting to individual PV strings quickly and safely. Some inverters, particularly those with fused dc inputs, already provide this capability.

Figure 6 I-V curve signatures for each of the five classes of PV performance impairments are summarized here. Two classes affect the height or width of the curve. The remaining three classes affect the shape of the curve.



Commercial systems. In commercial PV systems, curve tracer measurements are performed at the combiner box, as shown in the photo to the right. The combiner is isolated from the rest of the array and the inverter by opening its dc disconnect switch. Then the combiner box is opened and all the touch-safe fuses are lifted. Once the busbars are de-energized, the curve tracer's test leads are clipped onto the busbars. Fuses are inserted one at a time for measurement of individual strings. Once an I-V curve is captured, it can be saved electronically. Some I-V curve tracers, like the Solmetric PVA-600, also allow the measured I-V curve to be compared via integrated software to a model I-V curve. The entire process typically takes 10–15 seconds per string.

PERFORMANCE STANDARDS

Verifying PV array capacity requires a standard of comparison, regardless of the testing equipment used. The standard of comparison may be a contracted power value or the prediction result from a PV array model. In the case of commercial-scale PV systems, performance verification test limits and even the test equipment itself are often specified in the performance guarantee contract. In troubleshooting situations, the standard for comparison is often a neighboring PV string.

The most common standard for performance verification measurements in the field is the nameplate specifications for the PV module. Since these apply at STC, measured I-V parameters must be translated to an irradiance of 1,000 W/m^2 and a cell temperature of 25°C. Curve-tracing instruments, however, can use PV models to predict the expected I-V curve shape. This allows the user to instantly verify performance or diagnose problems by looking for deviations between the measured curve and the expected curve predicted by the PV model or models.

Several types of PV performance models are commonly used for estimating array capacity. These models describe the performance of PV modules, strings and arrays. The three performance models most often used in the PV industry are (in order of most to least detailed): the Sandia PV array performance model, the 5-parameter model and the single-point efficiency model. These models are provided in NREL's Solar Advisor Model (SAM) simulation software. Assuming data for a PV module is available, the first two of these models can be used to generate a predicted I-V curve, given sufficient detail about system components, array orientation and environmental conditions. This makes them ideal candidates for predictive models built into curve tracing equipment. The third model predicts the maximum CONTINUED ON PAGE 88

Courtesy Solmetric (2)

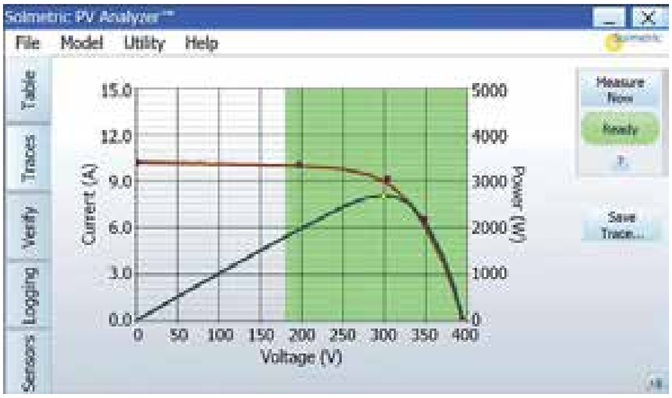
Field measurements After electrically isolating the ungrounded busbar in the combiner box, test leads to the I-V curve tracer are clamped in place. Individual source circuits can then be curve-traced by closing the series fuses one at a time, as shown here.

power value and is a good backup when a PV module is not represented in either the Sandia or 5-parameter model databases.

Sandia model. The Sandia PV array performance model was developed by David King and his co-workers at Sandia National Laboratories in Albuquerque, New Mexico, and features over 30 parameters representing irradiance and temperature dependence, spectral response, angle of incidence and other effects (see Resources). It is the most descriptive of the three PV performance models and has the greatest potential to benefit the PV industry. According to Richard Bozicevich, VP of business development for TÜV Rheinland PTL in Pheonix, Arizona: "Applications for the Sandia model include system design and sizing, translation of field performance measurements to standard reporting conditions, system performance optimization and real-time comparison of measured versus expected system performance."

The Sandia model database now contains parameters for more than 500 PV module model numbers. Under contract with Sandia and the US Department of Energy, TÜV Rheinland PTL has developed the in-house capability for measuring Sandia model parameters. Regarding the status of the technology transfer, Bozicevich reports that model validation is completed, and TUV Rheinland PTL

Model behavior This screen capture shows the I-V and P-V curve traces for two paralleled PV source circuits, each consisting of 10 modules, taken using the Solmetric PVA-600 PV Analyzer. The five black dots show the shape of the I-V curve predicted by the onboard PV models.



Courtesy Solmetric

has full capabilities to execute testing to the model for client samples.

"Top-tier manufacturers are starting to request the testing and are using the data to CONTINUED ON PAGE 90

"I often tell students in my classes to **learn to think like a PV array.** Thinking like a PV array requires understanding the I-V curve and how it changes based on ambient conditions and array problems. An I-V curve tracer is the best way to gain an understanding of these changes, since it provides a graphical representation of the array operating characteristics."
—Bill Brooks, Brooks Engineering

analyze their module performance," according to Bozicevich. "However, the likelihood that these manufacturers will release the parameters to the Sandia database remains an open question."

5-parameter model. The 5-parameter PV performance model was developed at the University of Wisconsin Solar Energy Laboratory. It is used by the California Energy Commission (CEC) to simulate PV system performance for its New Solar Homes Partnership. Patrick Saxton, senior electrical engineer at the CEC, reports that as of May 12, 2011, the CEC 5-parameter model database contains parameters for more than 4,900 PV module model numbers.

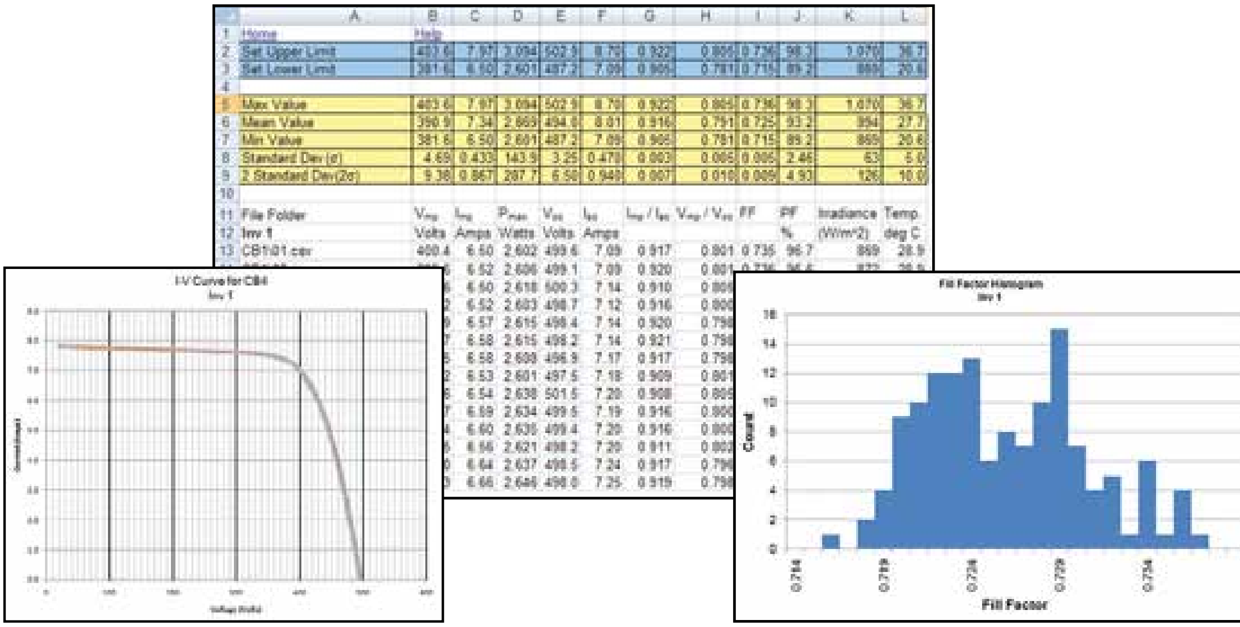
"The database has been growing at the rate of 300-400 new model numbers a month for at least the last year," Saxton says. "Some fraction of these may be repeat entries for private labels. Model parameters are generated at third-party testing facilities using a single sample module, often at the time of UL 1703 certification."

Single-point model. The single-point efficiency model predicts the maximum power value based on parameters normally listed in the PV module datasheet. The calculations for this method are familiar to installers who have used datasheet parameters to translate the maximum power value of a PV system to standard test conditions, or vice versa. (For more details on I-V parameter translation, see "PV System Commissioning," October/November, 2009, *SolarPro* magazine.)

Translation of measured I-V curve data to STC conditions always introduces error. The magnitude of the error increases with the difference in CONTINUED ON PAGE 92


Well, proven performance sure helps.
Who says you can't predict the future?

Figure 7a



Courtesy Solmetric (3)

Figure 7b

Figure 7c

Figures 7a, 7b and 7c Curve traces for a commercial PV array taken with the Solmetric PVA-600 yield a large amount of data. Automated data analysis tools, like summary tables (7a), I-V curve overlays (7b) and data distribution plots (7c), make it easy to spot strings that have performance problems.

irradiance or temperature that is measured versus the STC conditions. A way around this limitation is to use the Sandia model to predict the shape of the I-V curve and the values of the key performance parameters, taking into account instantaneous irradiance and temperature. This approach allows for immediate, high-quality assessments of string performance in the field.

DATA ANALYSIS

Analyzing PV array performance data always involves comparison of the results with a specification or model, and may involve detailed analysis of variations of I-V curves across the population of strings. The shape of a measured I-V curve gives important clues to the causes of performance problems. Combined with a predictive PV performance model, I-V curve traces provide the most complete picture of the electrical health of a PV module, string or array.

While commercial-scale PV arrays yield huge amounts of string-level performance data, automated measurement, data collection and analysis can be employed to increase throughput and reduce operator fatigue and data recording errors. Further, automated analysis tools quickly summarize results and make it easy to spot nonconforming strings.

Figures 7a, 7b and 7c show three automated analysis tools for a particular array. The table view, shown in Figure 7a, lists the key performance parameters extracted from the measured I-V traces. These include the familiar Isc, Imp, Vmp, Voc and Pmax values, and also fill factor and the current and voltage ratios that represent the slopes of the lower and upper voltage legs of the I-V curve. If a fill-factor value is out of line, the current and voltage ratios give hints as to whether series or shunt resistance effects may be involved. Statistics for each column are indicated, including the spread of the values. The user can define the acceptable range of values; out-of-range cells in the table are shaded yellow to identify the outlying string.

The I-V curve overlay graph, Figure 7b, gives a quick visual indication of the I-V curve consistency across strings. Figure 7c shows distribution plots or histograms that provide insight that simple statistical parameters such as max, min, mean and standard deviation do not. The shape of the distribution plot can indicate whether the spread or deviation measured is the result of random module performance or environment-sensing variations, a problem with the measurement setup, or even the outcome of more systematic effects. For example, the performance verification data for one commercial rooftop array showed an unusual distribution of string Voc data. Further analysis led to the discovery of a large temperature differential between strings at the edge of the array compared to strings located away from the edges where air circulation was limited. This is common in large rooftop arrays where modules are packed in a tight formation. CONTINUED ON PAGE 94

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25 year performance guarantee* for crystalline solar modules. Bosch develops, produces and monitors its modules at its own state-of-the-art plants. This way, Bosch establishes the conditions necessary for high long-term yields as well as a long service life of your modules. We also offer you a ten year Bosch product warranty for our crystalline modules. All of this contributes to making Bosch a dependable partner for you – short term as well as in the distant future. Would you like to find out more? www.bosch-solarenergy.com
BOSCH
Invented for life
*Bosch Solar Energy AG guarantees that the modules will yield at least 80% of the declared output over a period of 25 years.

