June/July 2011

Galvanic Corrosion Guidelines for PV Structures

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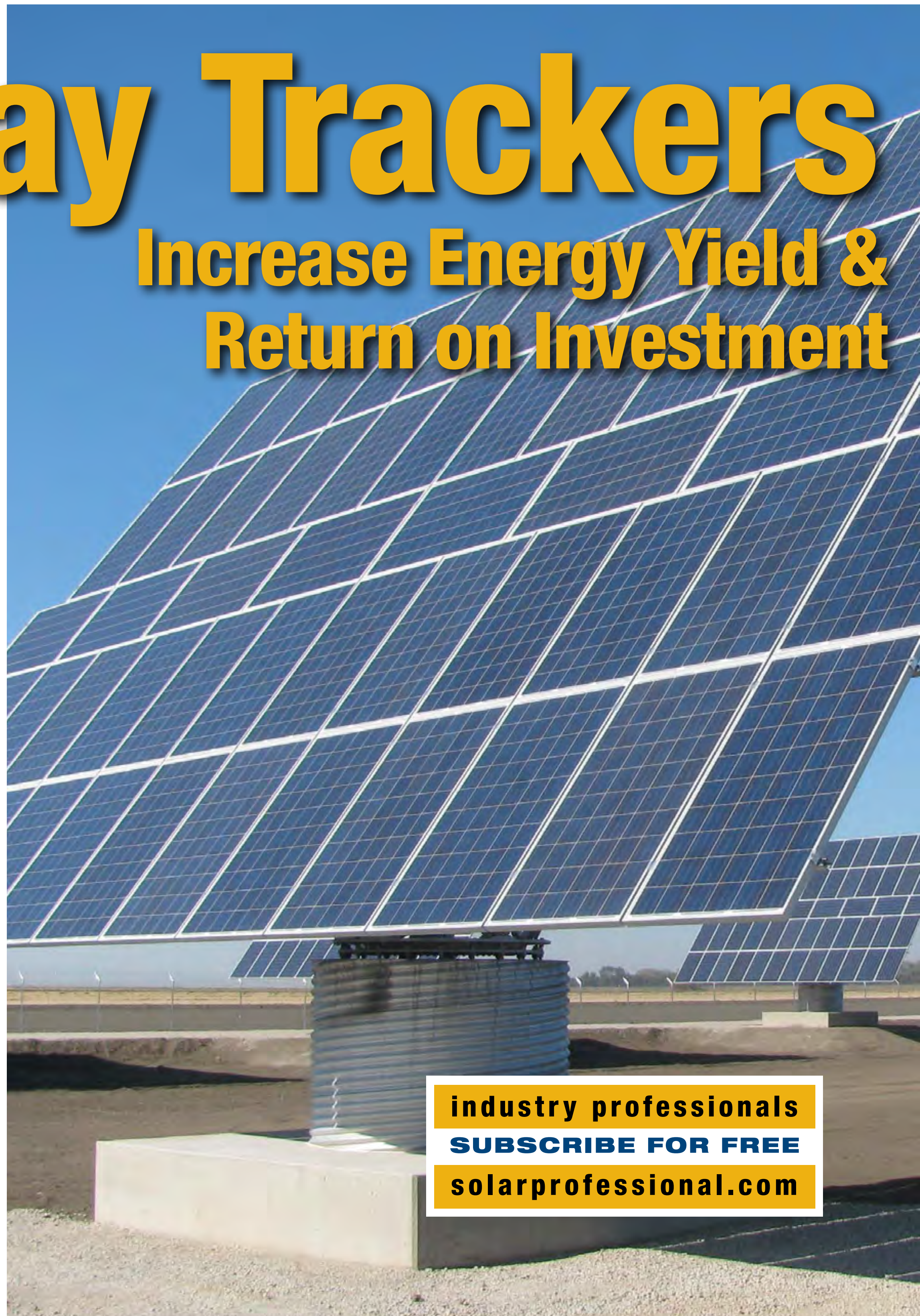

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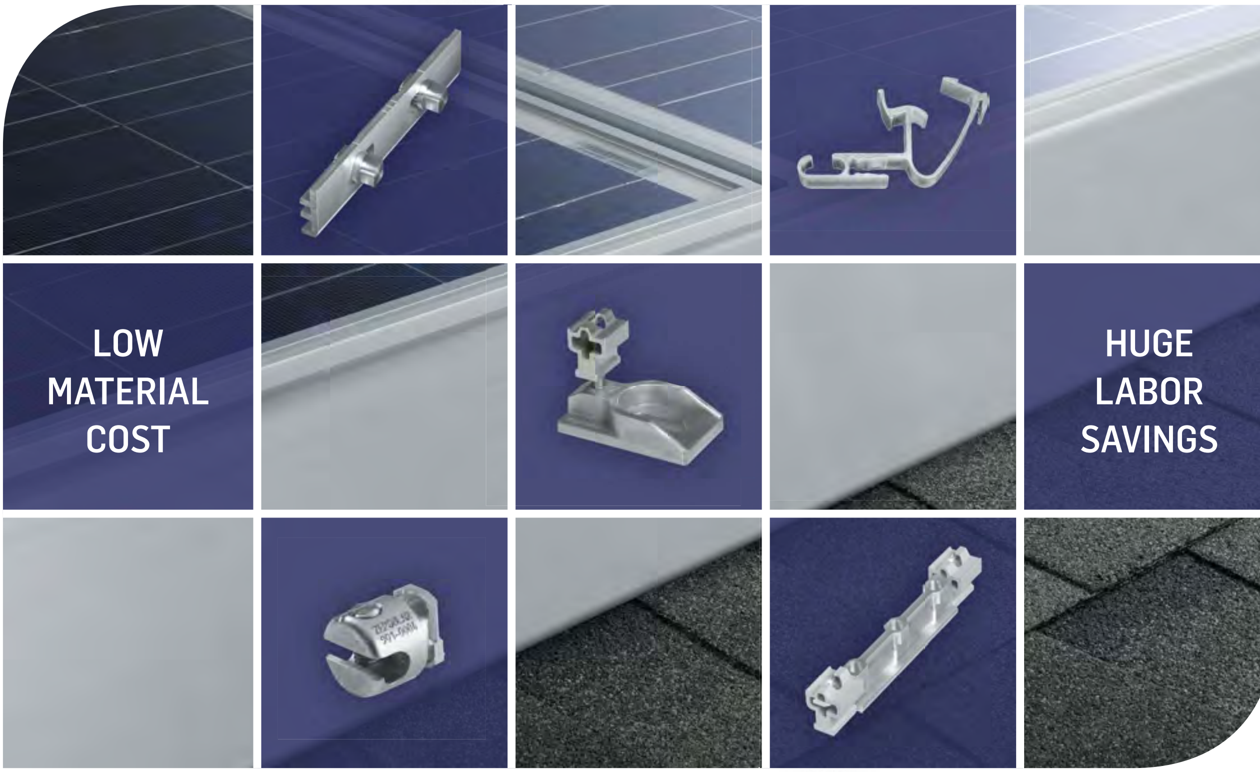

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The Zepulator is a system design tool that allows you to configure arrays per site engineering requirements, generate bills of material, and produce project summaries for thorough permit submittals. Check out the Zepulator at: **Zepulator.com**

U.S. Patent #7,592,537, U.S. & Int'l Patents Pending

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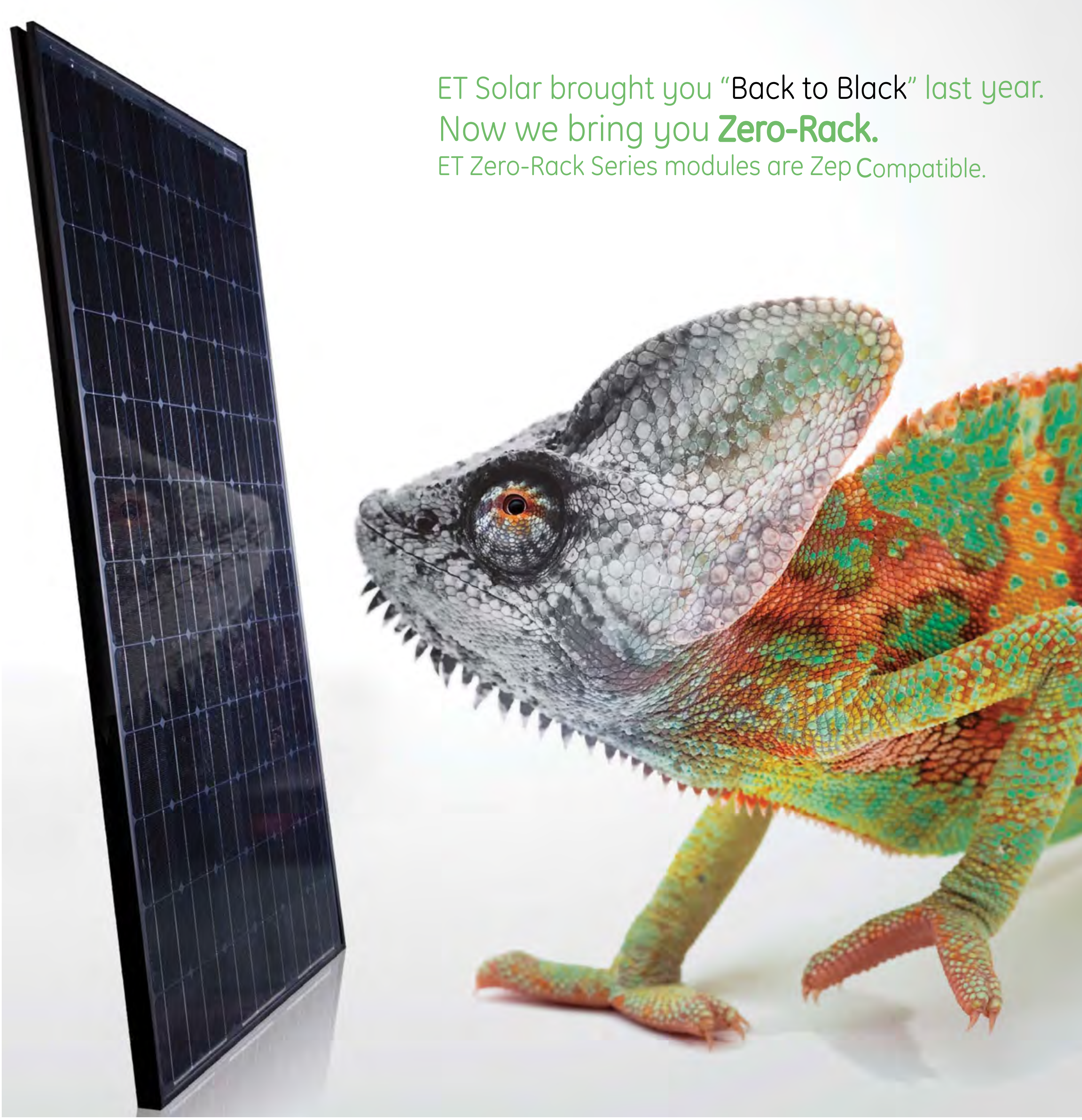

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ON THE COVER Thirty Mecasolar MS-2 Tracker 10 dual-axis trackers are deployed at the Reclamation District 108 Solar Farm in Knights Landing, CA. Foundations for the trackers elevate the arrays above the Sacramento River's 100-year flood plain. Bob Parkins, director of engineering for Solar Development, led the project team, with electrical installation by Butterfield Electric and structural work by Ascent Builders. The 386 kW array utilizes 1,680 Trina Solar modules.

Photo courtesy Solar Development

Contributors

Experience + Expertise

Stephen Smith is a 15-year veteran of the solar industry. He developed core technical skills as a project manager with PowerLight, which was acquired by SunPower. In 2006, Stephen left the company to pursue the development of high-concentration photovoltaics. In 2009 he founded Solvida Energy Group, a professional services firm, where he is now managing partner. Solvida's project portfolio totals more than 100 MW, and Stephen has developed more than 50 PV/HCPV solar projects for a broad range of clients.

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.

Justin Weil is president of SunWater Solar, a design/build company that has developed some of the largest commercial solar water heating systems in northern California. Justin is a NABCEP Certified Solar Thermal Installer and has been deeply involved in the solar thermal industry for more than 11 years. A well-respected industry expert, he advises several government entities on solar thermal policy issues.