"The best way to derive a dc system rating is with an I-V curve and using the performance coefficients provided by the module manufacturer to correct from actual conditions of irradiance and temperature to standard conditions. Energy modeling using TMY or other data can provide an estimated annual energy rating, but it all starts with an accurate power rating."
—Andrew Rosenthal,
Southwest Technology Development Institute

Field Applications for I-V Curve Tracers

The main field-testing applications for I-V curve tracers are system commissioning, routine operations and maintenance, and troubleshooting performance problems. Benchmarking system performance is an important aspect of system commissioning and acceptance, and it is valuable whenever PV performance guarantees are used. Once a performance benchmark is established, taking routine I-V curve traces can make preventative maintenance activities more meaningful for array operators. In the event that unscheduled maintenance is required, I-V curve collection and analysis can help to quickly pinpoint problems.

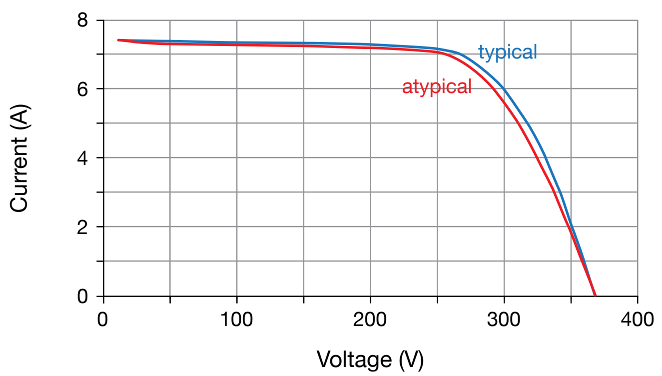
SunPower's Opalinsky believes that companies engaged in these activities should consider taking curve traces. "Anybody involved in the commissioning of PV systems—either as system owner, integrator or third-party commissioning agent—should consider I-V curve traces as a method of benchmarking system performance at the time of startup and for verifying performance in the future," Opalinsky says. "Companies involved in maintaining and operating PV systems should consider having at least one person on staff who is trained to use an I-V curve tracer and interpret the results."

COMMISSIONING PV ARRAYS

Developers, PPA financiers, engineering, procurement and construction (EPC) contractors, and providers of O&M services all have a strong interest in verifying and optimizing the performance of a solar asset. Each stakeholder stands to benefit from a test measurement method that provides deep insight into PV system operation and potential problems.

By employing proper performance measurements in solar PPA projects, financial risk can be reduced and ROI increased. When the developer and PPA financiers want to be sure that a system is fully functional and operating optimally, they can require a complete commissioning report that includes the measurement of I-V curves for every string. Any deviations of actual performance from expected performance beyond some agreed threshold are then corrected before funds are released to the EPC contractor.

For its part, the EPC contractor establishes a baseline of data that can be used in the future if performance questions or contract disputes arise. By curve tracing each string and demonstrating that the system is fully functional at the time of commission, the EPC contractor can prove that it has met the installation electrical performance verification portion of its contractual obligations. The CONTINUED ON PAGE 96



Courtesy Solmetric (2)

Figure 8a

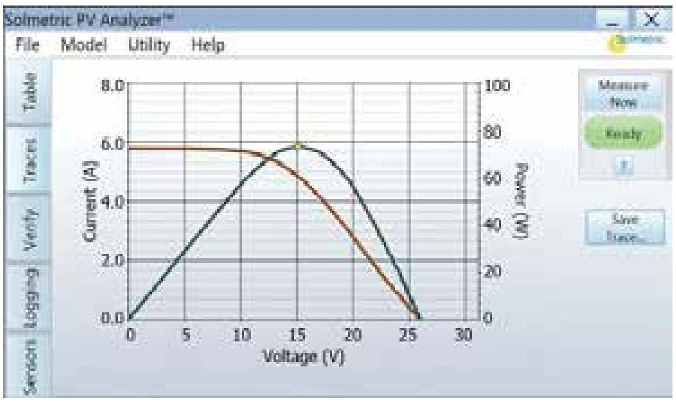
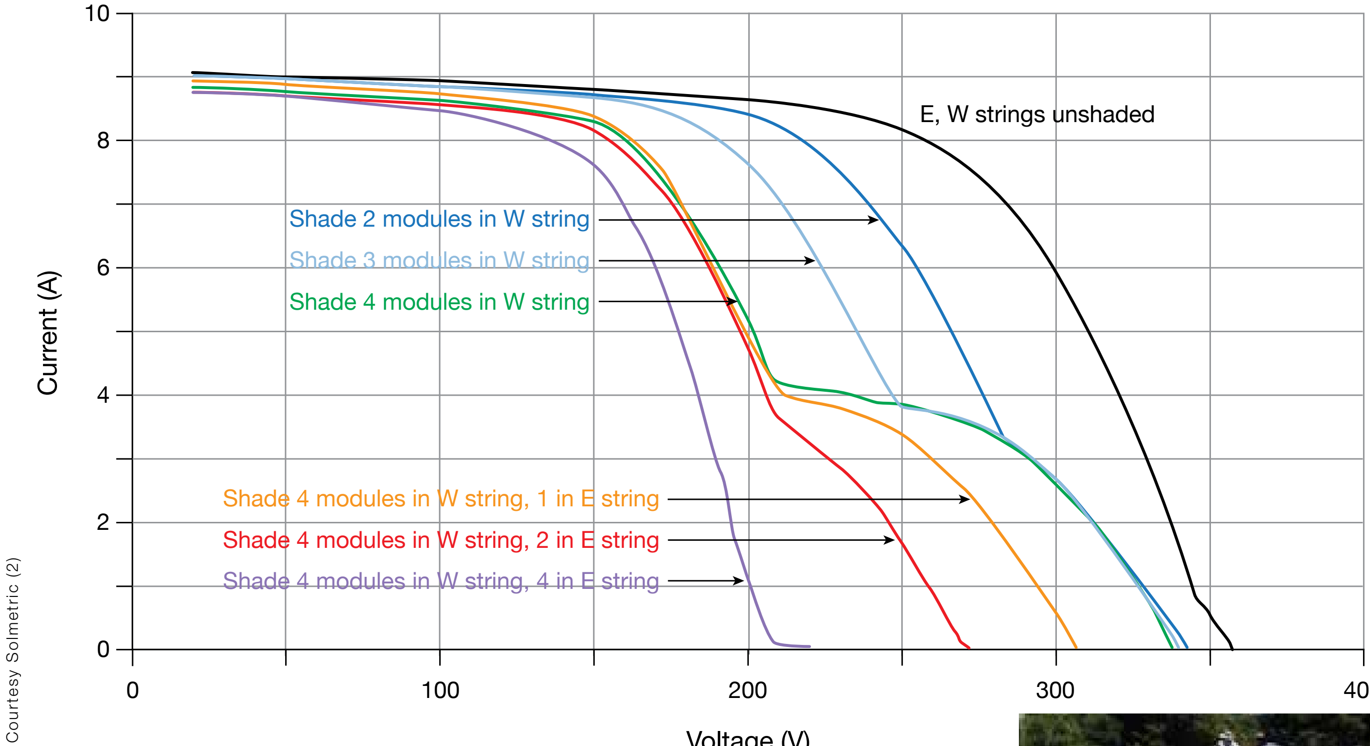


Figure 8b

Figures 8a and 8b After an atypical string was spotted in an overlay of I-V curve traces (8a), the underperforming string was analyzed in more detail. This led to the discovery of a single module with excess series resistance (8b). Small burn marks were subsequently observed on several cells within the module.



Figures 9a (above) and 9b (at right) The stepped I-V curve shapes (9a) caused by shading various combinations of modules in two paralleled strings are measured at a site provided by the solar division of Harmony Farm Supply (9b).

archived data is then referenced if there are performance issues in the future.

Performance verification is typically required by contract as part of the commissioning of new commercial systems, and it is likely to become commonplace for systems of any size, including residential, in the future. Recommissioning is appropriate at other points in the PV system's life cycle, including a change of ownership, a trauma to the PV system (lightning strike, extreme wind, theft and so on) and array removal and replacement for reroofing.

Traditionally, performance verification of commercial-scale arrays involves measuring and recording the string open-circuit voltages, as well as the string operating currents at the overall system MPP as determined by the inverter. The short-circuit current may also be measured. The drawbacks to this traditional approach are that the individual measurements and data recording take considerable time; they are limited in the performance issues they can identify; and they do not make independent maximum power measurements of each string.

I-V curve tracers overcome these limitations by integrating and automating the measurements and data recording, and by revealing all the performance issues. For example, open-circuit voltage measurements and clamp meter current measurements cannot detect excess series or shunt resistance, or module mismatch in a string, whereas curve traces can.

TROUBLESHOOTING PV ARRAYS

Troubleshooting may be triggered by a system owner's complaint of poor production, an alarm thrown by a monitoring system or by observations made during a routine checkup. The technician may turn to an I-V curve tracer after reading the inverter display and checking dc voltages and currents with a digital multimeter (DMM) and clamp meter. In troubleshooting situations, compared to using a DMM or clamp meter, an I-V curve tracer can provide far greater detail in the data that it reveals and the records it keeps of performance before and after the repair. If a module warranty return is in order, curve tracing provides the most complete documentation.

The first step in troubleshooting with a curve tracer requires no PV model or reference standard, but only the measurement of a string's I-V curve. Once the trace is complete, consider whether the curve has a normal shape. If it CONTINUED ON PAGE 98

does not—if there are steps or notches in the curve—consider the following:

- Is any of the string shaded, even a fraction of a cell?
- Is substantial, uneven soiling from birds, dirt dams, lichens or tree litter present?
- Are there burn marks on the front or back faces of the modules?

Comparing the curves of two or more strings is a good way to spot more subtle effects, like a softer knee in an I-V curve or reduced short-circuit current or open-circuit voltage. For a more objective test, translate the I-V curve to STC and compare key parameter values to the specifications on the modules' product data sheet. For the most reliable and accurate test, compare the shape of the trace with the predictions of an onboard PV performance model such as the Sandia model or 5-parameter model.

Fill factor is an effective initial screen for any performance problems that show up as subtle changes in the slopes or softness of the knee in an otherwise normal looking I-V curve. If the fill factor is low, check the Imp/Isc and Vmp/Voc ratios relative to neighboring strings or the predictions of the PV model.

Series resistance signature. Reduced Vmp/Voc may indicate increased series resistance. The I-V curve signature for series resistance is a reduced slope or inward tilt in the leg of the curve between Vmp and Voc. Figure 8 (p. 94) shows an example of this condition. I-V curves taken for two adjacent strings showed a noticeable difference in series resistance. Further investigation showed that the source of the extra resistance was a single module that had several fingerprint-sized burn marks scattered along several cells.

Increased series resistance does not always show physical signs on the module face or backsheet. Therefore, it may be necessary to successively break the string in two, using the *half-splitting* method to zero in on the damaged or degraded module. In this technique, a poor performing string is split into two substrings, and each substring is measured. Then the poor performing substring is again split and measured until the problem becomes obvious or the substring is reduced to an individual module.

Shunt resistance signature. Shunt resistance effects show up as increases in the slope of the leg of the I-V curve near Isc, but shunt resistance is not the only possible cause of this increased tilt. Tapered edge soiling (dirt dams) or slight shading that tapers gradually across a row of modules can produce a similar change in slope with no apparent bypass diode action.

Reduced current signature. If the I-V curve has a normal shape and width, but the Isc is lower than predicted by the PV model, check first for uniform soiling. Depending on the purpose of the testing, you may need to clean the array.

An accurate way to demonstrate the impact of uniform soiling is to measure the I-V curve before and after cleaning and compare the maximum power values. Do the test under clear sky conditions close to solar noon, so that the irradiance is constant. Measure I-V curves for two neighboring strings. One of these strings will be cleaned as part of the test; the other serves as a control to remove the effect of any irradiance changes. After cleaning one string, measure I-V curves for both strings again and observe how much the cleaning affected Isc and Pmax in the test string. If the control string showed changes as well, use these changes to correct the before and after results in the test string for a more accurate comparison.

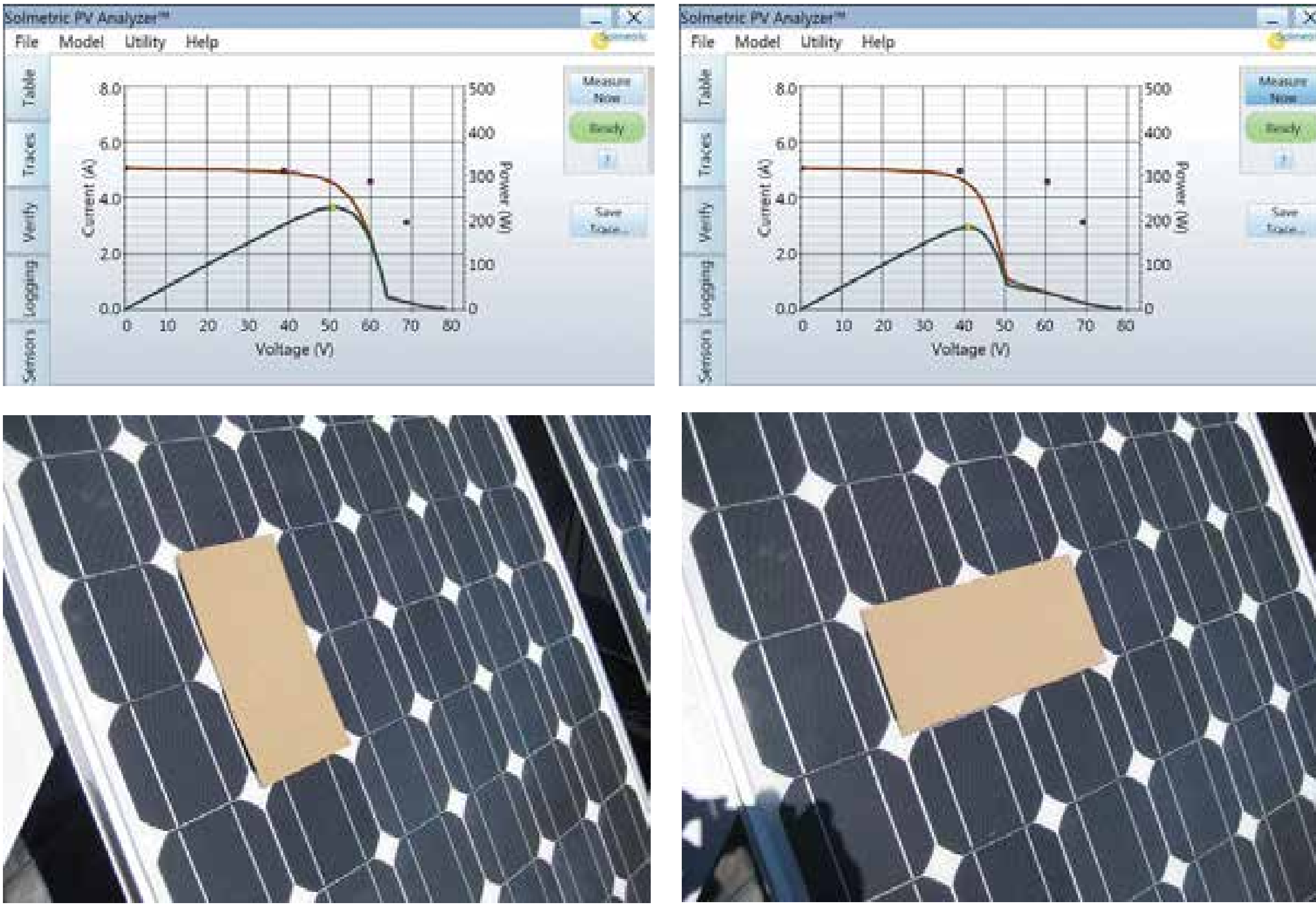
Certain module failure modes may also reduce module current. NREL's Kurtz describes two examples: "Especially for older modules deployed in hot, humid locations, some browning of the encapsulant may be visible, causing a somewhat decreased current but probably an undetectable change to the voltage. In addition, delamination can slightly decrease the current because of the reduced coupling of the light into the cell; in the long term, however, delamination can lead to corrosion and, eventually, catastrophic failure."

Reduced voltage signature. If the I-V curve of a single string has a normal shape and height, but the Voc value appears to be low, calculate the difference between the measured and expected Voc or translate to STC. Note that this comparison is done automatically when a curve tracer with an integrated PV model is used. If the difference happens to be close to the Voc of a single module, then a module may be missing from the source circuit—perhaps bypassed or not wired in. If the difference is smaller than the Voc for a single module, one or more cell strings within the modules may be bypassed or not functioning properly.

Bypass diodes sometimes play a role in PV module failures, particularly when modules are designed using inexpensive or undersized bypass diodes. "Frequent partial shading can cause a bypass diode to operate constantly, shortening its life," Kurtz observes. She notes that shade prone rooftop applications are particularly troubling in this regard. "The bypass diodes are stressed most when the module is partially shaded," she adds. "If they overheat, they may burn out."

Array installation methods, such as direct installation on a roof, can also cause overheating.

Mismatch signature. Shading, although not a problem caused by the array hardware, provides a good example of mismatch behavior. The shaded cell produces less current. If the shading is severe enough, the bypass diode spanning that cell string turns on and shunts current around it. The I-V curve shows a step on its falling slope, the width of which corresponds to that cell CONTINUED ON PAGE 100



Courtesy Solmetric (4)

Shading lab The impact of shade on PV performance depends as much on pattern of the shade as on its area. In the first example, two cells are shaded in the same cell string. In the second example, the area of the shading is the same, but two cell strings are impacted. These are typical 72-cell modules with three bypass diodes and cell strings.

string's open-circuit voltage. The reduction of current at the step is proportional to the cell area that is being bypassed. Figure 9 (p. 96) illustrates the shading of different numbers of modules in two parallel strings. The normal-shaped curves correspond to no shading or to equal numbers of modules shaded in each string.

Unlike solar thermal collectors, the dependence of PV production on the actual pattern of shade is very nonlinear. A simple outdoor lab setup demonstrates this. A source circuit consisting of two PV modules is shaded with a rectangular piece of cardboard large enough to cover two adjacent cells, as shown in the photos above. The modules have 72 cells each, split across three bypass diodes. The setup and results are shown in the photos and associated I-V curves. In the first example, the cardboard covers two cells in the same cell string, causing its bypass diode to conduct and dropping the string's voltage and output power by roughly one-sixth. In the second example, the cardboard is rotated to cover one cell in each of two adjacent cell strings, dropping the voltage and output power by twice that amount.

Taking Environmental Measurements

Accurate array performance verification requires careful selection and measurement of environmental conditions. The shape of an I-V curve taken in the field is determined in part by the irradiance in the plane of the array (POA) and the cell temperature at the time of measurement. Therefore, POA irradiance and cell temperature are often collected simultaneously with I-V curve measurements in the field. No measurement is exact. Random variations and systematic bias combine to create some level of uncertainty. This uncertainty is a function of the test equipment, the environmental conditions and the user's measurement technique. However, through the proper use of appropriate irradiance and temperature sensors and careful screening CONTINUED ON PAGE 102

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Using the Array as a Sensor

Array performance verification measurements, such as those taken during system commissioning, normally require the use of irradiance and temperature sensors so that these parameters can be recorded along with the I-V curves. However, much of the diagnostic testing can be done without use of external sensors. Another option is to calculate the temperature and irradiance from the measured I-V curve itself, using the array as a sensor. The mathematical basis for this feature combines formulas from the Sandia PV Array Model and the IEC 60904-5 standard on determining equivalent cell temperature (see Resources). The translation method relies on knowing the dependence of Isc and Voc on irradiance and temperature. Irradiance is calculated from Isc with a slight correction from Voc. Temperature is calculated from Voc with a slight correction from Isc.


Courtesy Solmetric

Sensor kit While I-V curve tracers include inputs for irradiance and temperature sensors—like those in this wireless sensor kit from Solmetric—using the array as a sensor can reduce measurement time and complexity.

"Array as sensor" is an optional operating mode in the Solmetric PVA-600 that can simplify the process and save time when readings from external sensors are not required. When the array-as-sensor method is used to provide irradiance and temperature values to a PV model, the predicted I-V curve is forced to align with the measured curve at Isc and Voc. Thus, the array-as-sensor approach is blind to the effects of uniform soiling and to degradation in Isc or Voc. However, the method is very helpful when examining the shape of the I-V curves. Since the endpoints of the predicted and measured I-V curves coincide, any deviation in the shapes of the curves is very easy to spot. The sensor values are effectively measured at the same time as the I-V curve, so comparing measured and predicted curve shapes is much less affected by wind and by rapid changes in irradiance. The determined temperature also represents the string as a whole, not just the temperature at the edge of the array where an actual sensor would be attached.

The temperature across a string can vary ±15°C because of different exposure to wind, reflections and racking. In many cases, therefore, it is actually more accurate to use the array-as-sensor mode to determine the temperature because it measures the average cell junction temperature across the entire string rather than one specific spot measurement on the back of a single module.

The array-as-sensor mode is also useful for checking the I-V curve shape of basic functional modules, particularly when deploying a full sensor kit is not practical. The user can also mix sensor modes, using the array-as-sensor mode to determine temperature, while capturing irradiance with an external sensor mounted in any open area at the same orientation as the array. The temperature will be reasonably accurate as long as all of the modules and cell strings are operating. This can be assured by checking that Voc is roughly consistent across strings. ●

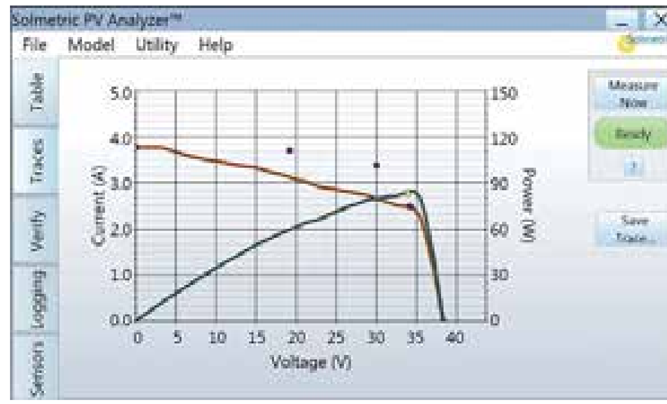
of sky conditions, both random and systematic errors can be reduced.

Irradiance measurement. This measurement is used to determine the irradiance in the plane of the array at the time of the trace. Good irradiance measurements can be obtained by selecting a high-quality sensor that uses a technology similar to that of the array being tested and is designed for backside mounting. To ensure that the sensor is mounted in the plane of the array, attach the sensor to a bar that is in turn clamped to the frame of a PV module.

If the irradiance sensor is not mounted in the plane of the array, it presents a different area to the sun; this is a key source of irradiance measurement error. Reflected light is another potential source of measurement error. Be aware of possible sources of reflected light and try to locate the irradiance sensor at a location that is representative of normal operating conditions for the array.

While handheld irradiance sensors can be used in I-V curve testing, they are usually difficult to accurately position in the plane of the array. In addition, the sensor technology and packaging are often quite different from the PV modules themselves. This can introduce spectral and angle of incidence errors. The angle of incidence is the angle between an incident light ray and a line that is normal (perpendicular) to the PV module. The angle of incidence response of the irradiance sensor and the PV modules under test should be reasonably well matched.