Erika Weliczko is founder and president of REpower SOLUTIONS, a renewable energy systems integration company that serves northeast Ohio. She holds degrees in engineering and music from Case Western Reserve University and in teaching from Kent State University. Erika is a NABCEP Certified Solar PV and Small Wind Installer, a licensed electrical contractor and a technical editor for *Home Power* magazine.

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Galvanic Corrosion Considerations for PV Arrays

Photovoltaic modules are designed for an operational life span of more than 25 years in the field. The design of the entire installation, not just these expensive components, should target a similar life span. The focus here is to describe the potential impact of galvanic corrosion on array structures and to identify best practices to minimize this impact. While some visible cosmetic corrosion effects over time may be tolerable, the failure of structural components is clearly not.

The Galvanic Series

Galvanic corrosion is the result of an electrochemical reaction. For galvanic corrosion to take place, four things must exist simultaneously: an anode, a cathode, an electrolyte and a conductive path between two pieces of metal. A galvanic circuit is created in which the anode loses electrons to the cathode with the assistance of the electrolyte. The galvanic cell created by two dissimilar metals and the presence of the electrolyte operates only in one direction. Consequently, the anode eventually disintegrates.

In PV installations, the anode and cathode consist of metals, such as stainless steel, copper and aluminum. Water commonly serves as the electrolyte. Whether galvanic corrosion is a serious problem depends on the potential failure point. For a PV installation, the long-term effects of corrosion can range from unsightly finishes to racking or fastener failure.

The more dissimilar the metals, as reflected by their relative position in the galvanic series (see Table 1), the greater the corrosion potential in the galvanic circuit. The general rule is to avoid joining metals far apart in the galvanic series. For example, steel is anodic next to brass, and stainless steel is cathodic next to zinc or aluminum. Another way to read this is that steel corrodes next to brass and stainless steel, while aluminum and zinc corrode next to steel when an electrolyte and a conductive path are present.

Every metal has a standard electrical potential (voltage) based on its ability to release or accept electrons when in contact with a dissimilar metal and an electrolyte. In reality, the galvanic system is more dynamic than most published material on voltage-potential data suggests. The actual reaction that takes place between two metals in the environment is dependent on electrolyte concentration, pH, temperature and other factors. Rob Haddock from Metal Roof Innovations, manufacturer of the S-5! mounting clamp, provides a word of caution about using the galvanic scale. "Some installers might want to use the galvanic scale to identify dissimilar metals, but the graphical galvanic scale is not always a good way to determine whether one metal is compatible with another," he says. "When metals oxidize, the oxide layer created is a new material that may or may not exhibit the electrochemical characteristics of the parent material."

In general, the greater the potential between two metals, the greater the driving force of the galvanic circuit and the more rapid the corrosion rate. If the potential is small, the driving force may be of no consequence. Whether or not a metal serves as an anode or a cathode is determined by the neighboring materials. The local environment also influences the reaction.

Moisture provides the electrolyte that enables galvanic corrosion to occur. Generally speaking, as humidity increases, so does the rate of corrosion. Atmospheric contaminants, such as chlorides (in marine environments) and sulfur dioxide and nitrous oxides (in industrial locations), are deposited on array structures. Once deposited, the contaminants react with oxygen and water and typically increase corrosion rates by releasing electrons from the metal's surface. It is interesting to note that corrosion rates can be effectively decreased in areas of high rainfall, as contaminants are regularly washed away from the structural materials.

Galvanic Series

Magnesium	Active (Anode)
Zinc	↑
Galvanized Steel	
Aluminum	
Mild Steel	
Cast Iron	
Lead	
Brass	
Copper	
Bronze	
Monel	
Nickel (passive)	
Stainless Steel 304 (passive)	
Stainless Steel 316 (passive)	
Silver	
Titanium	
Gold	
Graphite	
Platinum	Noble (Cathode)

Adapted from Advanced Materials, Manufacturing, and Testing Information Analysis Center

Table 1 The similarity of metals is indicated by their relative position in the galvanic series. The more dissimilar the metals, the greater the corrosion potential in a galvanic circuit.

Corrosion Mitigation Guidelines

The Advanced Materials, Manufacturing and Testing Information Analysis CONTINUED ON PAGE 16


Learn Solar, Buy Solar,
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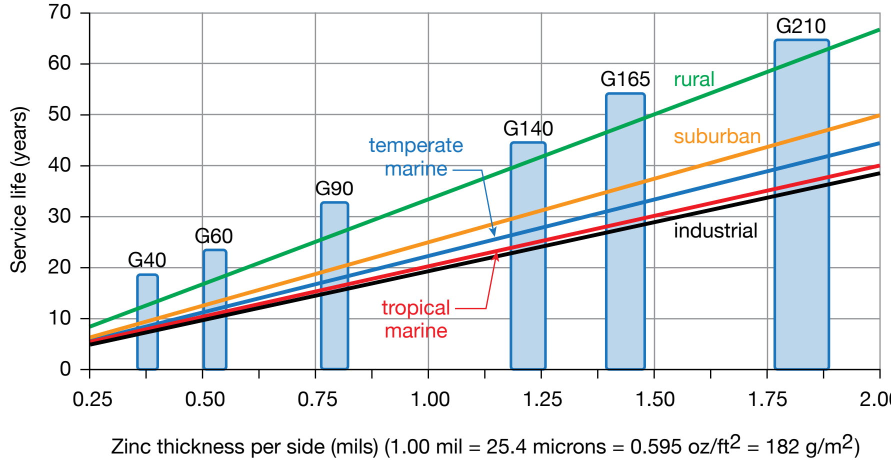
Center's *Guide to Corrosion Prevention and Control* (download at ammtiac.alionscience.com/pdf/Corrosion_Hdbk_S2.pdf) suggests some general best practices.

- Use only one material to fabricate electrically isolated systems or components where practical.
- If mixed-metal systems are used, select combinations of metals as close together as possible in the galvanic series, or select metals that are galvanically compatible.
- Avoid the unfavorable area effect of a small anode and large cathode. Small parts or critical components such as fasteners should be the more noble metal.
- Insulate dissimilar metals wherever practical, such as when using a gasket. It is important to insulate completely if possible.
- Apply coatings with caution. Keep the coatings in good repair, particularly the one on the anodic material.
- Avoid threaded joints for materials far apart in the series.
- Design for the use of readily replaceable anodic parts, or make them thicker for longer life.

How does this translate to practice? Since an anode, a cathode, an electrolyte and a conductive path are necessary to create a galvanic cell, controlling those four elements can decrease the rate of corrosion.

Ideally, one could eliminate the anode or cathode by using only one metal type for the array structure. Controlling the electrolyte is not so practical. If the electrolyte (moisture) is removed, the likelihood of corrosion decreases significantly. This is why PV systems installed in desert climates are less prone to galvanic corrosion than those located in more humid environments. Unfortunately, we can only plan to have weather, not control it.

The most practical ways to reduce the potential for galvanic corrosion are to choose metals that are close together on the galvanic scale, select the appropriate protective coatings for an installation's environmental conditions, reduce the contact area between dissimilar metals and physically isolate dissimilar metals with nonconductive, nonporous materials.



Courtesy GalvInfo Center

Figure 1 The service life for hot-dip galvanized finishes depends on the environmental conditions of its installation.

Material coatings. While the galvanic series showcases relative reactivity, coatings trump the raw metal potential. Corrosion is most often combated with paints, electroplating or other coatings such as hot-dip galvanization. If intact and properly maintained, the coating prevails in the material interactions and limits potential galvanic corrosion.

The aluminum used in module frames and array rails is anodized to increase the material's corrosion resistance. Aluminum naturally builds up an oxide layer when exposed to oxygen. The anodizing creates a thicker oxide layer, which acts as a barrier to corrosion.

In some cases, one metal's corrosion potential is used to protect another metal. For example, galvanized channel is protected by a zinc coating. The zinc in the galvanized coating reacts with the atmosphere to create layers of zinc oxide and zinc carbonate, protecting the steel underneath it. When used adjacent to other metals, the galvanized steel coating sacrifices itself to protect other, more structurally important metals.

Guidelines established by Unirac include data provided by the GalvInfo Center (galvinfo.com), which hosts the Zinc Coating Life Predictor, a calculator that incorporates rainfall, salinity, sulfur dioxide, relative humidity, temperature and sheltering as factors in predicting coating life. Steve Bauer, applications engineering manager at Unirac, recommends hot-dip galvanization for steel structural components. As shown in Figure 1, a thicker galvanization coating provides greater protection. The minimum coating for steel array structures is a G90 coating that is approximately 0.75 mils thick. The coating's service life varies considerably based on a project's location and environmental conditions, so thicker galvanization may be necessary.

Coatings should be repaired if damaged, especially if they are on an anodic material such as steel. When galvanized channel is cut in the field, always apply cold-galvanizing paint to protect the steel. Since the occasional paint scratch is practically unavoidable during installation, repair or restore a chipped coating whenever possible. Unsightly rust can be reduced and the service life of the product extended. More than one product manufacturer recommends suitable paint for maintenance of a compromised coating. CONTINUED ON PAGE 18

Contact surface area. The rate of corrosion depends primarily on where two or more dissimilar metals fall in the galvanic series and the amount of electrolyte present. The metals' surface contact area is also an important consideration, since it determines the ratio of cathode to anode. Keep in mind that the galvanic cell is in solution. By overwhelming the solution with anodic material—but limiting the cathodic component—the solution becomes saturated with electrons and corrosion is limited.

In the reverse condition, as in steel nails used to fasten a copper material, the cathode dominates with its ability to absorb or dissolve any and all electrons offered by the anode. For example, if zinc-coated steel roofing nails are used to secure copper flashing, the nails quickly fail. It is best to avoid using a small amount of anode (steel) in contact with a large amount of cathode (copper).

Isolation strategies. When in doubt, seek ways to physically and electrically separate potentially problematic metal combinations. Using rubber washers to isolate galvanized screws from painted steel sheet goods is common practice in the roofing industry. Stainless steel washers with an ethylene propylene diene monomer (EPDM) gasket already adhered are commonly available at hardware supply houses.

Metal channel manufacturers have introduced products that isolate copper from the steel channel by way of plastic clamps. These are designed for plumbers who are clamping copper pipe to steel strut, whether electroplated with zinc or hot-dip galvanized. Cooper B-Line Iso-Pipe isolation wrap and isolating clamps such as Vibra-Clamps also provide material isolation and eliminate the metal-to-metal contact that can start the galvanic corrosion process.

EPDM rubber can be used to isolate dissimilar metals, whether built into the washer or inserted as a separate material sheet. Certain plastics may suffice if they are rated for outdoor conditions. Some installers have more confidence in EPDM roofing materials than in plastics, even if the plastic material selected is designed to sustain UV exposure.

Fastener selection. The major selection you need to make is fastening hardware. Since many corrosion events take place at a bolted connection, the integrity of each connection is a legitimate concern. The fastener selected should not be anodic in relation to the structural members. In PV applications, stainless fasteners commonly available as 18-8 variety meet this requirement.

Always consider the points of contact. Thoroughly review the product manufacturer's specification sheets and installation manuals and look for opportunities to exceed the stated goal in these instructions. For example, REC Solar product literature recommends the use of stainless steel fasteners to prevent galvanic corrosion, but also allows for galvanized or zinc-plated fasteners. Sharp Solar, in a recent addendum on grounding, recommends stainless steel hardware only. Cooper B-Line recommends the use of stainless steel hardware with its aluminum channel. According to Tom Young at DPW Solar, the intent of using stainless steel fasteners is "to keep them less active than the materials they're fastening."

While stainless steel has become commonplace in PV hardware assemblies, the new Dura-Con line of fasteners offered by Mudge Fasteners employs coatings that reportedly meet or exceed the performance of stainless steel. According to Paul Mudge, the new line of nuts, bolts, washers and lag bolts offers a lower-cost alternative to stainless steel hardware and reduces the potential for galvanic corrosion between the fastener and the aluminum structure.

The cost of materials is always a factor. While metal prices change on a regular basis due to market factors, at the time of writing aluminum strut channel costs twice as much as galvanized channel, and stainless steel channel is four times the cost of galvanized. For hardware, stainless steel fasteners are about four times more expensive than their zinc-plated counterparts.

Long-Term Durability

Always carefully consider the metals specified for your PV installation. Focus on long-term durability, and pay close attention to mechanical connections that may be susceptible to galvanic corrosion and possible structural failures after 10 or 20 years in service. Consult with equipment manufacturers regarding installation best practices that take into account the climate where the array is located. In addition, consult with material trade associations, such as the American Galvanizers Association (galvanizeit.org). They can offer sound guidance and summaries of past research related to galvanic corrosion.