Changing irradiance conditions is another potential source of error. Using an I-V curve tracer CONTINUED ON PAGE 104



Courtesy Solmetric (2)

Tapered shading As shown in this photo and associated I-V curve, tapered shading or soiling can result in a shunt resistance I-V curve signature, with an increased slope above Isc. This effect can be produced by shading from adjacent tilt-up arrays, by shading from building features such as parapet walls, or by dirt buildup along the edges of PV modules mounted at low tilt angles.

capable of making rapid curve sweeps can minimize these errors. Many curve tracers also offer optional sensor kits. When these kits are used, the curve tracer logs the irradiance measurement simultaneously with the I-V curve. Manual measurement and recording of irradiance and temperature can more than double I-V curve measurement time, and the delay between sensor readings and the I-V sweep can introduce significant random error. The preferred technique is to use a curve tracer with sensors that are triggered and recorded at the same time as the I-V curve sweep.

Temperature measurements. Temperature measurement for performance verification usually involves a thermocouple or resistive temperature device taped to the backside of the PV module. The sensor should be placed toward the center of the module, as the edges tend to run cooler than the rest of the array. High-temperature tape, applied with firm pressure, assures good thermal contact between the sensor element and the module backsheet.

Digital infrared (IR) thermometers are sometimes used for this purpose, but their accuracy is very dependent on the emissivity of the surface. Calibration of the IR thermometer can be accomplished using a side-by-side measurement of the same PV cell using the IR and thermocouple methods. The emissivity control on the IR device can then be adjusted to make the two temperature readings match. IR temperature measurements are typically less accurate when taken through the face of the module than when taken off the backsheet.

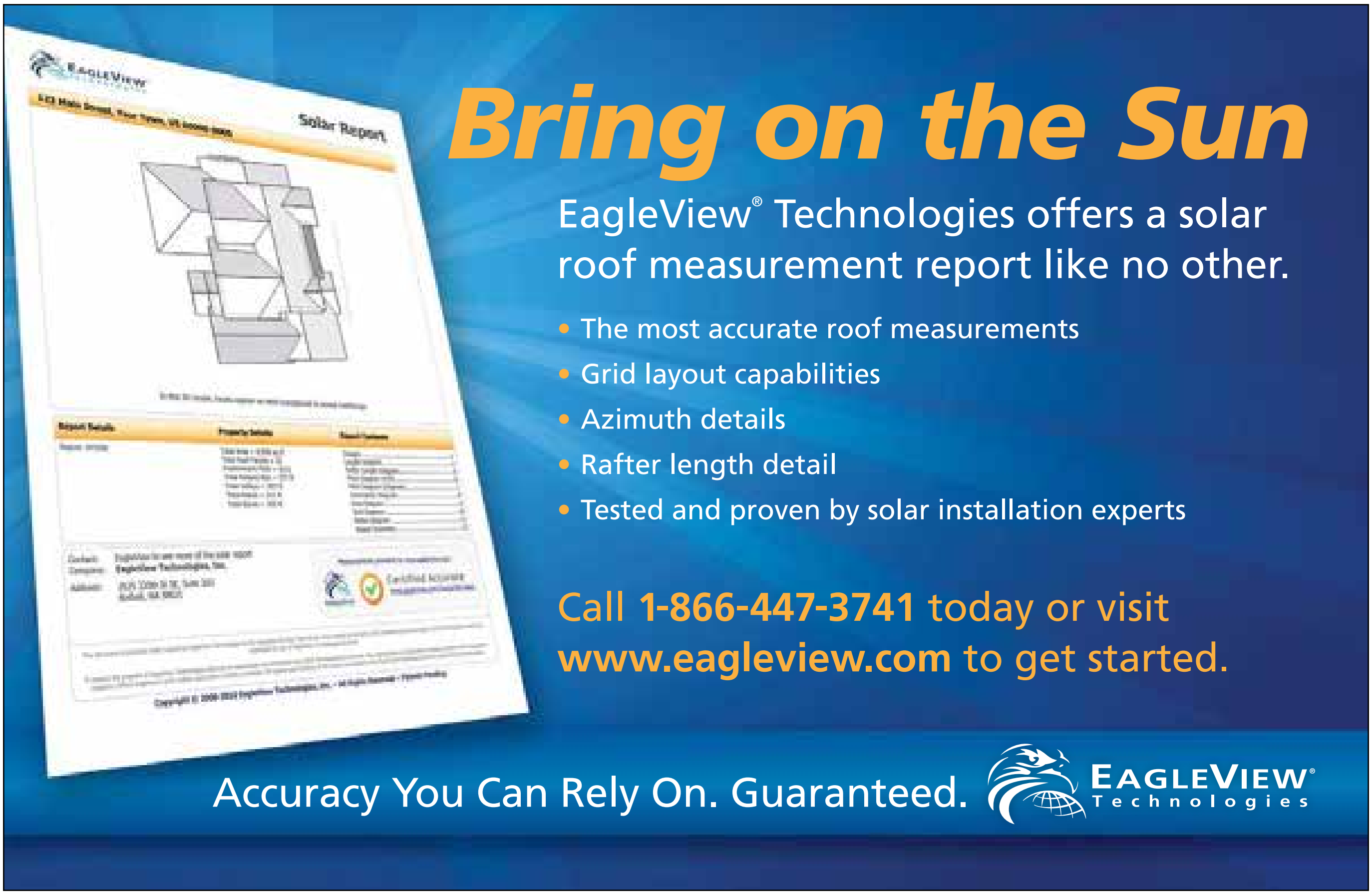
ENVIRONMENTAL CONDITIONS

Because a PV source responds to changing environmental conditions, verifying PV performance in the field is potentially challenging. DK Solar Works' King explains, "PV module and array performance in outdoor conditions is continuously changing due to a large number of factors, including variations in solar irradiance level and spectral content, ambient temperature, wind speed, thermal heat capacitance of the modules themselves, module shading, soiling and so on." Taking performance verification measurements under the recommended environmental conditions helps give consistent results when remeasuring the same site at a later date.

The rule of thumb espoused by Dr. Jennifer Granata, technical lead of the PV Test, Evaluation and Characterization group in the Photovoltaic and Grid Integration Department at Sandia National Laboratories, is to gather performance test data in a stable environment. "The ideal is to test during clear sky conditions with a stable irradiance level, stable spectrum and stable temperature, including wind effects," she states. "This usually occurs in the 4-hour window centered at solar noon."

Determination of irradiance typically has the most significant impact on the accuracy of PV performance measurements. The direct radiation component of sunlight is larger during the 4-hour window around solar noon. Since direct radiation measurements tend to be more repeatable than measurements of the diffuse radiation component, test results during this window tend to be more accurate and repeatable. The proportion of diffuse radiation is lower around solar noon than it is at other times of the day.

Temperature measurement errors also affect the results. Windy conditions cause rapid variation of array temperature. More importantly, wind—even a steady wind—can change the pattern of temperature across the array, making measured string performance look less consistent. CONTINUED ON PAGE 106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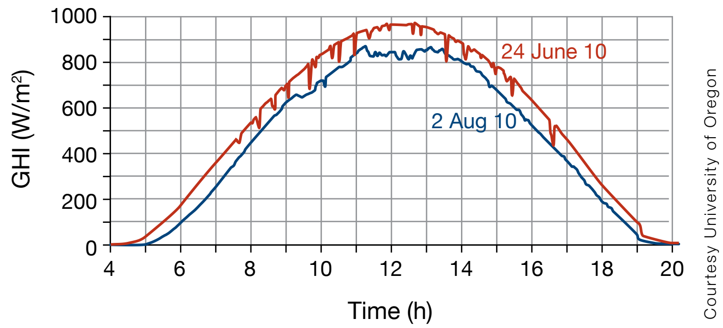
Testing in a wind speed of 2 mph or less is a good guideline for PV performance measurements.

Brooks agrees with the necessity for stable conditions. He states: "Ideally we always want a cloudless sky with no variations or jet contrails. This is rare for most of the US, so we normally have to compromise. It seems like clouds follow curve tracers, but the key is to take I-V curves when both the irradiance and module temperature are stable. If either one is moving at the time of the I-V curve, the data is going to be dubious. If we are just trying to get a ballpark shot for simple commissioning purposes, slight changes are okay. Temperature changes, since they tend to be much slower than irradiance changes, are more tolerable. Also, temperature changes have a much smaller impact on the curve, so the data error may be small. Irradiance changes of more than 1% or 2% while the curve tracer is measuring the data results in bad data. A 10% change results in a curve that looks like a major malfunction is present on a perfectly operating array."

While it is not always possible to avoid clouds, some clouds are worse than others. Large, slow-moving clouds located a significant angle from the sun in an otherwise clear sky contribute some additional irradiance from cloud effect, but this variation may be slow enough to be corrected for by the sensors. According to Bill Sekulic, master research technician at NREL's PV Performance and Reliability R&D group, "Large or spotty cumulus clouds located at fairly large distances from the sun are generally not an issue while taking curves." However, if there are fast-moving clouds near the sun, performance measurements should be postponed. Cirrus cloud cover is another showstopper, reports Sekulic. "Cirrus clouds cause irregular variations in irradiance, as well as a magnification of irradiance called cloud effect," he says. "Because cirrus clouds usually occur at high altitude, they can give an appearance of clear sky conditions that masks irradiance irregularities and cloud effect magnification."

Air mass (AM) 1.5 is one of the standard test conditions under which PV modules are specified. The earth's atmosphere affects the power spectrum of sunlight, and at AM 1.5 the atmospheric path length is 1.5 times more than it would be at sea level with the sun directly overhead. Sandia National Laboratories' Granata warns: "Although modules and arrays are rated under the AM 1.5 spectrum, the spectrum and irradiance can change rapidly as the sun moves through the AM 1.5 position, depending on location and time of year."

It is also important to recognize that PV module I-V curves change shape as light levels change. It is difficult to accurately extrapolate an I-V curve at STC from a trace taken at low irradiance levels. Granata recommends taking field measurements under conditions that are close to the reference condition: "Another aspect of choosing the conditions for testing an array is how one intends to normalize the data. If normalizing to standard reporting conditions or PTC, being as close to those conditions as possible is recommended to minimize uncertainties when translating the data."



Variable input These global horizontal irradiance curves for Eugene, OR, were captured by Dr. Frank Vignola of the University of Oregon in 2010. The results illustrate that irradiance can vary substantially even on relatively clear days.

CONTACT

Paul Hernday / Solmetric / Sebastopol, CA / solmetric.com / paul@solmetric.com

Resources

California Energy Commission, New Solar Homes Partnership / gosolarcalifornia.org/nshp

National Renewable Energy Laboratory Solar Advisor Model / nrel.gov/analysis/sam/

NFPA-70E, Electrical Safety in the Workplace, National Fire Protection Association / nfpa.org

Publications

"Photovoltaic Array Performance Model," D.L. King, W.E. Boyson, J.A. Kratochvil, Sandia Report: SANDIA2004—3535, 2004

"Photovoltaic Devices—Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method," International Electrochemical Commission, International Standard: IEC 60904-5, 1993