Field Inspection Guidelines for PV Systems, written by Bill Brooks of Brooks Engineering (available from Interstate Renewable Energy Council, irecusa.org), calls out the importance of proper array structure materials selection and installation. According to Brooks: "Historically, in the California market due to the low corrosion rates, dissimilar metals are commonly seen in contact with one another. The fact that installations often have this error should not be seen as license to continue a practice that can have severe consequences in high corrosion environments."

—Erika Weliczko / REpower SOLUTIONS / Cleveland, OH / repowersolutions.com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U.S. Solar Market Insight Published

[Washington, DC] Growth in the solar industry is the highlight of the 2010 year-in-review report published by the Solar Energy Industries Association (SEIA) and GTM Research. In the executive summary, available for free download, the two groups report that the US solar industry as a whole grew by 67% over the previous year. The report is broken out into three market segments: PV, concentrating solar power (CSP) and solar heating and cooling (SHC).

The report indicates that the installed capacity of grid-connected PV systems grew to 878 MW in 2010, a 102% increase over 2009. The largest growth sector was in utility-scale PV, growing from an installed capacity of 70 MW in 2009 to 242 MW in 2010. The PV industry saw a relatively even distribution among the residential, nonresidential and utility markets, helping to keep the industry balanced. Even with the strong growth, the US market share in global installations fell from 6.5% in 2009 to 5% in 2010.

The CSP and SHC components of the report show promising growth as well. Only three CSP projects came online in 2010 for a total of 77.5 MWac. This may not seem impressive, but considering that the CSP industry did not see any installations between 1992 and 2006, this growth is good news. For SHC, the report breaks out the installations into solar water and space heating (SWH) and solar pool heating (SPH) applications. The report indicates more modest gains for SWH, with 5% annual growth. The SPH industry saw a small gain as well, after 3 years of decline.

The executive summary does a good job of outlining the big picture for all technologies. The full report can be purchased directly through GTM and includes more in-depth information and analysis.

SEIA / 202.682.0556 / seia.org

Annual PV Installed Capacity by Market Segment, 2005-2010

	2005	2006	2007	2008	2009	2010
Total	79	105	160	290	435	878
Utility	1	0	9	22	70	242
Non-Residential	51	67	93	190	208	372
Residential	27	38	58	77	157	264

Electrical Tool Tether Products Available

[Ventura, CA] The tether products from Hammerhead Industries were designed to help reduce workplace accidents caused by falling tools. Its Gear Keeper line of products includes retractable tethers and energy absorbing lanyards that accommodate tools and instruments weighing up to 30 pounds. Products can be configured to match the needs of nearly any user. The retractable tethers include a flushing mechanism that automatically clears any collected debris from the retractor. There are options for belt clips that offer 360° rotation, allowing a full range of motion for your tools, and shoulder strap clips that allow tools to slide along the strap for convenience and safety.

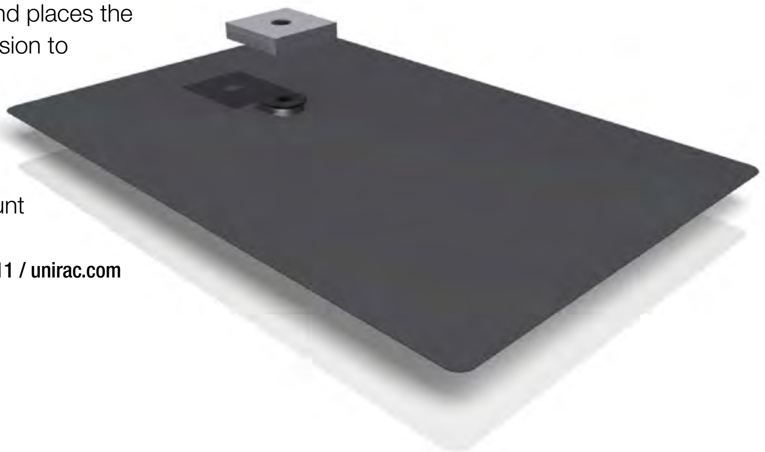
Hammerhead Industries / 888.588.9981 / gearkeeper.com


Scan for Pike Energy Solution's complete engineering profile. Download the tag reader at http://gettag.mobi
PIKE

Unirac Releases Flat Flashing

[Albuquerque, NM] In an effort to increase quality and simplicity in racking installations, Unirac has introduced its Flat Flashing. This two-part flashing is intended for use on any composition asphalt shingle roof and requires sealant only when the installer feels it is necessary. The 8-inch-by-12-inch flashing has a factory-installed gasket to seal the lag screw penetration point. The flashing also comes standard with a square aluminum plate, which gives the L foot a solid surface to sit on and places the gasket in compression to create a positive seal. The flashing is compatible with all Unirac roof-mount and tilt-up arrays.

Unirac / 505.242.6411 / unirac.com



Snake Tray Provides Wire Management

[Bay Shore, NY] Snake Tray offers two products specifically for the PV market. Solar Snake Tray options are available for low-slope roof applications and ground-mount installations. The rooftop tray is manufactured with stainless

steel and is hand-bendable, allowing the tray to be easily routed around obstacles. The built-in mounting rings and stainless steel hardware aid in the installation process and allow for connection to equipment, securing the tray in place. The "lobster trap" design allows easy placement of the conductors and securely holds them in place. The ground-mount solution is a UL classified cable management system and can span 30 feet between the integrated supports. It includes a mounting rail for combiner box installation and is available in stainless steel or hot-dip galvanized steel.

Snake Tray / 800.308.6788 / snaketray.com

Power-One Introduces 3-Phase String Inverters

[Camarillo, CA] The Aurora Trio 10 kW and 12 kW inverters incorporate 3-phase output for use in commercial applications. Similar to the smaller residential units from Power-One, the Trio inverters offer dual dc input sections, each with an independent MPPT, allowing for greater flexibility in system design and installation. The enclosures are rated at NEMA 4X and have integrated disconnects. Power-One offers a standard 10-year warranty with an option for 15 or 20 years. The 10 kW unit has options for 208, 480 and 600 Vac, and the 12 kW is available in 480 or 600 Vac. All inverters in this line include nighttime disconnect to help reduce tare losses. In January 2011, Power-One also celebrated the opening of its Phoenix, Arizona, manufacturing facility that is expected to employ 350 people. The facility will produce 1 GW of inverters by the end of the year and has room to expand to 4 GW.

Power-One / 805.987.8741 / power-one.com

Breaker-Based Combiners Offered

[San Jose, CA] Bentek Solar offers a full line of string combiners and recombiners for residential, commercial and utility-scale projects. They have added a new line of circuit breaker–based recombiners targeting commercial-scale projects at 250 kW to 1 MW. The 600 Vdc breakers serve as the overcurrent protection as well as the disconnecting means. The enclosures are available in

steel and stainless steel configurations with NEMA 3R or 4 ratings. A NEMA 4X enclosure is available in fiberglass. The recombiners come in two classifications. One accommodates two, three or four inputs, and breaker ratings range from 80 to 400 amps. The other accepts up to six strings inputs protected with either 100, 200 or 400 amp-rated breakers. Bentek offers options for smart combiners, integrating modbus connections for monitoring options, and makes combiners to order.

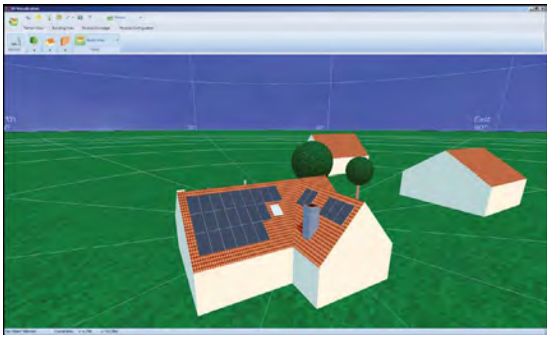
Bentek Solar / 866.505.0303 / bentek.com

Flir Imaging Cameras Aid O&M

[Boston, MA] A thermal imaging camera can be a great addition to most integrator's tool belts. These cameras allow you to visualize and analyze temperatures of mechanical and electrical equipment and quickly identify problem areas. While imaging cameras are not specifically designed for PV or solar thermal applications, they can provide valuable insight into unexpected problems. The Flir i-Series, consisting of the i-3, i-5 and i-7, offers intuitive designs at a lower cost. These cameras have precise temperature measurements and the ability to transfer data collected on-site to a computer for full inclusion in reports. The E-Series of cameras offers higher screen resolution and includes a 3-megapixel camera. The E-series also provides a wireless connection to mobile devices, such as the iPhone and iPad, and can transmit data between Meterlink-enabled measurement instruments, such as digital multimeters.

Flir / 800.464.6372 / flir.com

Valentin Software Releases Revisions



[Carlsbad, CA] Valentin Software, producers of design and modeling software for the PV and solar thermal industries, released version 5.0 for its PV*Sol Expert program and 5.0 for T*Sol Pro. The PV*Sol revision introduces the ability to incorporate a digital image of the proposed array location so it can be represented virtually and all roof dimensions can be analyzed. The new version also includes a number of additions to the drawing library, allowing the placement of site-specific obstructions to the modeling program and automatic optimization of array angles and interrow distances. The new version of T*Sol is focused on the US thermal market, allowing users to model systems based on US cities and commonly available products, including Solar Rating and Certification Corporation (SRCC) certified collectors. T*Sol 5.0 also includes new screen design and graphics features.

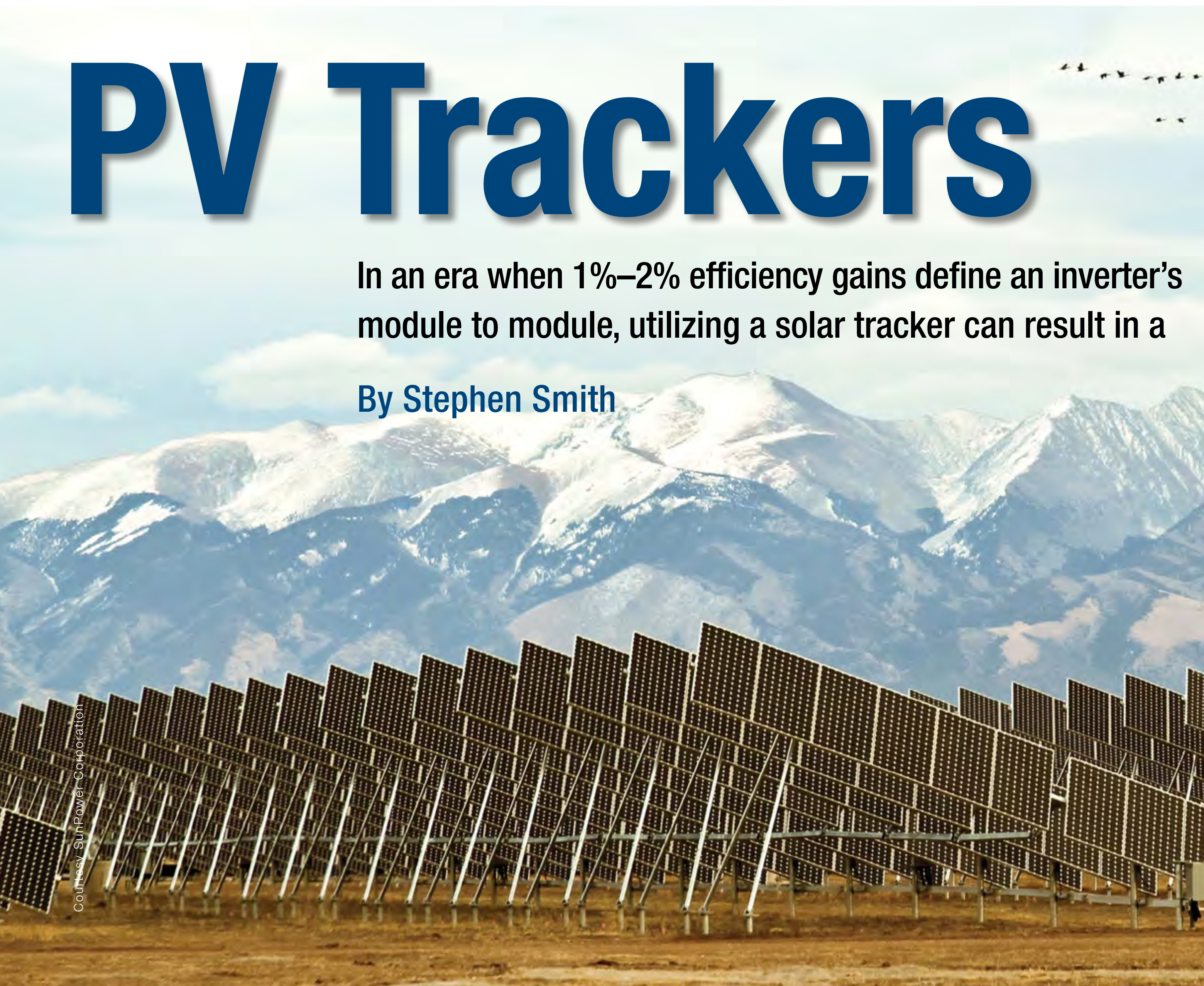
Valentin Software / 888.786.9455 / valentin-software.com

By aiming a solar generating source at the sun throughout the solar day, tracking systems increase energy harvest more than any other BOS components. Given their highly prominent role in squeezing as many usable electrons out of a group of solar panels as possible, why do some solar integrators, financiers and developers shy away from specifying tracker systems? Why do some consider trackers obsolete and prime candidates for the cost-chopping guillotine on the race to grid parity?

PV Trackers

In an era when 1%–2% efficiency gains define an inverter's module to module, utilizing a solar tracker can result in a

By Stephen Smith



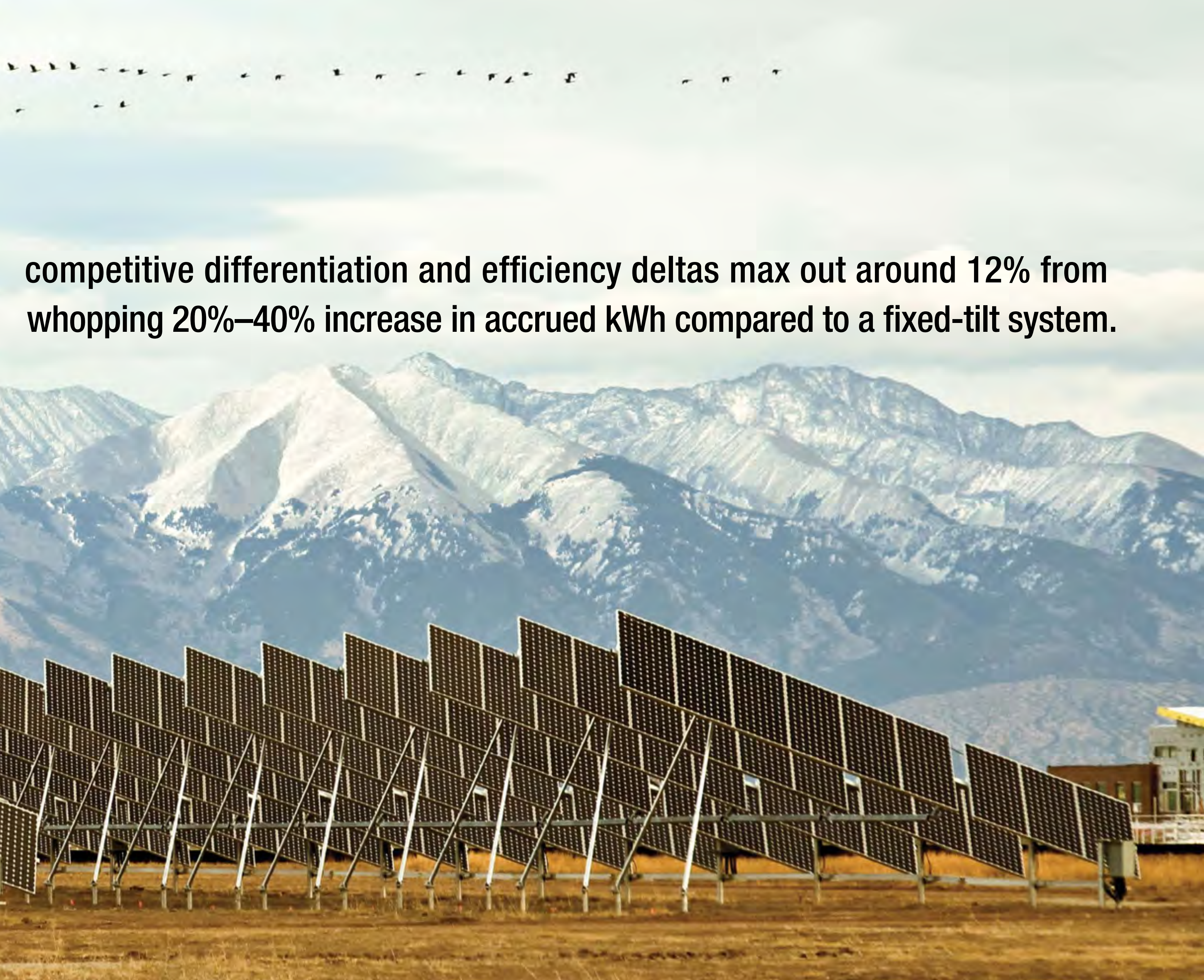
Courtesy SunPower Corporation

Trackers beautifully illustrate human ingenuity and applications engineering. A solar tracker can elegantly remove a significant constraint on a PV panel's ability to capture light and convert it to electricity. So what is the deal? Are the naysayer's arguments valid or just a case of efficiency envy? Are trackers the best answer for large ground-mounted PV arrays? The answer is fairly common in the dynamic and diverse solar industry—it depends.

My goal here is to help demystify trackers for on-site power generation. Because print resources on this subject are limited, I interviewed many industry subject matter experts and share their insights along with my own. The pros and cons of tracking systems must be communicated transparently. This requires realistic cost and performance numbers. At the same time, customers need guidance to understand site-specific requirements. When this due diligence is not followed, the results can be embarrassing. Tobin Booth, president and CEO of Blue Oak Energy, cautions: "Be aware that trackers may become fixed-tilt arrays before you are finished with the design." However, diligence in matters regarding site-specific requirements ensures that viable projects move forward from concept to completion, which is the best way to further the acceptance of trackers throughout the solar industry.

History

Solar trackers have been around for almost 50 years. Steve Baer, a founder and former president of Zomeworks, says he built his first passive tracker in 1968. "We only began



Courtesy Zomeworks

Passive tracking The Track Rack from Zomeworks follows the sun passively, using compressed fluid with a low boiling point. It was one of the earliest PV trackers developed and sold commercially.

manufacturing passive trackers for sale in the late 1970s, when we figured Willard Geer's patent on the idea had expired." Track Rack, still in production today, is a nonmotorized pole-top tracker that uses refrigerant and aluminum channel reflectors to shift PV panels toward the sun. In the 1980s, Array Technologies—which, like Zomeworks, is based in Albuquerque, New Mexico—began offering closed-loop, optically controlled Wattsun solar trackers that are still produced today.

Before the US grid-tied PV market developed, the Track Rack and Wattsun products were primarily sold to the residential off-grid market where trackers were a particularly good match for summer peak loads. Baer points to stock watering as an example: "A tracker enables greater use of a pump, well and water trough." As described by Wattsun founder Ron Corio in *Solar Cells and Their Applications* (see Resources), in the 1980s and 1990s the evolution of the PV tracker market "exhibited slow but steady growth."

The first large-scale solar trackers were built in 1983 on the Carrizo Plains in California. (This happens to be the same area chosen more recently by industry behemoths First Solar and SunPower for 750 MW of proposed solar power plants.) In 1977, ARCO Solar began manufacturing solar panels in response to the oil and energy crisis. A few years later, ARCO leased land on the Carrizo Plains and assembled two intricately designed and controlled dual-axis tracker PV power plants, totaling 5.2 MW. However, power from these plants was sold to the grid at a mere $0.04 per kilowatt-hour. Since the plants were not economically viable, they were eventually sold off and disassembled.

New tracker design for PV power plants stagnated during most of the Reagan era. As the solar market started its phoenix-like rise in the 1990s, a few CONTINUED ON PAGE 32

Horizontal single-axis tracker This 505 kW tracking PV system was installed in 2005 at a Johnson & Johnson facility in Skillman, NJ, using PowerLight's PowerTracker. A prototype, the MaxTracker by Shingleton Design, was deployed as early as 1999. After SunPower acquired PowerLight in 2006, the PowerTracker was renamed the T0 (or tilt zero) tracker. It is reportedly the most widely deployed tracker system in the world today.

Courtesy SunPower Corporation

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Courtesy SunPower Corporation

Tilted single-axis tracker Each electric linear actuator in the SunPower T20 tracker system—pictured here at the Greater Sandhill Solar Farm in Mosca, CO—can drive up to 177 kW of PV mounted on up to 48 trackers. The driveline connections are articulated to accommodate uneven terrain.

tracker products came to market. Early 1990s designs lacked the standardization, reliability and, most importantly, the cost structure to be implemented on a large scale. Solar economics were (and still are) driven by the nature of various subsidy programs. Prevalent programs in the 1990s were based on system peak ratings (kWp) and not performance (kWh), so the increased capital investment for a tracker design made less financial sense.

This all changed in Germany during the late 1990s. A grassroots effort towards energy independence spurred the creation of the Renewable Energy Sources Act. This landmark policy eventually highlighted a feed-in-tariff (FIT) program, a highly effective policy framework for accelerating the deployment of renewable energy. The key to its success is that a FIT provides a guaranteed financial return on investment based on the sale of energy to the utility grid.

Concurrently in the United States, PowerLight Corporation, the largest US-based systems integrator at the time, orchestrated a deal with Shingleton Design, a small engineering firm, to jointly license and distribute Shingleton's single-axis tracker invention: the MaxTracker. It was subsequently rebranded as the PowerLight PowerTracker. This innovative single-axis tracker used only one small motor to rotate nearly 200 kW of PV modules. PowerLight's timing in bringing this product to market was impeccable. Within a year of the deal, PowerLight contracted to install what was the largest solar park in the world, the 10 MW Bavaria Solar One project in Germany, which employed Sharp Solar modules and PowerLight's proprietary PowerTracker. This project, completed in late 2004, validated the possibility of building and financing utility-scale tracker projects.

The PowerTracker is widely considered to be the precursor to all large-scale single-axis tracker products. In its latest revision, the PowerTracker is called the T0 tracker (for tilt zero tracker) by SunPower, which purchased PowerLight in 2006. According to Christiana Rattazzi, marketing manager for utility and power plants at SunPower, the T0 is currently the most widely deployed single-axis PV tracker system in the world. Subsequent efforts to improve on the performance of the T0 single-axis tracker resulted in a tilted single-axis tracker system with a 20° tilt angle, the SunPower T20.

The message became quite clear to project developers: Gleaning maximum energy and thus maximum revenue from utility-scale power plants was most feasible with solar trackers. The German FIT kick-started the global solar industry and, in turn, the PV tracker industry. Installed solar capacity doubled annually between 2003 and 2008. FIT policy structures were approved in Spain, South Korea, Greece, Australia and Italy in the following years. Within 6 years of Bavaria Solar One's completion, there were over 100 manufacturers selling trackers to the global market. The success of PV trackers was so overwhelming that Paula Mints, principal PV analyst at Navigant Consulting, is widely quoted as having predicted that between 2009 and 2012 tracking systems would be used in at least 80% of PV installations above 1 MW. CONTINUED ON PAGE 34


Nature provides us with the gift of energy through the sun, but unfortunately, nature's wrath may not be all that friendly to your PV system under stressful conditions. Snow, wind, extreme heat or cold, and seismic activities can wreak havoc on underengineered, underdesigned and insufficiently tested racking structures. Only UNIRAC solar structures have been engineered and third-party tested to withstand the harshest of elements and events for a long and enduring service life. Complies with IBC, IRC, ASCE-7-05, ADM, AISI, AISC, NEC and UL. For the highest level of engineering and construction with the lowest cost of ownership in the business, Unirac is the 24/365 solution for performance in and out of the sun. Visit unirac.com for more information.
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Courtesy Amonix

Direct-point tracker The concentrated PV technology from Amonix uses acrylic Fresnel lenses to concentrate direct sunlight up to 500 times its usual intensity onto high-efficiency multijunction solar cells. Each proprietary tracker carries the equivalent of 53 kWac and uses highly accurate dual-axis tracking to follow the sun's position within 1°.