Manufacturers

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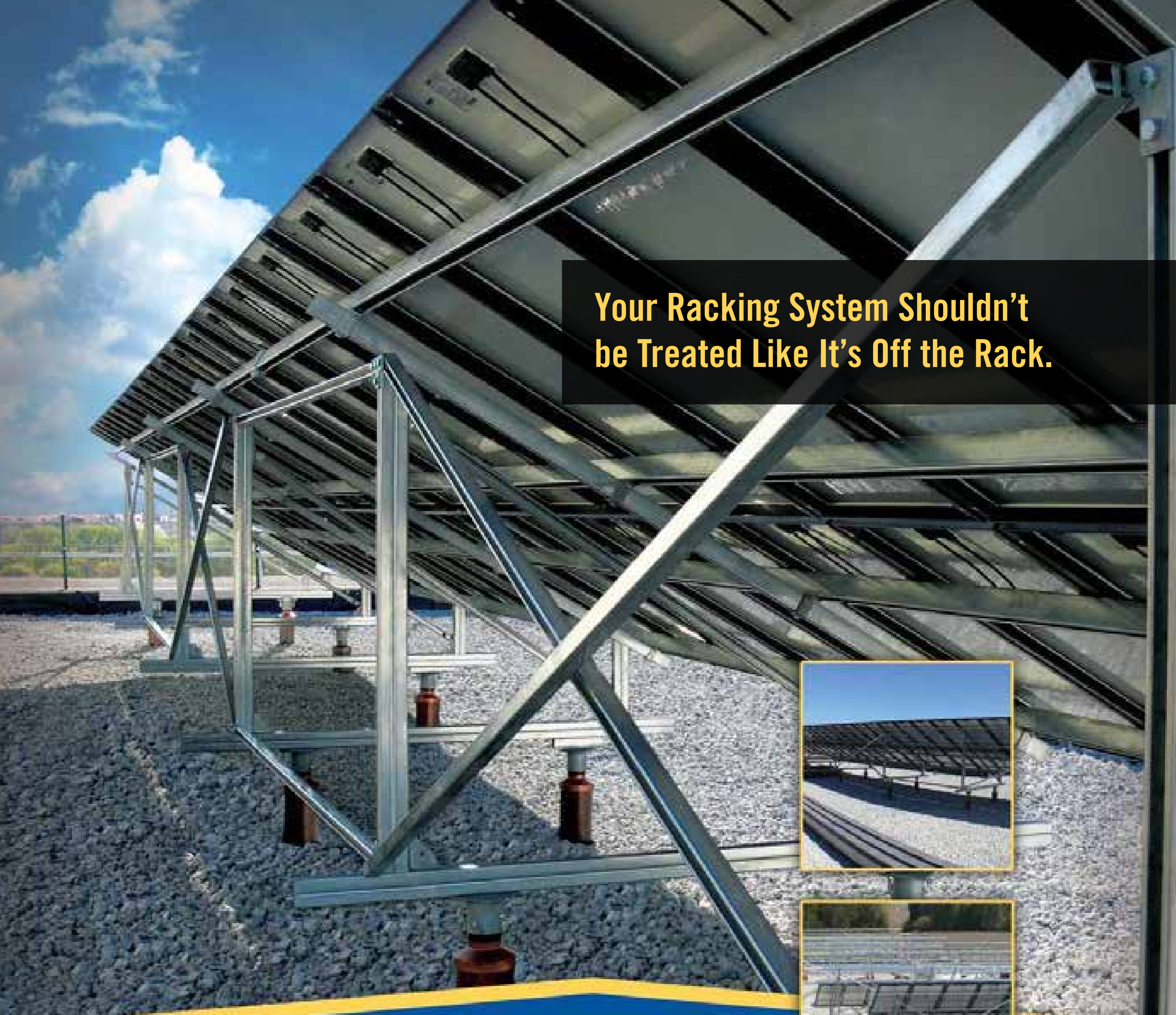
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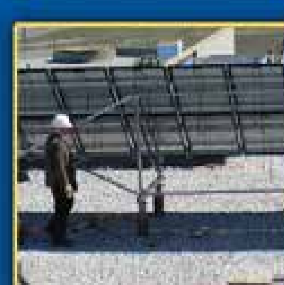


PART TWO

DETERMINING PERFORMANCE GUARANTEE DETAILS

PV Performance Guarantees: Proof of Performance & Guarantee Structures

By Mat Taylor and David Williams

Shawn Schreiner (2)

PV performance guarantees are intended to keep large-scale PV systems operating as expected and mitigate the risk to project owners and investors. The system owners must be legally at risk in order to claim the 30% federal investment tax credit. However, the owners are typically not in the business of designing and operating large-scale PV systems. The engineering, procurement and construction (EPC) contractor has this expertise. Therefore, the EPC contractor who designs and constructs a large-scale PV system is generally required to guarantee a predetermined level of performance.

In Part One of this article ("PV Performance Guarantees: Managing Risks & Expectations," June/July, 2011, *SolarPro* magazine) we described the dynamic between the protagonists in performance guarantee negotiations in great detail. We also described the concepts and calculations that typically inform a performance guarantee—such as a project's specific production or performance ratio—and considered guidelines for measurement, accuracy and proof. Having established this background, we now outline the major approaches to proof of system performance and discuss the hardware required for collecting plant metrics. We also describe the typical structures found in a performance guarantee and call out some structures that require special consideration.

Approaches to Proof of Performance

Because of the complex operational dynamics of PV energy plants, owners are anxious to apply a simple and exact method for proving performance. Here we outline the most common approaches.

Full-wrap product warranty. This type of performance guarantee asks the EPC contractor to manage the performance expectations and manufacturer warranties for the primary equipment, including PV modules, inverters and main collection gear (transformers, switchgear and substations). This "one neck to wring" approach asks the EPC contractor to handle product warranty issues and periodic system checkups. This model is essentially a pass-through of multiple product manufacturer warranties and usually includes workmanship warranty underwriting under an O&M contract. Some semblance of a full-wrap warranty is included in almost all performance guarantee structures.

Output performance guarantee. The only thing that matters with an output performance guarantee is system production at the meter. Although it offers a simple way to measure performance, such an arrangement implies a comparison to simulation, regardless of the near-term climate conditions, and has a tendency to place all of the risk assessment and risk responsibility on the EPC contractor.

Performance ratio guarantee. This type of guarantee attempts to draw a correlation between measured solar energy (and other site conditions) and system output—the classic modules-to-meter approach. Such a method often places all hopes on measurement accuracy and, as such, depends greatly on the appropriate performance measurements, or plant metrics. In this model, the complexity of the operating PV plant is not taken into account; it is replaced by a simple input/output determination. The performance ratio attempts to take climate out of the determination so that weather predictions are not needed. The performance ratio is instead tied directly to instrumentation and precise measurements of site conditions and system operation.

Calibrated performance guarantee. The final standard PV performance guarantee model is essentially a hybrid, a mix of expected or simulated plant behavior and real-time plant metrics. Although a calibrated performance guarantee tends to be complicated and expensive, this type of guarantee can help investors and developers achieve greater financial confidence. Such a model sets up an inherent need to measure, validate and mitigate problems with consistently underperforming systems.

KEY CONCEPTS

It bears mentioning that most attempts to broadly characterize PV output fail in some respects and, conversely, most in-depth attempts tend to overcomplicate a relatively simple set of concepts. While it is hard to get it just right, a well-structured performance guarantee helps ensure a project's success. Unfortunately, getting the performance guarantee structure just right is not as easy as it might seem. PV plants are input-dependent and temperature-dependent, with variable impedance and multistage current sources. The implications of all this variability are difficult even for veteran solar professionals to fully grasp. Understanding the following two key concepts is essential when crafting a PV performance guarantee.

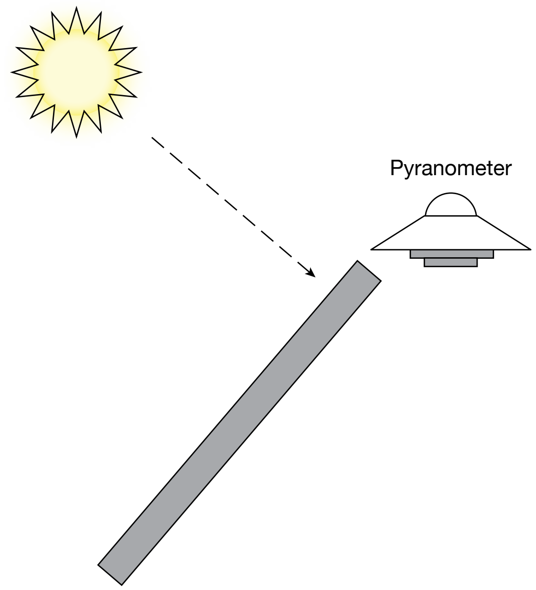
Power over time equals energy. This basic concept is frequently misunderstood or misapplied. While a PV plant can easily be characterized by nameplate capacity alone ($MW_{DC\text{-}STC}$), this is just the *power* part of the equation. The problem with this metric is that PV plants operate far from nameplate values most of the time, and each component of

Performance characterization While PV system production, as measured at the utility meter, ultimately determines plant revenue, this meter reading alone is not adequate to determine whether the asset is performing properly.

the system behaves decidedly differently under changing conditions. *Energy* (MWh) is ultimately what produces revenue. Understanding PV performance characteristics is key to understanding how nameplate ratings change over time.

Performance is climate-dependent. Quantitative PV performance depends on climate conditions. The two most directly indicative factors are module cell temperature and plane-of-array (POA) irradiance, but there are dozens of second-order factors. As a result, the only way to objectively evaluate PV power plant performance is to take the weather out of the analysis. This takes some very accurate measurements and relatively tricky math, as described in Part One of this article.

From these two simple concepts, two things are clear about evaluating PV plant performance. First, you must know what should happen, which is done through simulation and modeling. Second, you must know what did happen, which is accomplished by plant metrics.



Sensor selection While it is possible to extrapolate plane-of-array irradiance from a horizontally mounted pyranometer, a simpler solution is to specify an irradiance sensor that can be mounted at the same tilt as the array.

PLANT METRICS

Regardless of the method being used to prove performance, all interested parties must understand the methods, expectations and protocols for plant metrics. These measurements are ultimately key to proving plant performance.

The project team must first establish a basis of design for the pieces of the system between the modules and the point of interconnection. This can take any number of forms, but within the scope of a performance guarantee, it should represent the mutually agreed upon electrical behavior and climate response of the system. The design basis should include parameters for system losses, efficiencies and valid assumptions for temperature response. Defining the basis of design is instrumental in setting the expectations for system performance.

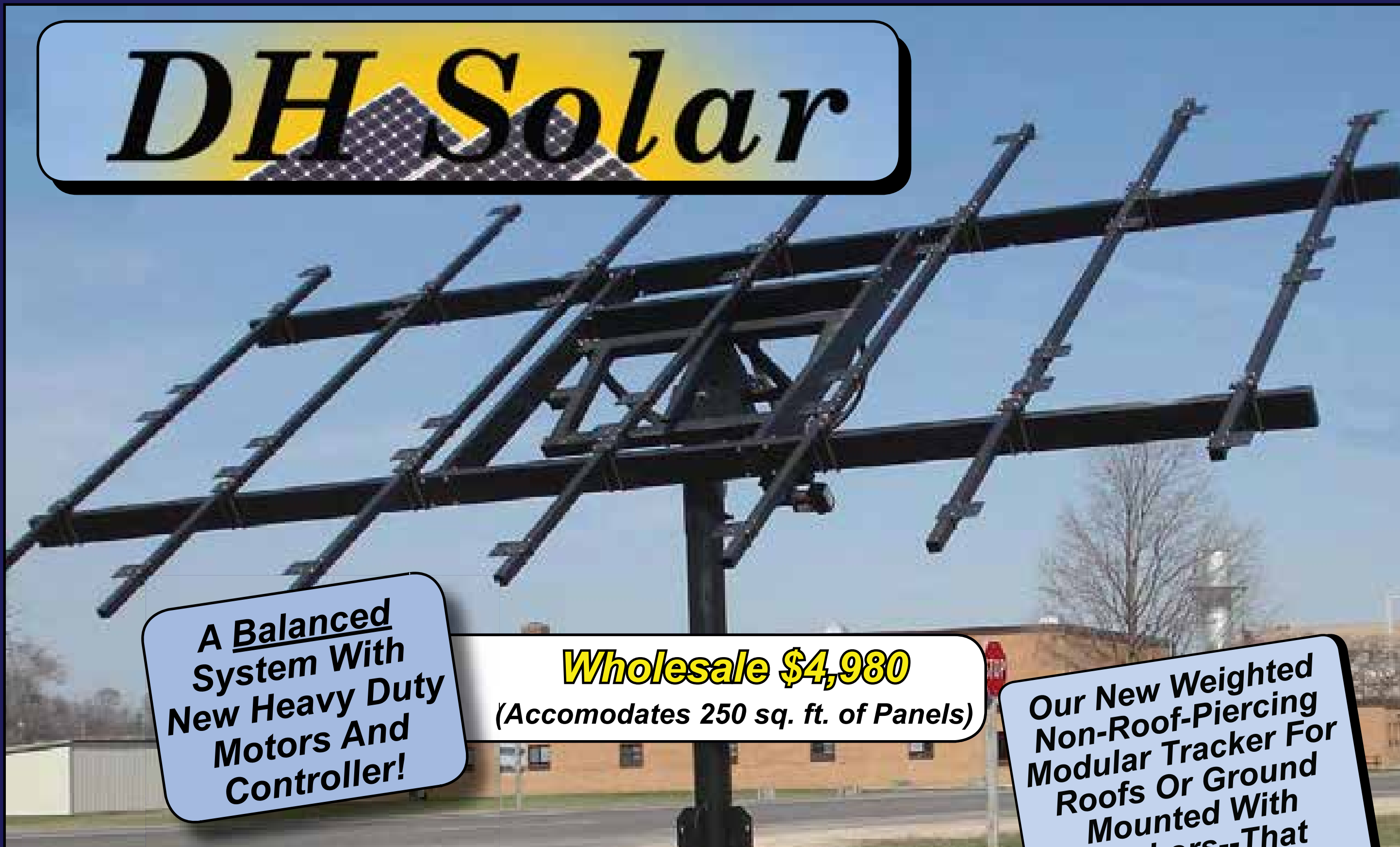
Definitive plant parameters to include when you are drafting a design basis for a performance guarantee include dc wiring losses, transformer losses and module soiling. Rather than rely solely on inferred values for these quantities, it is good practice to compare actual values to calculated values. Part-load wiring and transformer losses, for example, are drastically different than full-load values. In order to accurately consider this effect when detailing expected production values, it is very useful to use measured values that are taken once the system is operational. Module soiling, similarly, varies over time and in a decidedly nonlinear fashion, so the effects of soiling should be quantified in the field in a before-and-after approach with strategic module cleaning.

After the basis of design is established, PV plant output is primarily a function of the following measured or measurable quantities: plane-of-array irradiance, cell or module temperature, module degradation, inverter efficiency and ac collection losses.

Plane-of-array irradiance. POA irradiance is a critical metric for performance calculations because current and power are directly proportional to irradiance in the plane of the array. The sensors are placed in precisely the equivalent installed condition as the array. Undoubtedly, a high degree of measurement overlap and redundancy is needed to mitigate the effects of clouds and shading, and to check for sensor correlation. There should be a minimum of two pyranometers for every project greater than 1 MW; there should also be at least one irradiance meter for every additional MW. POA sensors are electrically similar to PV modules, so they tend to respond to irradiance much like a module does. Other methods to arrive at plane-of-array values use transposition factors and calculations to approximate POA irradiance from, for example, global horizontal values, but POA measurement instruments eliminate the need for any intermediary steps.

Module or cell temperature. Highly accurate temperature sensing is an extremely cost-effective way to help predict system performance. High degrees of sensor overlap and redundancy are easy to implement and give very good indications of operating conditions. For systems larger than 3 MW, there should be one sensor for every 500 kW of array capacity. In large arrays, the module temperature can vary greatly, however, so strategic placement of sensors is imperative to ensure that measurements accurately match average conditions. Using the information correctly is tricky and requires sophisticated solar expertise.

DC power output. Measuring dc power output for the array, subarrays, source circuits and modules is obviously important. However, module degradation—a critical variable in PV performance guarantee assumptions—is very difficult to measure in the field. Manufacturer warranties typically guarantee that module output power CONTINUED ON PAGE 112



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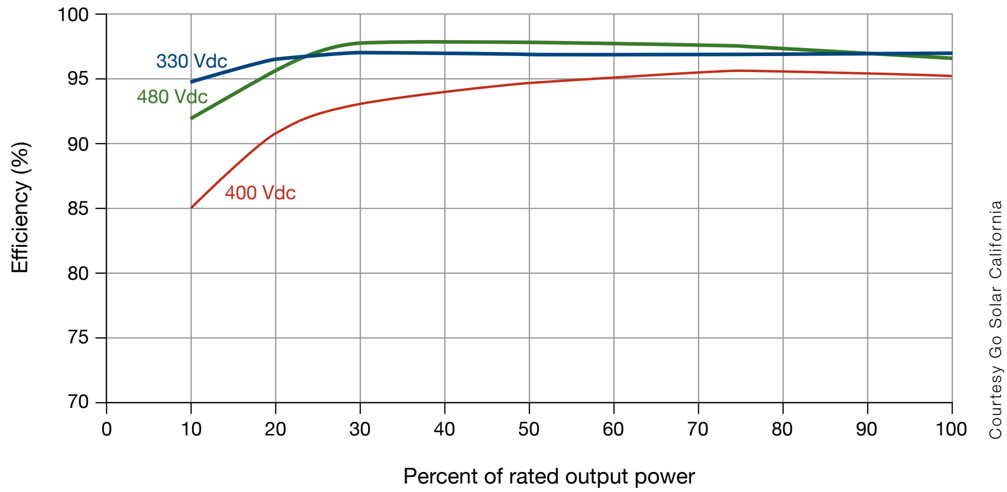

Diagram 1 While the CEC efficiency for the 350 kW Siemens SINVERT PVS351 UL is nominally 96%, the measured efficiency at different input power and voltage levels are weighted very specifically to derive this "average." If inverter efficiency is being guaranteed in the field, it may be necessary to similarly filter or limit the data to exclude atypical inverter efficiency measurements, such as those taken at very low irradiance conditions.

degradation will not exceed a fraction of a percent per year. It is a challenge, therefore, to prove low performance as part of a warranty claim. It is difficult, if not impossible, to measure a 0.5% change in module output when the system instrumentation has a 1% margin of error. Since module power-output degradation is a slow process, the hope is that accurate power measurements at least identify decisively flawed modules.

Inverter efficiency. Constructs such as CEC and Euro-eta efficiency measurements hint at a common condition for all solar inverters—partial load. Some PV performance guarantees ask for an inverter efficiency guarantee, and inverter efficiency is relatively easy to measure. However, there needs to be an allowance for part-load conditions at very low POA irradiance to ensure a good representation of inverter efficiency. As shown in Diagram 1, low power operating conditions are not a good representation of typical or weighted inverter efficiency. One way to limit this problem is by measuring plant performance indices under consistent conditions.

AC collection losses. Like inverter efficiency, dc losses and other irradiance-dependent (and thus current-dependent) system variables, ac collection losses need to be addressed at part-load conditions. Many production models oversimplify the collection system from the inverters to the point of common coupling, an approach that can drastically over- or under-predict metered energy. Because in situ values for ac losses are difficult and expensive to measure, one of the keys to understanding whole-system ac losses is plant characterization. This can be accomplished through verification of the production model used and thorough ac collection system commissioning.

Typical Performance Guarantee

Performance guarantees can take many forms, but typically contain the following elements: term, calculation of performance, expected performance level, damage, cure and limits of damages. The length of the term is chosen to balance the commitment phobia of contractors with the insecurity of investors. Calculation of performance is discussed in detail in Part One of this article. The expected performance level can take different forms, but it is essentially the amount of energy (kilowatt-hours) that the system is expected to produce. The damage describes the amount of money and how it is to be paid. The cure is possibly the most important part of the performance guarantee: it outlines the way that the guarantor can help ensure that the system performs (instead of simply paying the damage). Finally, there is a limit to the amount of damage that can be claimed.

A general performance guarantee for a large-scale PV asset might include the following:

- Performance guarantee backed by an EPC or O&M company with a substantial balance sheet
- 5-year term, starting after construction is complete
- 2-year correction payment period
- Target plant performance ratio of between 0.70 and 0.90
- Energy harvest equal to 95% of mutually agreed upon simulation or performance ratio analysis
- Liability limited to damage of 30% nonperformance

Counterintuitively, some contractors prefer a longer term. This gives them sufficient time to find a way to make the system perform without being obligated to just pay a monetary cure.

It is critical that the guarantor has the ability to cure the lack of performance. The ability to take corrective action gives guarantors comfort because it is how they are generally used to solving problems. The cure might be to add additional modules or increase the efficiency of the inverters. These activities are a good fit with the skills of the guarantor. CONTINUED ON PAGE 114

The guarantor also needs to account for the contingent liability, which is the amount of money that could be due in damages. However unlikely damages may be, the performance guarantee provider needs to make sure to have enough money to pay those potential bills. The longer the guarantor carries the obligation, the longer this potential bill remains on the books. Although the money may never actually be due, this can negatively affect the returns of the company or limit bonding capacity.

Solar PV systems must operate within a few percentage points of the expected production. A system that is designed, built and commissioned well works close to expected performance—a dramatic loss of production would be 10%. In performance guarantee contracts, it is common to limit the damage due to loss in order to lower the contingent liability and the cost of the performance guarantee. The acceptable terms and conditions are unique for each project and stakeholder. Each set of risks needs to be identified, reviewed and mitigated through the performance guarantee.

WHAT TO LOOK FOR IN GUARANTEE STRUCTURE

Many conditions have made their way into performance guarantees. Some are good and some are bad. The following is a brief list of conditions that require deep scrutiny by all parties involved in the execution of a performance guarantee. In all cases described below, there are terms and conditions that could be deal killers.

Historical climate data and expected energy. Climate data sets should always be used within their limits. Simulations are vitally important to project viability, but the performance model outcome needs to be considered within the time frame of the data. For example, typical meteorological year (TMY) data are usually used for system simulation. Despite the outstanding level of detail and painstaking attention to accurate synthesis, these data do not quantitatively predict future energy harvest. TMY data sets are compiled using many years of actual data, so they are most accurate over a similar time frame—well beyond a decade at least. (See “Production Modeling for Grid-Tied PV Systems,” April/May, 2010, *SolarPro* magazine.)

Historical climate data sets cannot tell anyone how many megawatt hours a system will produce in year one, for example. They can, however, reveal how the system might react to actual conditions over time. Without getting too deep into the derivation of the available TMY data, it is important that everyone involved in solar projects CONTINUED ON PAGE 116

Courtesy Solectria Renewables

Results may vary While TMY data sets are good indicators of long-term PV system performance, according to the National Renewable Energy Laboratory the data can vary as much as ±10% in any given year and ±30% in any given month. For this reason, most EPC contractors want to tie PV performance guarantees to actual measured weather data taken on-site and not to predicted results based on historical weather data.

understands this key concept: climate data sets are synthetic representations of the height, depth and duration of key solar indices. Therefore, any performance guarantee that ties a specific energy output value to a system simulation that uses historical data is challenging and perhaps even counterproductive. For example, use of such a model is very likely to miss poor production in an especially cool, sunny year.

100% revenue stream recovery. In the case of a system shortfall, recouped losses usually take the form of $X.XX for every percent of shortfall. This kind of guarantee is highly dependent on both the production model and the expected energy target.

In some cases, investors attempt to recoup all foreseen losses of revenue in direct proportion to assessed damages. In other words, the contractor is expected to pay the owner for the estimated lost production and the revenue therein. From a financial view, this arrangement makes good sense; it is more or less a sure bet for investors. However, system owners have little incentive to get things fixed, since their revenue stream is not affected by underperformance. This type of contract is essentially a complete transfer of financial risk to the EPC contractor from the owner for the guarantee term.

There are two potential problems with this type of structure. First, EPC contractors tend to look for more of a partnership when writing performance guarantees. Second, the federal investment tax credit requires the owner to be clearly at risk. According to the legal definition of *at risk,* the system must be worth more to the owner if it is on than if it is off. However, if the EPC contractor has guaranteed a return on the owner's investment regardless of whether the system is operating, then the owner is not technically at risk.

Oversimplified terms. Many PV performance guarantee contracts appear to be stopgaps, with the intention of getting the bank's approval. In the most oversimplified cases, the PV system owner asks the EPC contractor to take care of everything and make sure that the system pays back as the pro forma documents specify. In other words, the contract language asks the EPC contractor to take care of all system parts, all of the measurement and instrumentation, and pay damages if it does not work out as the power purchase agreement (PPA) projections predict.