Tracker Types

In general, trackers can be broken down according to motive method (passive or active) and the number of axes in which they move (single or dual). *Active trackers* use motors to move their solar generating source from horizon to horizon. *Passive trackers* employ the heating and cooling of refrigerant-like liquid/gas elements and reflective mirrors to tilt the tracking array towards the sun. Passive trackers are less accurate than active trackers. However, accuracy is less important for flat-plate PV arrays, which generate power with global horizontal irradiance, the sum of both direct normal irradiance and diffuse horizontal irradiance, than it is for concentrated or concentrating solar technologies.

The next delineation between tracker types is the number of axes in which they move. *Single-axis trackers* follow the sun using one axis of rotation; *dual-axis trackers* follow the sun in two axes.

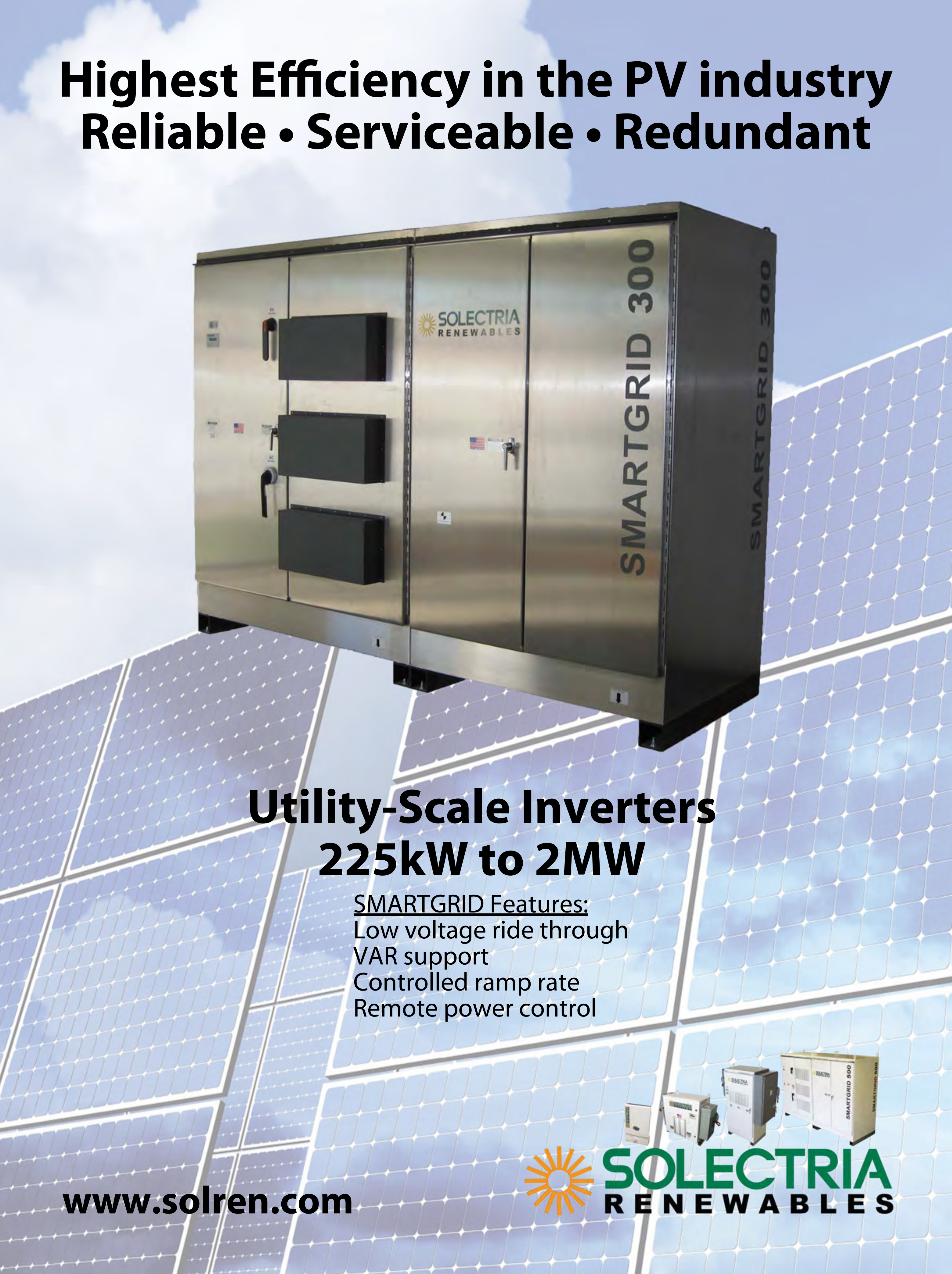
SINGLE-AXIS TRACKERS

PV trackers designed with a single axis of rotation account for the most installed capacity globally. In the US, SunPower has built several large PV systems using single-axis trackers, including 25 MW of T0 trackers at the DeSoto Energy Center, 15 MW of T20 trackers at Nellis Air Force Base in Nevada and 19 MW of T20 trackers at the recently commissioned Greater Sandhill Solar Farm in Mosca, Colorado. Other notable single-axis tracker manufacturers are Array Technologies, First Solar (RayTracker), Patriot Solar Group, SunCarrier (a division of a+f GmbH), and Thompson Technology Industries (TTI).

The three main single-axis tracker subcategories—horizontal, vertical and tilted—are differentiated by the relationship of the axis of rotation relative to the ground.

Horizontal single-axis tracker. This is the most common single-axis tracker design. As the name suggests, a horizontal tracker rotates east-to-west on an axis parallel to the ground. This type of tracker is typically characterized by a small drive motor connected to a long central drive arm running east-west between rows of panels mounted on steel tubes. The drive member connects to the panel tubes via welded or bolted connections. As the drive member is pushed or pulled via an assortment of mechanisms, it slowly moves its panels from east to west throughout the day. Planarity keeps all array panels pointing uniformly and maintains a geometry that reduces motor maintenance over time. By maintaining the planarity of an entire horizontal tracker array, designers can ensure equalized loading on the tracker's motor. Because horizontal trackers can be packed closely together without excessive self-shading, they can achieve relatively high power densities per acre. Typical horizontal single-axis tracker systems in North America include the DuraTrack HZ from Array Technologies, the T0 from SunPower and the SunSeeker from TTI.

Vertical single-axis tracker. These trackers rotate east to west with an axis perpendicular to the ground. Because their profile is not parallel to the ground, vertical trackers have an easier time maintaining a consistent angle of solar incidence when the sun is lower in the sky. This is of particular benefit in northern latitudes, for example, between 40° and 55°. However, unlike planar horizontal arrays, vertical field layouts must accommodate the CONTINUED ON PAGE 36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vertical tracker's taller profile and spread units out to avoid self-shading and unnecessary energy losses. As a result, vertical single-axis trackers tend to have a relatively lower power density per acre. At the residential or small commercial scale, vertical single-axis tracking is typified by solutions like the Wattsun single-axis azimuth trackers from Array Technologies. At the utility scale, SunCarrier's massive vertical single-axis trackers that rotate to follow the sun using a circular rail system are capable of carrying 20 kW to 50 kW of PV per tracker.

Tilted single-axis tracker. In some cases, the axis of rotation for a single-axis tracker is neither horizontal nor vertical, but is optimized at a fixed tilt somewhere in between, such as 20° or 30°. Tilted single-axis trackers have some of the advantages of horizontal designs, such as the ability to be densely packed per land unit. These trackers are also capable of significant energy harvest improvements relative to horizontal trackers. In a subcontract report for NREL (see Resources), Jeff Shingleton notes: "The tilted-axis design of [SunPower's] T20 allows for a 6–7% increase in performance over horizontal-axis trackers, and approaches the performance of dual-axis trackers." However, because the optimal tilt angle in the US is at least 20°, tilted single-axis trackers are subject to increased wind loading compared to horizontal units. Structural requirements are higher as a result, meaning more steel and concrete are used relative to a comparable horizontal array. Since tilted single-axis arrays can be 10 or 15 feet tall at the highest point, designers must consider shading issues, similar to those with vertical single-axis arrays, when doing field layouts. While the SunPower T20 is the primary tilted single-axis tracker used in North American markets, DEGERenergie manufactures 30° tilted single-axis trackers in Europe.

DUAL-AXIS TRACKERS

Tracking both the sun's east-to-west azimuth and elevation off of the horizon maintains a more constant and accurate angle of incidence between the collector aperture and the sun. This results in a higher capacity factor and specific yield compared to fixed-tilt or single-axis tracker mounting, which may be desirable in certain flat-plate PV applications. In other applications, dual-axis tracking is a design requirement. This is the case when the PV technology in question relies exclusively on direct normal irradiance as the fuel source. While low-concentration PV technologies, like those being developed by Solaria, are designed to work with single-axis tracking, concentrated PV designs, like the technology pioneered by Amonix, require a tracking accuracy of within 1° to maintain consistent power output, which only dual axis tracking can provide.

Dual-axis PV tracking started simply enough, with passive tracker designs like those from Zomeworks. Modern designs, like the products from Mecasolar (see cover photo), can support more than 13 kW of flat-plate PV per tracker. The mammoth proprietary dual-axis tracker from Amonix supports a concentrated PV array rated at 53 kWac. Arrays are constructed with galvanized steel and usually mounted on a single central pole supported by a concrete foundation. Dual-axis arrays tend to be taller with increased wind and structural loading. These trackers also need to be spread out to alleviate shading, which decreases the relative power density per acre compared to horizontal single-axis trackers or fixed-tilt mounting.

Financial Considerations

Whether the use of a tracker makes financial sense can be boiled down to a simple question: Is the productivity gain worth the additional cost associated with a tracking system?

Yield versus cost. *Solar Cells and Their Applications, Second Edition* includes a relatively current comparison of fixed-tilt PV mounting to single- or dual-axis tracker mounting for utility-scale applications. The authors of Chapter 9—Ron Corio and Michael Reed of Array Technologies and Lewis Fraas of JX Crystals—consider historical, current and future PV module and system cost scenarios and conclude that single-axis trackers typically improve PV plant performance by 24% over fixed-tilt mounting while incurring a cost increase in the 3%–5% range. For dual-axis trackers, the authors assume yield improvements of 38% but estimate a double-digit cost increase of 12% to 14%.

These conclusions are fairly representative of the conventional wisdom among financiers, developers, and engineering, procurement and construction (EPC) contractors working in the US today. It is generally accepted that paying in the range of $0.15 more per watt to increase system performance by 24% is a compelling argument in favor of single-axis tracking. The dual-axis tracker sales proposition, meanwhile, is greeted more coolly. Stakeholders are generally unwilling to pay $0.45 per watt more in order to extract the additional yield that dual-axis tracker systems offer (14% in this example).

While it may reflect commonly held opinions in the industry, the Corio, Fraas and Reed analysis is of limited value. For example, it unrealistically assumes a uniform total system cost for all three mounting options. In reality, a shift from fixed tilt to single- or double-axis tracking has complex and cascading cost implications. To undertake an accurate cost benefit analysis is equally complex. Many financial variables need to be quantified and compared, including increased costs for land, labor, materials and O&M, as well as the increased value of the energy revenue projections. These revenue projections are in turn impacted by PV technology, inverter selection, mounting system, location, climate and the rate structure of the off-taker, the utility purchasing the power.

Third-party verification. Industry veteran Chris Edgette, director of StrateGen Consulting, stresses CONTINUED ON PAGE 38

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> "Tracking systems are by no means designed and priced equally. Make sure to account for costly and time-consuming practices such as site grading, trenching, concrete pours, on-site welding, hand-screwing and wiring when cost-comparing total systems."
>
> —Amy Holbrook, PV Trackers

the importance of undertaking a comprehensive, independent financial analysis for proposed PV tracker applications. "Project owners spending millions of dollars on these large-scale PV systems would do well to spend $100,000 up front in order to properly perform due diligence on the advantages tracking could have for their project," he says. "In an industry renowned for lofty claims, taking manufacturers' words for granted can kill a project. The industry is maturing, and there are enough unbiased independent resources to provide project owners with worthy input on which to base their decisions."

Levelized cost of energy. The ideal way to roll up all of the relevant financial inputs into an apples-to-apples comparison is to use a levelized cost of energy (LCOE) calculation for each type of array and compare the results. Typical LCOE equations for full project evaluations include the cited variables and the financial aspects of the investment, such as debt versus equity financing, discount rates, depreciation, taxation and subsidies. To compare the LCOE between tracker options, some of the metrics related to the project finance deal can be omitted.