The performance guarantee should not be a financial solution only. The EPC contractor should be able to regularly evaluate system performance and to get involved early to solve potential problems.

It is important that the complexity of PV system operation is incorporated into measurement and cure. The EPC provider is the guarantor not just because of its large balance sheet. It also has the technical understanding and the skills to solve problems. The performance guarantee should not be a financial solution only. The EPC contractor should be able to regularly evaluate system performance and to get involved early to solve potential problems. Oversimplified terms may not facilitate this. CONTINUED ON PAGE 118

In a slightly more complex model, the owner reads the meter, measures the solar input, compares the two and assesses damages if the expected performance was not achieved. In the most laissez-faire version of this model, measurements are taken all year, these values are summed and averaged at the end of the year, and then damages are assessed. The owner essentially waits all year before sending the bad news to the contractor. This model not only fails to keep the system operating as it was intended, but it is also likely to be unacceptable to the EPC contractor.

Overly complex structures. There are several PV performance guarantee constructs that are mind-bogglingly complicated. For example, there are clauses and detailed procedures for dual methods of sensor drift assessment, soiling approximations and in situ verification, third-order corrections for incidence angle and so forth. These are overly specific at best. They also have the tendency to bring out the worst in project team members.

What complicated structures implicitly call for is a long period of finger pointing when things go awry. A list of detailed calculations, procedures and measurement specifics is basically a long list of things that can be called into question when a shortfall is perceived to happen. In this case, simpler is better.

Limitations of liability. Establishing acceptable limits of liability is essential to a successful performance guarantee. It is common to limit this exposure to a portion of the EPC contract. This is where negotiations typically become sensitive. EPC contractors are comfortable wrapping completion and workmanship, but ensuring future performance is a gray area at best. It is difficult to account for the administrative requirements. In addition, while smaller EPC contractors may offer solid guarantees, they may not have sufficient financial security to give comfort to investors. To make sure that the desired level of commitment is achieved at an acceptable cost, it is critical to have explicit liability limitations, as well as a clear set of rules and formulae for evaluating the strength of the guarantee.

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Interview

An Experienced Perspective

Ole Pilgaard, Heliodyne

Bringing European Experience to the US Solar Thermal Industry

Founded in 1976, Heliodyne is the oldest continuously operating solar water heating equipment manufacturer in the US. Ole Pilgaard has served as president of Heliodyne since 2007. Previously, Ole was head of the solar energy division for VELUX. He also served as president of the European Solar Industry Federation, director of the European Energy Council and chairman for the European Solar Thermal Conference. Ole has been on the board of the Solar Rating & Certification Corporation (SRCC) since 2008 and currently serves as chair of the SRCC industry group. He holds degrees in mechanical engineering from the Engineering College of Copenhagen and in international economics and trade from Copenhagen Business School.

Courtesy Heliodyne

Ole Pilgaard, president, Heliodyne Experience in the European solar thermal industry gives Ole a unique perspective on the steps required to develop a similarly robust thermal market here in the US.

SP: The European solar thermal (ST) industry is robust compared to the US market. What are the key factors that account for this difference?

OP: Issues of energy security in the European Union became apparent much earlier in Europe than in the US, so politicians have pushed renewable energy for much longer. Furthermore, the European solar thermal industry did not go through the turmoil that occurred in the US after the tax credits were abolished back in the '80s. Consequently, the solar thermal market has experienced a more consistent and uninterrupted evolution in Europe. There is a much higher rate of awareness about solar thermal, and the ongoing demand has created a solid work force.

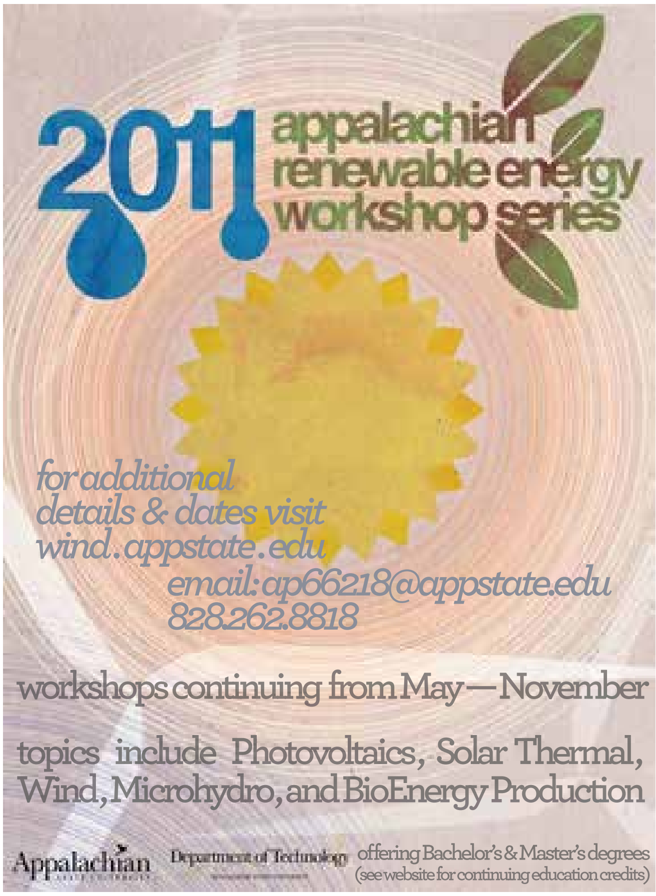
SP: Based on your experience in the European market, did you implement any significant changes in Heliodyne's direction or product lines when you took the helm?

OP: The most apparent changes were made in moving the company focus away from merely manufacturing collectors and forcing installers to piece a system together. We moved toward a system approach in which all the components are plug-and-play and easy to install. As more developed, European-manufactured equipment was being introduced to the US market, it was important to improve Heliodyne's equipment design and also make a differentiated product platform. Furthermore, it was important to profile Heliodyne as a reliable supplier with a 35-year track record of supplying quality products in the US.

SP: Drainback system design for freeze protection is not as popular in Europe as it is in the US. What is the source of this fundamental variation in design philosophy?

OP: The European solar thermal industry developed faster in the northern countries, like Germany and Austria, where freeze protection is more of an issue than stagnation. Some malfunctioning drainback systems received bad publicity in Europe when solar thermal grew into the mainstream contractor business. As a result, it became more apparent that drainback systems are extremely sensitive to correct installation. The European solar thermal technology platform therefore developed in the direction of fully flooded glycol systems, which are more reliable than drainback systems and less sensitive to correct installation.

SP: Why is serpentine-tube collector construction popular with European flat-plate manufacturers while US manufacturers, including Heliodyne, CONTINUED ON PAGE 122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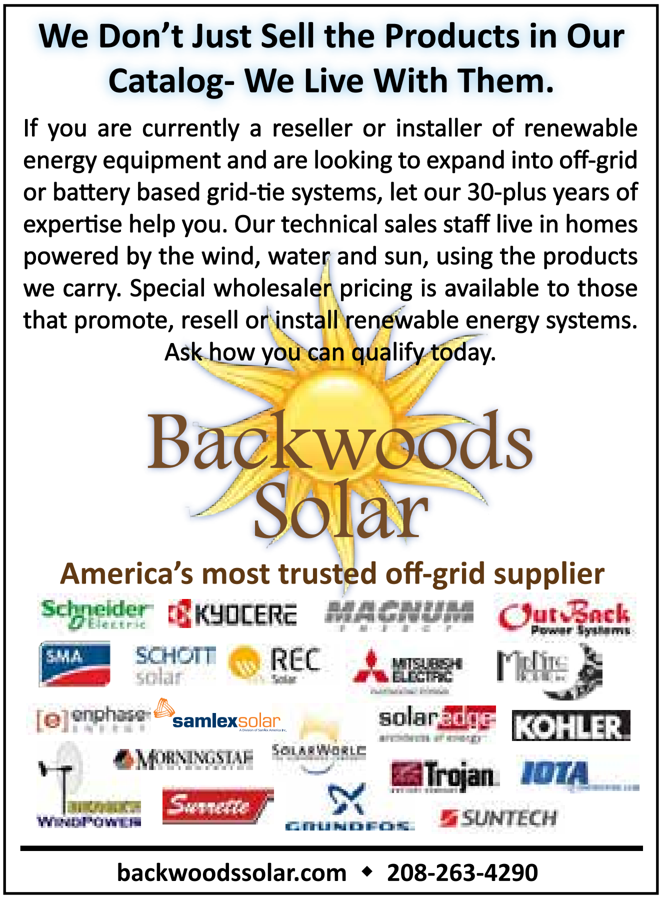
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exclusively use a grid-type, or harp, absorber construction?

OP: It's really quite simple. The serpentine concept, contrary to the harp design, is based on one riser and consequently has a lot fewer joints to braze. It's therefore cheaper to produce. US manufacturers have been hesitant to move to serpentine collector design because of the larger pressure drop inherent in this design approach and the resulting decrease in flow rates and performance because the collectors operate at a higher delta T.

SP: Lower-priced, Asian manufactured twin-tube evacuated heat pipe systems are gaining traction in the US market. Has this trend influenced Heliodyne's long- or short-term business strategies?

OP: Heliodyne is monitoring the development of the tube business in the US very carefully, but so far we have no desire to enter that market. This is primarily because we believe twin-tube technology is not suitable for the general US ST market. The technology creates issues with stagnation, cost and ease of installation—and it is more vulnerable to weather events such as hail.

SP: Most flat-plate collector manufacturers are moving to laser, ultrasonic or other automated methods of tube-to-plate attachment. Why does Heliodyne use laser welding?

OP: Laser welding is an avenue toward manufacturing low cost absorbers without sacrificing performance and aesthetics. Heliodyne currently holds the exclusive rights to the use of laser welding in the solar collector manufacturing space and sublicenses that technology in the US.

SP: The certification backlog that occurred at SRCC from 2006 to 2010 has been widely reported. Since 2008, the number of accredited testing laboratories in North America has increased from two to six, and at least two additional labs will

Courtesy Heliodyne

Specialization required While the US thermal industry is currently well-represented by solar industry organizations, Ole believes that the creation of a specialized solar thermal advocacy group would increase industry cooperation and long-term growth.

likely be added in the US in the near future. Do you think that the certification bottlenecks have been adequately addressed? What are the current time frames for OG-100 and OG-300 certification?

OP: Yes, the backlogs have been adequately addressed. Collectors can now be tested and listed with SRCC within a time frame of 3–4 months. Only a few years ago, it was as long as 2 years. Similarly, OG-300 system certification experienced backlog issues when some of the major solar incentive programs began using it as eligibility criteria. That's now also under control with certification throughput times in the order of 4–6 months. Continuous work is being done at SRCC to reduce this time frame even further with automated application processes and the hiring of more OG-300 reviewers.

SP: One of the steps in SRCC certification is an outdoor efficiency test that can last from 45 to 120 days. In comparison, we do not see a similar requirement in the California Energy Commission's eligibility requirements for PV modules. Do you think that this particular SRCC test is necessary or could adequate testing occur in a laboratory environment to help speed the certification process?

OP: Exposure testing is absolutely necessary. Outdoor testing is adequate, quick and less expensive compared to lab testing—especially now that additional outdoor test labs are available in areas with abundant amounts of solar radiation. The solar thermal industry is still mending the black eye it got back in the '80s when just about anything qualified for tax credits. I genuinely believe that the PV industry should learn from that experience and adopt a similar solar certification process to avoid a repetition.

SP: The Uniform Solar Energy Code stipulates that any collector made with glass shall utilize tempered glass. Ongoing discussions within the industry suggest that the SRCC has plans for a specific durability test and rating for collectors made with glazings other than tempered glass. Can you give us an update on related SRCC testing procedures?