The first thing to calculate and compare is the actual physical area needed. For each product or mounting technology, a different quantity of land is needed to accommodate a given project capacity. Fixed-tilt systems require the least land; single-axis trackers require relatively more land; dual-axis tracker systems typically require the most land.

Capital costs for material and labor are the next consideration. According to Booth at Blue Oak Energy, "Because of the increased space required to avoid self-shading between module rows, there are more expenses in conductors and other materials." Trackers also require more structure per panel and in most cases more significant foundations relative to fixed-tilt systems. Quantifying the difference in labor costs for different mounting solutions is another variable that needs to be addressed in LCOE analyses.

Calculating how O&M costs are affected is another important element of the LCOE calculation. This is complicated by the fact that tracker system designs are so varied. It can be difficult to compare one to the other with confidence. Some systems have hundreds more serviceable parts than others. However, bigger, more monolithic components may present other challenges. Denise Thompson, general manager of TTI, cautions: "When considering a particular model of tracker, pay close attention to the number of drive motors and controllers, and the electrical distribution system required to meet the needs of these components."

Energy production modeling is vitally important when determining the LCOE for a specific set of design assumptions.

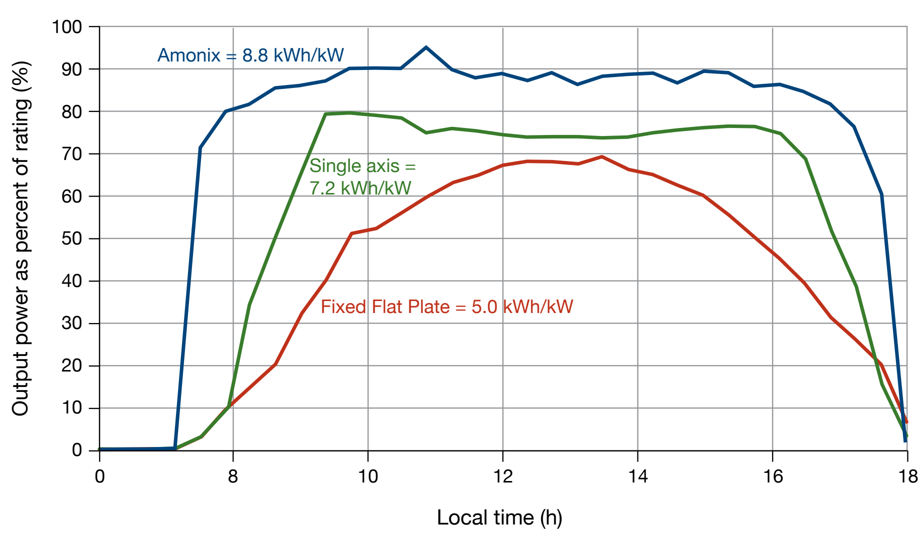

Figure 1 The power curve for any PV array mounted on a tracker is broader than that for a fixed array, and thus is deemed to add better shoulders to the curve. This figure shows the relative power curves for flat-plate PV mounted at a fixed tilt, flat-plate PV mounted on single-axis trackers and Amonix concentrated PV mounted on dual-axis trackers.

(See "Production Modeling for Grid-Tied PV Systems," April/May, 2010, *SolarPro* magazine.) It is essential to take the site's climate into account, as well as other regional sensitivities like the availability of time-of-use metering. Amy Holbrook, marketing manager at PV Trackers, recommends that solar professionals take the time to study the cost benefits of tracking systems: "When customers are interested only in up-front cost, we know they have not researched the financial benefits of tracking. In addition, it is critical to compare total-system costs. Tracking systems are by no means designed and priced equally."

Bankability. Concurrent with the LCOE analysis, when specifying a tracker the probability of financing a project must be considered. The term *bankability* is used in the industry by project financiers and others to describe a project's or product's ability to be financed. A bankable tracking system is one that has passed the financier's due diligence process and is considered a viable long-term investment. The bankability of a tracker system is also a function of the EPC contractor installing it. Tyroan Hardy, vice president of customer applications at Solaria, notes: "Securing competitive bids with viable EPC contractors is a concrete means of balancing cost with performance during the construction of a tracking project."

Many consider First Solar's recent acquisition of RayTracker as a validation of PV trackers in general. RayTracker is a manufacturer of horizontal single-axis trackers that feature an architecture of distributed actuation, using many small actuators in place of a single large motor. While RayTracker has deployed its products on less than 5 MW of PV globally, First Solar has a proven track record for simplifying BOS concepts and driving down the costs of its offerings. Adding trackers to that suite of offerings is a significant statement about the bankability of trackers.

To find bankable solutions, developers specifying trackers with new projects can start by reviewing installations where trackers are already deployed. According to Eben Russell, director of utility sales for Array Technologies, "As more and more projects make it through the due diligence process, get built, and start establishing an operating history, the easier it is becoming to get new projects approved." Array Technologies, Conergy, Solon and SunPower, for example, all have large-scale, single-axis tracking systems installed and operating in the US. In Europe, there are at least 20 brands of utility-scale single- and dual-axis trackers installed, including ADES, DEGEREnergie, Mecasolar, OPEL Solar and SunCarrier.

Production modeling. The best way to consider the energy production benefits of tracking for a proposed site is to use typical meteorological year (TMY) data and model system production with software products like PVSyst, PV*SOL or SAM. For example, PVSyst can provide a quick apples-to-apples comparison between the simulated performances for a 1 MWdc

Payment Allocation Factor	
Period 1:	2.2049
Period 2:	1.12237
Period 3:	0.68988
Period 4:	1.05783
Period 5:	0.93477
Period 6:	0.76384
Period 7:	1.14588
Period 8:	0.84634
Period 9:	0.64235

Weekday Schedule	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
Jan	6	6	6	6	6	6	5	5	5	5	5	5	4	4	4	4	4	4	4	4	5	5	6	6
Feb	6	6	6	6	6	6	5	5	5	5	5	5	4	4	4	4	4	4	4	4	5	5	6	6
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Nov	6	6	6	6	6	6	5	5	5	5	5	5	4	4	4	4	4	4	4	4	5	5	6	6
Dec	6	6	6	6	6	6	5	5	5	5	5	5	4	4	4	4	4	4	4	4	5	5	6	6

Figure 2 PG&E, a public utility serving parts of northern and southern California, compensates wholesale electric generators at different rates at different times of the day and week. As illustrated in PG&E's weekday schedule, the multiplier or payment allocation factor is highest for summer afternoons. Designs with PV trackers take better advantage of these premium rates.

dual-axis tracking polycrystalline PV system in Los Angeles or in Miami. The results, which consider the relative latitude and weather, show that on average the Los Angeles site would harvest 8% more energy annually, smog factors included. The software can also model the increased production for single- or dual-axis tracking for a given site versus fixed-tilt racking.

While production models are needed to evaluate any proposed tracker project, there are some general rules that apply. For example, the benefits of horizontal single-axis tracking increase the closer the site is to the equator. While this geometry is still very effective at 35° north latitude, its benefits taper off for sites farther north, even for tilted single-axis trackers. According to Booth at Blue Oak Energy, "The increased effects of single-axis tracking are marginal for sites located above 45° degrees latitude." As a result, dual-axis tracking may be a better approach for northern sites. The benefits of tracking are most apparent in regions with high, direct normal irradiance. When both of these factors are considered, it becomes clear why regions like the Southwest—which is located at the southern extreme of the mid-latitudes and experiences a lot of direct sun—are generally considered ideal for PV tracker applications.

Of course, anyone in the solar industry realizes that there is not a direct correlation between regions with the best solar resource and regions with the best solar markets. Utility rates or rate structures are also relevant, as illustrated by the successful FIT programs in Germany and Ontario, Canada—regions not known for an abundance of direct sunlight.

Rate structure. It is easier to make the case for a tracking system's additional capital expenditure in regions where the utility pays time-of-use rates for the power generated by a PV plant and sold to the grid. Because utilities are starving for energy generation capacity at certain times of the day and year—namely, hot summer afternoons—they pay wholesale generators a higher multiple CONTINUED ON PAGE 42

Courtesy Blue Oak Energy

Scheduled maintenance The motors, drives and actuators used in PV tracker designs are generally robust, reliable and simple. The key to controlling O&M costs is adhering to the manufacturer-recommended preventative maintenance activities and service intervals.

of the base contract rate in the power purchase agreement (PPA) for the energy they provide during these critical times. Since tracking arrays face the sun continuously throughout the day, they generate more power and harvest more energy when the grid needs it most.

The added energy that PV trackers can harvest is illustrated in Figure 1 (p. 38), which shows relative power curves representative of fixed-tilt mounting, single-axis tracking and dual-axis tracking. Now match the afternoon shoulder in Figure 1 to the afternoon rate schedule in Figure 2 (p. 40). This weekday time-of-use chart for the Pacific Gas and Electric Company (PG&E) conveys visually how a time-of-use compensation schedule may allow for the majority of the annual financial revenue from a tracked PV system to be generated during summer afternoons.

Relative power density. When comparing different PV technologies, relative power density is synonymous with conversion efficiency. When comparing mounting options, however, peak capacity per acre is also a function of acceptable field layout, which must account for self-shading between rows. According to Michael Reed, residential sales manager for Array Technologies: “Improper spacing of trackers is a common mistake that can be avoided simply by performing a shading analysis.”

The ratio of land to solar aperture for a PV plant is described by the term *ground coverage ratio* (GCR). The higher the GCR, the higher the peak generating capacity that can be installed per unit of land. GCR for an array that is mounted horizontally and monolithically is 1.0, meaning 100% of the available area is covered with PV. Other mounting options require spacing in order to avoid unacceptable energy harvest losses due to self-shading from row to row or tracker to tracker.

> “Keeping an inventory of spare parts also plays a key role in reducing tracker downtime. Understanding which components are most likely to fail and which have long logistical lead times helps prioritize which parts and how many to keep on hand, without holding the liability of a large inventory.”
>
> —Adam Burstein, Next Phase Solar

Trackers invariably have a lower GCR than fixed-tilt mounts, and the GCR for double-axis tracking is lower than for single axis. According to metrics published by SunPower in several white papers, a typical dual-axis tracking system might need a GCR of 0.20 to reduce power loss due to self-shading to 2% or less. By comparison, a single-axis tracking system might be installed with a GCR of 0.35, while a 0.55 ratio might be possible with a 20° degree fixed-tilt array.

Operations and maintenance. The increased costs resulting from the presence of moving parts is almost always the poisoned arrow in the quiver of PV tracker naysayers. Their logic is that if it moves, it breaks. Why pay more for something that breaks more often?

Understanding the interrelated elements of any solar plant’s O&M program is a great way to assess the maintenance needs for PV trackers relative to a stationary array. The two cost elements of any PV project’s O&M program are preventive (scheduled) maintenance and variable (unscheduled) maintenance. For trackers, the preventative elements are critical.

According to Adam Burstein, president of Next Phase Solar, a company that provides PV O&M services, being proactive is the key to managing an investment in PV trackers. “There are several important practices for maintaining high tracker availability,” he says. “The first is a strong preventive maintenance program, in which field personnel visually inspect the tracker mechanism periodically and perform mechanical and electrical maintenance on the controller, actuator and so forth. The ability to detect field issues before they result in an emergency outage is the best approach to reducing downtime and operational costs.”

A strong preventative maintenance plan has ripple effects for a project’s viability beyond the obvious. Project financiers engaging with an owner in a PPA contract want to know how their investment is going to be managed after the wine and cheese gathering for dignitaries celebrating system startup. A preventative maintenance plan presented by a viable and experienced O&M services provider can improve the project’s chance of getting funded.

The utility on the hook for buying the power is also concerned. Russell at Array Technologies welcomes scrutiny from utilities. “As PV projects become larger, they are having a greater impact on the grid,” says Russell. “Utilities are beginning to require that the power from PV plants be generated more consistently throughout the day, which makes trackers a necessity.”

System monitoring can also be used to facilitate O&M activities and ensure system uptime. Holbrook at PV Trackers acknowledges that the main challenge to the general acceptance of tracker systems is a fear of moving parts. “We have addressed this issue at our company by developing a customer web portal and tracker CONTINUED ON PAGE 44

monitoring service," she says. "Each of our sites has wireless Internet connectivity and web cameras that allow the trackers to be visually and mechanically monitored at all times." If something breaks, the monitoring system makes sure the plant operator is immediately notified.

Rounded cost estimates for O&M costs are extremely variable. Sources for O&M estimates include utility program information, Wall Street market analysis, EPC contractors and O&M companies. O&M costs depend greatly on who is performing the work (whether prevailing wages are applicable), the location of the project (O&M in India is going to be more affordable than O&M in California or New York) and the number of serviceable components for a project. Roll it all up and a safe estimate for annual onsite O&M costs is in the $12/kWp to $25/kWp range.

Since relatively few of the very large systems currently in development are on the ground and running, gauging the validity of O&M numbers is difficult. As a result, the market has generally approached this problem conservatively. Nearly all of the subject matter experts interviewed for this article commented that O&M cost assumptions are too high. According to Thompson at TTI, "The biggest myth around trackers is that O&M costs are significantly higher than fixed systems."

In reality, as pointed out by Ron Corio and his coauthors in *Solar Cells and Their Applications, Second Edition*, electric motors are commonplace and reliable; there is an existing O&M infrastructure for them; and PV tracker applications have a low duty cycle. "Note that solar trackers only turn one revolution per day. This equates to 7,300 revolutions in 20 years. By analogy, with a simple wristwatch, this equates to the number of revolutions the second hand on a watch will make in 5 days."

Specification and Deployment

Typically, integrators look to a third-party manufacturer to provide trackers for their projects. The search to match an ideal tracker to a project is not an easy one. A conservative assessment is that there are more than 20 solar tracker manufacturers active in North American markets. Many of these companies offer multiple tracker products and product lines. A few of the notable flat-plate solar integrators, like Solon and SunPower, have proprietary trackers in their quiver of products. Similarly, almost every concentrated PV or high-concentration PV manufacturer has a high-performance tracker of its own design. CONTINUED ON PAGE 46

"The larger the project, the flatter the site, the better the soil is for setting posts, and the closer the site is to the equator, the more the tracking will positively impact PV plant ROI. With that said, we have shipped trackers to Canada for installations on sites with solid bedrock, and the ROI gain over fixed-tilt still made sense."
—Eben Russell, Array Technologies

Making an informed decision may first require filtering out the hype. Marketing messages from tracker manufacturers focus on the hook—an exponential increase in kilowatt-hours—while leaving out the fine print about the constraints under which this increase is possible. As the tracker market has expanded rapidly over the last decade, innovative product-design revisions have successfully loosened many of the constraints that historically held back the market

Even after all of these proprietary solutions are filtered out, this still leaves a long list of tracker solutions and suppliers for system developers, financiers, designers and integrators to choose from.

acceptance of trackers. Products have been revised with an eye to making installations easier, faster and less expensive. Manufacturers have accomplished this in part by adding value, such as factory preassembly, CONTINUED ON PAGE 48

Avoiding Common Mistakes

No one knows the potential pitfalls of PV trackers like the product manufacturers and their applications engineers. Here is a summary of common mistakes that these experts caution against.

Going it alone. Thorough communication with product manufacturers and engineers is critical to success. According to Raúl Sanz, CEO at Mecasolar US, very few professional developers and engineering services companies have done the research necessary to truly understand the tracker world. "Matching PV system design requirements with the tracker design, setting layouts and understanding O&M implications requires active communication with your technological partner," he says.

Tom Herron, systems engineering manager at PV Trackers, points out that manufacturers are continuously working to improve the installation experience for their customers. "We can help integrators organize their installations into work packages that allow projects to move forward as smoothly as possible," he says. "For example, we have a system for how to mark the locations of our trackers in the field that minimizes the surveyor's time. When this system does not get communicated to the surveyor, it creates extra work. We also have other recommendations relating to trenching and the order of different operations."


Courtesy Array Technologies

Alignment Ganged tracker designs like this DuraTrack HZ from Array Technologies require careful alignment of foundation posts. A single motor can drive 350–650 kWp.

Foundation misalignment. The key to avoiding a host of near and long-term problems is to set foundations correctly, according to Eben Russell, director of utility sales for Array Technologies. He notes: "With the posts set correctly, constructing the rest of the tracking system is no more difficult than an 8th grade shop project. How can post installation mistakes be avoided? Use an experienced geotech and foundation engineering firm before you begin so that you have a clear understanding of what challenges may lie beneath; set target plates accurately; measure twice, set once; and work methodically with the correct equipment for the job."

Array shading. Performing a shade analysis and working with the manufacturer on plant layout should ensure that losses due to self-shading are within the project design tolerance. The goal is to optimize both energy harvest and land use for best return on investment. Because trackers are typically ground mounted, potential shading from other obstructions, like adjacent buildings or distant topography, needs to be taken into account. Wendy Beach, communications manager at Array Technologies, warns: "Avoid locating trackers in areas that will be shaded within a short time from growing trees or land development." ●

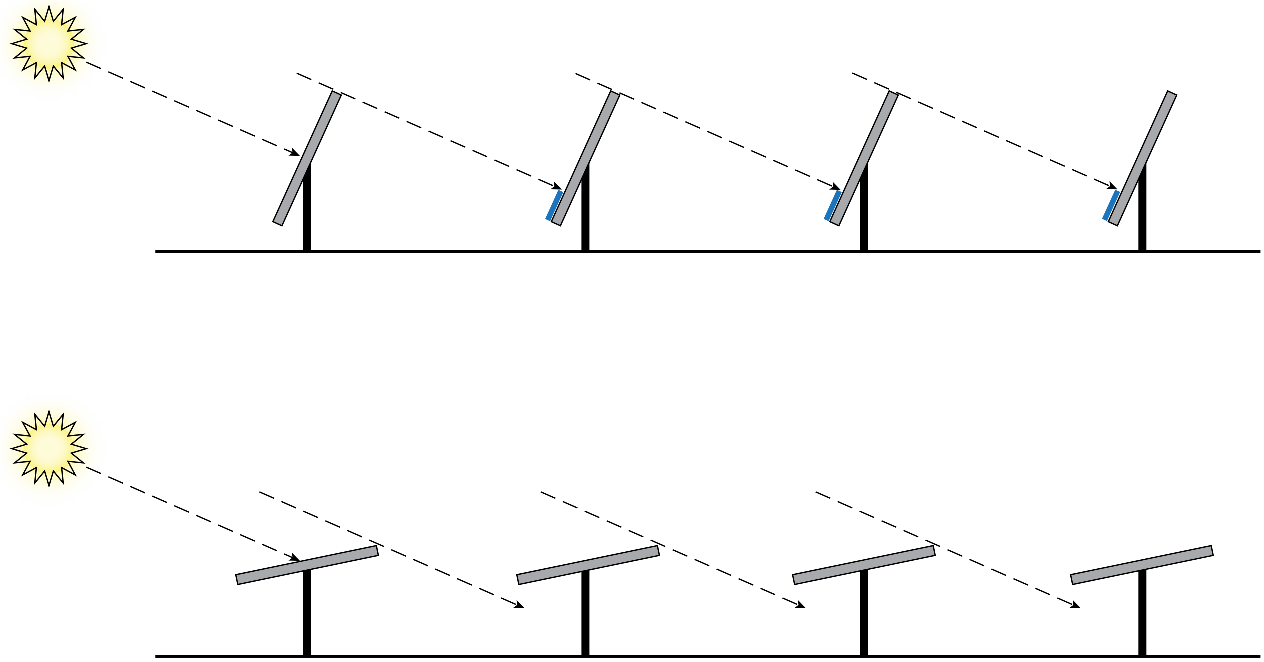
to the overall system integration wherever possible. Regardless, tracker systems still require a relatively aligned set of variables in order to deliver on their promised performance.

Site evaluation. When asked about the ideal set of circumstances for PV tracker deployment, the subject matter experts interviewed for this article most commonly pointed to ground-mounted applications. According to PV Tracker's Holbrook, "Tracking is always a better solution than fixed-tilt systems for ground-mount applications; however, different styles of trackers are appropriate for different purposes." Clearly, some tracts of land are better suited for tracker mounting systems than others. In general, trackers are often deployed on large tracts of land that are flat and relatively inexpensive. Obviously, soil conditions also matter. While PV trackers can be installed on ballasted foundations, they are typically installed using driven-steel piles or ground screws. Therefore, soil conditions that accommodate these foundation types are ideal.

In practice, site boundaries, topology or soil type generally present design challenges. According to Booth at Blue Oak Energy, it is important to pay careful attention to the financial implications of different technical approaches to these problems. "One of the primary challenges in dealing with trackers over topographical features is to know when to grade versus when to increase the vertical column height and potentially the footing," says Booth. "There is a delicate economic balance to achieve when laying out a tracking system on any given property."

The variety of tracking manufacturers, designs and solutions means that solar tracker applications are not limited to large, flat parcels of land. According to Tom Herron, systems engineering manager at PV Trackers, the availability of technical solutions for suboptimal terrain is often overlooked. "Dual-axis trackers are often easier to install in rolling or mildly sloped landscapes than are single-axis trackers that require straight, level support placement," he says. While larger turret-style dual-axis trackers may accommodate installation on sloped topography, it is not always possible to cost-effectively deliver and pour 10 cubic yards of concrete per foundation on a sloped site. Alternatively, smaller dual-axis designs from PV Trackers that use helical pier foundations could be considered.

Another variable to consider when evaluating a potential tracker site is whether it offers unobstructed views of the horizon. In order to harvest additional energy in the morning or evening, the east and west horizon need to be visible from the array field. (See "Avoiding Common Mistakes" p. 46.) CONTINUED ON PAGE 50



Backtracking When the sun's elevation angle is low in the sky, early or late in the day, self-shading between tracker rows has the potential to dramatically reduce system output. Backtracking rotates the array aperture away from the sun, eliminating deleterious effects of self-shading and maximizing ground cover ratio.

Field layout. Single-axis tracker groupings, typically called *blocks,* consist of the central motor arm that actuates the drive member, the linkages to each row of steel tubes, the modules supported on these tubes and the BOS components required to deliver power from the block to the inverter. The quantity and length of rows per tracker motor is a function of the module type, module size, wind speeds and soil conditions for a particular site. The product manufacturer's systems engineers can characterize a relatively standard block for their tracker design. Once they receive site-specific wind and soil information, they can validate the block design and tweak it if needed. An optimal site allows for the size and shape of the tracker block to be consistent across the PV power plant. Typical tracker blocks of this type tend to be about 250 feet long north to south and 350 to 400 feet wide east to west. Thus, a site that is rectangular or square allows for the maximization of steel rows per motor unit.

While single-axis trackers can be installed on sites with aberrant geometry relative to the product architecture, there will be a corresponding increase in capital expenditure due to the need for more tracker motors. If a well-shaped site results in a standard block of 250 kWp per tracker motor and a poorly shaped site results in 100 kWp per tracker motor, the designer is paying for motor capacity they are not utilizing and creating more failure points and critical maintenance points. The centralized nature of the motor is generally one of most desired attributes of single-axis tracking. However, this also means that most single-axis trackers have a *ganged* or interconnected architecture, which can also be a constraint.

Tracker blocks designed using the Duratrack HZ from Array Technologies or the SunPower T0 CONTINUED ON PAGE 52

DEGERconecter The tracker controller used by DEGERenergie operates according to a principal of maximum light detection, which ensures that each tracker is directed at the brightest point in the sky at all times.

Courtesy PV Trackers

Design flexibility Design flexibility with trackers may be limited. While these dual-axis devices from PV Trackers were able to accommodate this ungraded, sloped site, they also use a relatively expensive central controller, which is not well suited to projects with less than 20 trackers.

typically have to be installed on a site with a slope of 5° or less. This is due to the geometry involved in turning the array rows and the interconnectivity between the steel structures that make up the tracker blocks. The distributed actuation architecture touted by First Solar's RayTracker is a design response to this shortcoming. Because each individual row has its own actuator, RayTracker can be installed on a site with a greater slope than other horizontal single-axis trackers.

Distributed tracker actuation may also use distributed control systems. Frank Middleton, the vice president and COO of OPEL Solar, believes this is a natural evolution because it minimizes the size and impact of a single point of failure. He notes: "There is a school of thought regarding tracking systems that 'bigger is better.' It assumes, for example, that trackers with common control are more dependable than trackers with distributed control. If one looks at the trend in almost all other industries, it has been in the opposite direction. Computers are a good example, pushing intelligence away from the core onto the nodes."

Control systems. Tracker controllers generally fall into two categories: astronomical or light sensing. Astronomical tracking uses computers or programmable logic controllers and astronomical data. It is capable of very precise backtracking, which is a technique used to maximize GCR while minimizing self shading. Light-sensing controllers, however, track in the direction that the light sensors indicate will produce the most power at any given moment in time. This allows the tracker to utilize incidental light from snow, scattered clouds or overcast skies.