OP: I'm not aware of this issue. To avoid any conflict of interest, I'm not informed about individual applications. From a general standpoint, however, SRCC has a responsibility to evaluate the safety aspects of the products being submitted for certification and should also follow the Uniform Building Code (UBC) to the extent that it is relevant for solar thermal technology. Jim Huggins, a colleague at SRCC, provided the following information on the topic: "In 2009, there was an SRCC subcommittee appointed by the Standards Committee to investigate safety issues with glass cover plates. One of the issues was that tubular collectors are made of nontempered glass. The subcommittee found that glass in that shape cannot be tempered. It also reviewed UBC requirements for flat glass. The subcommittee recommended that an impact test for all nontempered glass covers be added to the requirements of Standard 100. The Standards Committee and the board CONTINUED ON PAGE 124

accepted this recommendation, and Standard 100 was modified. The test labs have begun conducting the impact test, and we have seen a few reports with results from this test. Our next step is to modify the rating page to add the impact rating. We plan to make this change with the implementation of the new database and website later this year."

SP: Have you seen a shift in project focus from residential to commercial ST systems here in the US?
OP: Heliodyne has always been very focused on the commercial solar thermal market and has developed proprietary technology highly suited for those applications. Consequently the commercial market accounts for a significant part of our business. With advantageous rules of depreciation, tax credits and incentives for solar energy, it's a very attractive investment for business and real estate owners. We expect to see continued growth in the commercial ST application space.

SP: In 2010, the California Solar Initiative (CSI)-Thermal Program was launched. What is your opinion of the program's success to date?
OP: I think it's still early to evaluate the success of the CSI-Thermal Program. The small residential rebate was launched in May 2010, at the tail end of the recession and in an environment of very low natural gas prices. The commercial program was launched much later and consequently needs more time to materialize. There are some indications that the process installers have to go through to gain access to incentives is a bit tedious and to some not worth the trouble and time spent (read cost), in particular when it comes to small residential. The commercial program will undoubtedly be a huge success, and the CSI-Thermal Program may prove to be the most important initiative for the solar thermal industry in the US, just as CSI was for the PV industry.

The CSI-Thermal Program may prove to be the most important initiative for the solar thermal industry in the US, just as CSI was for the PV industry.

Furthermore, the CSI-Thermal Program should get some more traction once the program administrators launch the market awareness program.

SP: We have seen tremendous growth in the US PV industry in recent years. The latest *U.S. Solar Market Insight* year-in-review report indicated a year-over-year increase in installed grid-tied PV capacity of 102% from 2009 to 2010. In comparison, the ST industry showed a modest gain of 5% in the same time frame. Low natural gas prices are one obvious factor, but what other variables contribute to this disparity?
OP: Besides the low conventional energy costs, I think that the second most important barrier for solar thermal in the US is lack of awareness among both consumers and contractors.

SP: Do you think that ST interests are receiving adequate representation from US solar industry groups?
OP: Without exception, all solar industry groups embrace both PV and ST. Some political initiatives for financial and fiscal measures serve both technology platforms well, but some initiatives need a more differentiated approach. Since PV is currently overshadowing the solar thermal industry, most initiatives are geared towards PV; solar thermal tries to fit in and get the best out of it. That's not optimal, and I strongly believe there is room for a specialized solar thermal advocacy group. This group could work in close cooperation with the general solar energy industry groups and develop advocacy material and industry road maps specifically for the solar thermal industry. Considering that more than 40% of US energy consumption relates to heating and cooling, such an advocacy group should develop an industry road map proposing political actions to explore this potential.

SP: As an industry, what can ST professionals do to force more rapid market growth?
OP: The US solar thermal industry should come together like it did in Europe and develop a strong road map for growth. In my view, the road map should address the small, domestic hot water solar market as a separate segment with its own technology. The main barriers to growth in that market are a lack of public awareness, a lack of a developed professional work force and a lack of a level playing field with fossil-fuel–based technology. Besides political measures to deal with these barriers, the road map should include the idea of increasing the energy performance of buildings through stricter building regulations that force renewable technology into the building envelope. In addition, government should continuously endorse the technology through use in its own buildings.

When it comes to the tertiary, commercial, industrial and agricultural sectors, better standards, techniques and designs should be developed to tap into this enormous market through higher-temperature collectors and sophisticated BOS components. These large-scale application market segments should be treated differently from the domestic ST market, since the instruments needed to develop the full potential of these two distinct markets are not the same.

Finally, research into long-term low-temperature storage systems is needed to eliminate the need for backup heating with conventional fuels. In addition, solar cooling and solar assisted heat pumps should be high on the R&D agenda.

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mikeholt.com

Georgia

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iec-chesapeake.com

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Morrisville
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Northampton Community College
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Overview

DESIGNER: Jayme Garcia, PE, electrical engineer, Blue Oak Energy, blueoakenergy.com

PROJECT MANAGER: Morgan Vickery, Velocitel Energy Solutions, energy.velocitel.com

DATE COMMISSIONED: August 2010

INSTALLATION TIME FRAME: 68 days

LOCATION: Pico Rivera, CA, 34.1°N

SOLAR RESOURCE: 5.66 kWh/m²/day

HIGH/LOW DESIGN TEMPERATURES: per solarabcs.org/permitting/map: 88°F/36°F

ARRAY CAPACITY: 561 kW

ANNUAL AC PRODUCTION: 905.5 MWh

Velocitel Energy Solutions contracted directly with BP Solar to install a 561 kW PV array at the Pico Rivera Towne Center, a large retail mall in southeastern Los Angeles, California. The design team had to consider extensive existing rooftop conditions, including 198 skylights, and the relocation of hundreds of feet of HVAC gas and condensation pipes, as well as 350 new roof penetrations and attachment points.

The rooftop skylights presented two challenges: providing fall protection for workers and accommodating an irregular array layout. Prior to mobilization, fall protection railings were erected around every skylight. Twenty-eight separate subarrays comprised the array layout, and installation crews needed to double and triple check the subarray locations before beginning to install each one. The roof was split into three zones, with a separate installation team dedicated to each zone. Teams worked from south to north, panelizing the modules for mounting to the SunLink supports at workstations that migrated south to north along with the installation progress.

Due to seismic considerations, the designers were required to locate 10 to 15 attachment points to the building per subarray. These followed an irregular pattern due to the segmented array layout. A team of roofers preceded each array installation crew. The roofers cut holes in the roof membrane and insulation down to the corrugated metal roof deck at points identified by a surveyor. The

Courtesy Velocitel Energy Solutions (2)

Courtesy Vortex Aerial

roofers then attached cylindrical stanchions to the roof deck and flashed the penetrations with TPO single-ply roofing membrane that followed the membrane manufacturer's published specification.

The electrical side of the installation faced its own set of challenges. The utility transformer that fed the store switchgear was an older unit that needed to be replaced. However, the utility was not aware that shutting down the transformer during the PV system interconnection was too dangerous in the transformer's current state. Just hours before the scheduled outage, after weeks of preparation and the scheduling of a 1 MW backup generator and refrigeration trucks—as well as teams from BP Solar, Blue Oak Energy, Southern California Edison, Velocitel, SASCO and the building owner—the utility canceled the shutdown due to the unsafe conditions inside the transformer. The interconnection had to be rescheduled for after the transformer was replaced. Several weeks later, the interconnection was successfully completed during a 2am outage that had no negative impacts on the stores' operations.

Ultimately, despite the challenges, the installation was completed within budget and on schedule to the satisfaction of BP Solar and the building owner.

> "The complex nature of this installation required the expertise of many different trades. Electricians, plumbers, roofers, surveyors, civil contractors, fencing contractors, safety consultants, utility workers and retail managers all worked together to deliver the project. It was a true team effort."
>
> *—Morgan Vickery, Velocitel Energy Solutions*

Equipment Specifications

MODULES: 3,300 BP Solar 3170N, 170 W STC, -3%/+5%, 4.8 Imp, 35.6 Vmp, 5.2 Isc, 44.3 Voc

INVERTERS: 3-phase, 277/480 Vac service, two Schneider Electric Xantrex GT250-480, 250 kW, 600 Vdc maximum input, 300–480 Vdc MPPT range

ARRAY: 12 modules per source circuit (2,040 W, 4.8 Imp, 427.2 Vmp, 5.2 Isc, 531.6 Voc); 139 source circuits on Inverter One (284 kW, 667.2 Imp, 427.2 Vmp, 722.8 Isc, 531.6 Voc); 136 source circuits on Inverter Two (277 kW, 652.8 Imp, 427.2 Vmp, 707.2 Isc, 531.6 Voc)

ARRAY INSTALLATION: SunLink Roof Mounting System installed on single-ply thermoplastic olyphen (TPO) membrane, 213° azimuth, 20° tilt

ARRAY STRING COMBINERS: 24 Steven Engineering String Combiner, 9 A fuses

SYSTEM MONITORING: National Semiconductor/Energy Recommerce RECtrack 3

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FREDERICKSON ELECTRIC

Poulsbo Middle School

Overview

DESIGNER: Hans Frederickson, Frederickson Electric, fredelectric.com

LEAD INSTALLER: Bret Ortlieb, Frederickson Electric

PROJECT DEVELOPER: Rick Lander, Washington Solar Incentives, wa-solar-incentives.com

DATE COMMISSIONED: March 2011

INSTALLATION TIME FRAME: 60 days

LOCATION: Poulsbo, WA, 47.7°N

SOLAR RESOURCE: 3.7 kWh/m^2/day

HIGH/LOW DESIGN TEMPERATURES: per solarabcs.org/permitting/map: 84°F/18°F

ARRAY CAPACITY: 74.1 kW

ANNUAL AC PRODUCTION: 72.2 MWh

Equipment Specifications

MODULES: 390 Silicon Energy SiE-190, 190W STC, ±3%, 7.5 Imp, 25.3 Vmp, 7.9 Isc, 30.5 Voc

INVERTERS: 3-phase, 277/480 Vac service, 15 Power-One PVI-4.2-OUTD-US, 4.2 kW, 600 Vdc maximum input, 90–580 Vdc operating MPPT range, 200–530 Vdc full power MPPT range; Silicon Energy prewired inverter system assemblies with dc and ac disconnects

ARRAY: 13 modules per string (2,470 W, 7.5 Imp, 328.9 Vmp, 7.9 Isc, 396.5 Voc), two parallel strings per inverter (4,940 W, 15 Imp, 328.9 Vmp, 15.8 Isc, 396.5 Voc)

ARRAY INSTALLATION: Silicon Energy mounting hardware secured to custom-built galvanized steel rack. Aluminum racking components isolated from galvanized steel with rubber tape. 182° azimuth, 5° tilt

SYSTEM MONITORING (fredelectric.com/pms.html)**:** Fat Spaniel inverter-direct monitoring with environmental sensors

Courtesy Washington Solar Incentives (2)

Sandwiched between Seattle and the Olympic Peninsula, picturesque Poulsbo, Washington, is home to the state's first full-capacity community solar project. The 75 kW array was developed by Washington Solar Incentives (WSI) and was installed by Frederickson Electric. WSI secured the host facility, negotiated all contracts, organized investors and oversaw the installation.

A first-in-the-nation Washington state incentive program that includes a community solar provision made the project at Poulsbo Middle School possible. The model allows community members to fund up to a 75 kW system on a public facility and receive a production incentive of $1.08/kWh. At the end of the incentive period in June 2020, the investors transfer ownership to the facility and are projected to have earned an average double-digit annual return.

The incentive requires the use of modules and inverter systems manufactured in Washington. The Silicon Energy modules feature frameless construction with a glass backsheet. The modules mount in a cascading fashion, which increases air circulation and effectively uses rainfall to clean the array. Silicon Energy developed the module racking system, which also serves as a raceway for the array conductors. The entire assembly is listed and has a Class A fire rating.

The 15 single-phase inverters take up an entire wall adjacent to the electrical service room. Inverter input and output wiring is organized in a gutter system surrounding the inverters and disconnects. The inverter outputs are combined five per phase in a dedicated distribution panelboard, which connects to the electrical service on the supply side to avoid backfeeding an existing GFI device on the main disconnect.

"It was an interesting challenge to design a 75 kW system with equipment manufactured in Washington. I'm pleased with the result, which combines very durable modules with an efficient inverter system."

—Hans Frederickson, Frederickson Electric


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