"Tracker capacity is limited by area and not power. So the cost per watt for the tracker is higher for low-efficiency modules than it is for high-efficiency ones. As a result, the lowest-cost panel does not typically produce the lowest-cost system."
—Tom Herron, PV Trackers

Electrical considerations. Different trackers lend themselves to different inverter architectures. For example, single-axis tracker blocks are generally grouped together to form an inverter block, the size of which is based on the inverter capacity. The inverter is typically located somewhere in the middle of this group of tracker blocks. This minimizes variation in the length of the dc feeder conductors from the field-mounted combiner boxes. Therefore, large central inverters tend to be preferred for large-scale, horizontal single-axis tracker arrays.

Since dual-axis and tilted single-axis arrays are more dispersed, there is more opportunity to optimize designs around alternative inverter architectures. PV systems designed with dual-axis trackers may invert dc to ac at each tracker, thus minimizing the dc wire run from the array to the inverter and minimizing voltage drop. Because individual subarrays each track the sun independently, a data reporting system is needed that monitors each subarray in order to accurately analyze system perfomance.

Limitations of use. With the right set of circumstances, the benefits of tracking are not only compelling, but they may also prove essential to project viability. However, even tracker manufacturers admit that there are limitations to their successful deployment. For example, expensive, small or irregularly shaped parcels of land may not be appropriate for PV trackers. Trackers may also not be appropriate for undulating terrain or land that cannot be graded. While some manufacturers have tracker products available specifically for roof- or carport-mounted applications, most trackers are designed exclusively for ground mounting.

> "In the same way that the price of PV panels continues to drop, design improvements in the tracker space have resulted in more cost-competitive products."
> —Frank Middleton, OPEL Solar

Extreme weather or climate may also effectively limit the applicability of trackers for certain sites. While design wind speed ratings vary by manufacturer, product and geometry, it is generally advisable to avoid specifying trackers in areas with high winds, especially hurricane zones. Both single- and dual-axis trackers have an emergency mode that stows modules at a horizontal plane to the ground when an on-site weather station logs wind speeds that could damage the system. Trackers may also not be appropriate in locations that commonly experience very high snowfall, although the fact that the array aperture rotates can help shed snow and avoid persistent shading of the cells.

Systems located close to salt water may need to be weatherized beyond the norm. Steel parts may require additional galvanization; welds may need special treatment; gears and exposed joints may require protective boots. Very hot and very cold climates may also require special consideration. Product specification may mitigate these limitations, since some manufacturers do offer extreme weather packages for their products. Even if the application engineering for a product accounts for these environmental concerns, the site's preventative maintenance program should also incorporate appropriate responses.

Keeping On Track

The future of tracker systems depends on whom you ask. StrateGen's Edgette sees trackers playing less of a role in the future. "The continual fall of PV module prices will mean less utilization of trackers," he says. "For areas with the right soil and snow load metrics, cheap PV means modules can be installed flat, or near to flat, maximizing kilowatts per acre and minimizing structure and engineering costs." Edgette predicts that over the next 20 years trackers will slowly disappear from the PV landscape, starting with dual-axis devices then followed by single-axis designs.

PV tracker manufacturers are more confident, pointing to the fact that innovation and economies of scale continue to drive down the costs. Raúl Sanz, CEO at Mecasolar US, does not dispute the fact that module prices have a direct impact on tracker viability, but he believes trackers can remain competitive regardless. Sanz states: "Our R&D department is engaged in a continuous process of redesigning products to reduce cost. If we add to this the fact that the modules are becoming more and more efficient and that energy policies tend to reward systems that are most effective at generating energy, then we find that there is a point of equilibrium at which using trackers is definitely the best option."

The good news for manufacturers of PV trackers is that the general trend toward larger and more efficient PV modules definitely helps their cause. Since the price per watt for trackers is based on tracker area, as PV technologies become more efficient, the price per watt for trackers goes down. However, the price of PV has also fallen so much that trackers have become a larger percentage of total system costs. This underscores the importance of a concerted effort to optimize total system cost and performance by streamlining planning, construction and installation.

It is worth noting that this effort is clearly well under way. For example, Suntech Power has launched its Reliathon platform, which was designed using a whole-system approach. The system features 270 W modules that self-align when mounted on the tracker. In addition to providing integrated wire management, Reliathon eliminates module frame grounding with a special frame-to-frame connection. With a similar end in mind, SunPower has developed the Oasis power plant, which is optimized around 1.5 MW power blocks. The Oasis system includes every part needed to deploy and operate these power blocks and is scalable to 500 MW.

Though every part of a PV power plant invariably has to stand before the cost-cutting guillotine and justify its value, few components have the potential to increase plant production like PV trackers. If the race to grid parity is a sprint and not a marathon, solar will clearly need its fastest horse to win.

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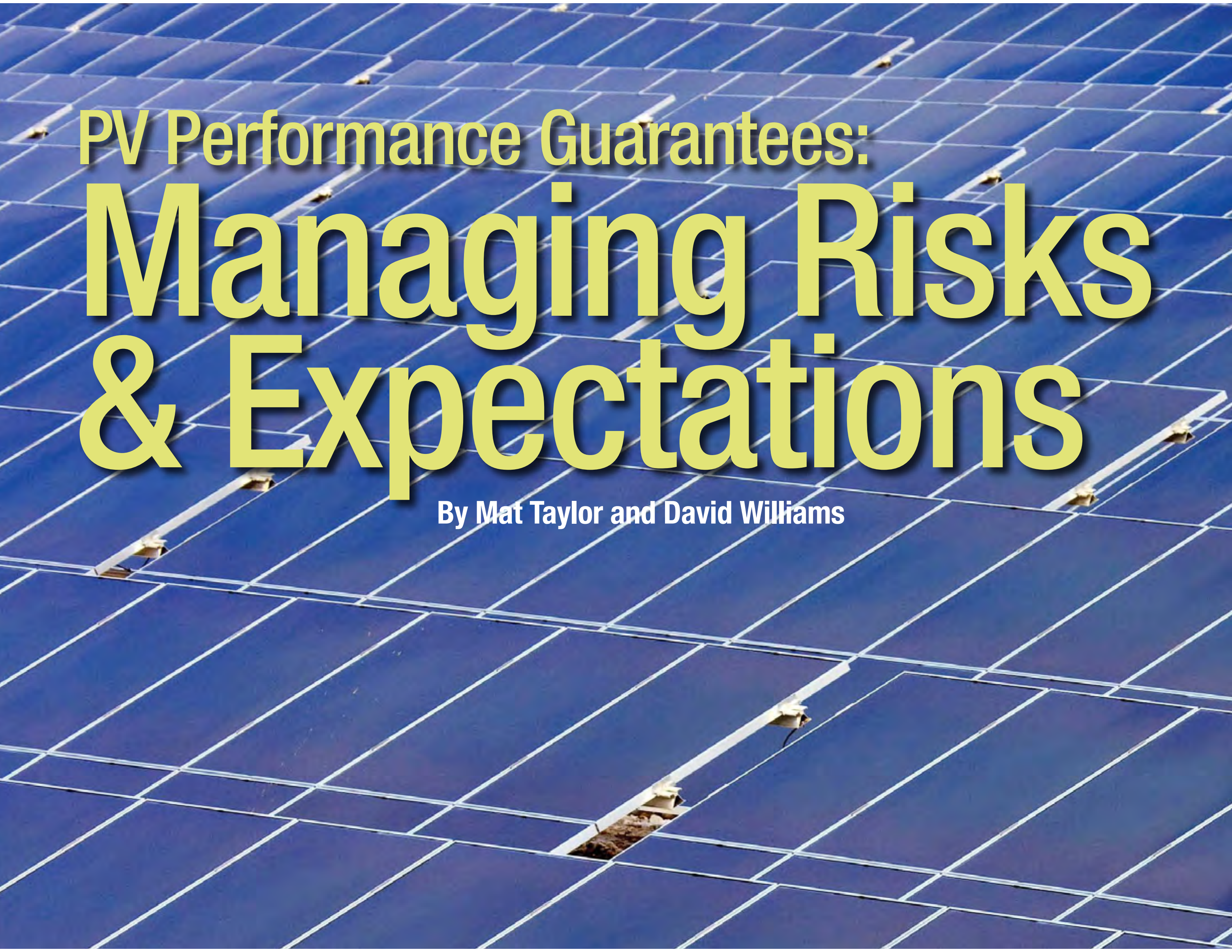
PV Performance Guarantees: Managing Risks & Expectations

By Mat Taylor and David Williams



PART ONE

CREATING A PERFORMANCE GUARANTEE

Performance guarantees are widely used in the commercial solar industry, yet they are frequently misunderstood. Their purpose, however, is no mystery. To finance and construct a large-scale solar project, there has to be a risk-mitigating mechanism in place to reassure investors, which include large banks and institutional investors. A PV performance guarantee contract is the tool used to give the at-risk owner confidence that the system and investment will perform as expected.

The starting point of the agreement is determining the appropriate contract terms and conditions. There are many competing ideas about what constitutes a good PV performance guarantee, and the debate is often heated. A complex team is required to deliver a large-scale solar project (see sidebar, p. 57). Each involved party—owner, developer, contractor, sponsor and financier—has a distinct point of view. Creating a successful PV performance guarantee is both a multidisciplinary exercise and a balancing act. It requires both a technical and holistic understanding of the factors that affect PV system performance and reliability. It requires financial vision. It requires complex contracts. Given thoughtful and thorough understanding on the part of all stakeholders, a PV performance guarantee can help make a good project happen and keep it operating properly for the life of the system.

In our current positions, working in project development and construction, we represent two of the protagonists in the PV performance guarantee debate: the project developer and the engineering, procurement and construction (EPC) contractor. We attempt to represent other points of view in this article as well. Together we provide some background and context for understanding this complex topic. We define essential concepts and consider their practical implementation. We describe the current market expectations of the main parties at the negotiating table and examine the obvious tension between the investors' wishes and the EPC contractor's abilities in some detail.

Courtesy Andy Snow

While we provide some concrete examples of what might be considered best practices for PV performance guarantees, our intent is not to define a one-size-fits-all solution—which would not be realistic—but rather to elevate the general level of discussion and understanding across the industry.

Why Performance Guarantees? Why Now?

In the construction industry, there are availability guarantees, operations and maintenance (O&M) contracts and product warranties in abundance. However, PV performance guarantees are somewhat unprecedented. What is unique about PV performance guarantee structures is that they percolate a contractor's responsibility through a long-term financial arrangement. They do so because PV systems must predictably perform for many years in order to meet the financial expectations for the project.

Protagonists in the PV Performance Guarantee Debate

The following parties are typically involved in the deployment of large-scale solar projects using PV performance guarantee contracts.

Owner: The owner, or purchaser, is the party who eventually runs, operates and derives revenue from the project. Because revenue is used to service debt, pay investors and so on, the clearest definition of *owner* is the person or people who coordinate and run the project from start to finish.

Developer: The developer, who may also be an investor, helps make the project happen by coordinating commercial and construction contracts. The key distinction between the owner and the developer is the latter's direct tie to project design and construction.

Contractor: The engineering, procurement and construction contractor designs and constructs the project and is the main holder of project risk with respect to the performance guarantee. In most cases, the EPC contractor is the *guarantor* in contract language.

Sponsor: The sponsor is either the developer or the EPC contractor. The sponsor's role is to negotiate and enforce the performance guarantee.

Financier: The financier provides most of the money for the project and the framework for the PV performance guarantee contract. Typically, the financier builds the language of the guarantee to help ensure a cash flow throughout the project life cycle. This role can loosely be defined as the project debt and equity provider. ●

There is significant competition between project developers in search of investment partners. This means that developers seek to prepare a project with the strongest level of guaranteed revenue in order to increase the likelihood of selling the project to debt and equity investment companies. To achieve this, developers tend to ask EPC contractors for comprehensive guarantees. A strong performance guarantee can centralize the responsibility for meeting many of the perceived challenges associated with a big project and make the whole project more attractive to investors. Large-scale solar is big business, and performance guarantees are big business by association. Almost all large-scale PV projects have performance guarantee contracts.

From the developer's point of view, it is easier to ask the contractor for a strong guarantee than to convince equity or debt partners that a comprehensive guarantee is unnecessary.

From the developer's point of view, it is easier to ask the contractor for a strong guarantee than to convince equity or debt partners that a comprehensive guarantee is unnecessary.

After all, the core business of the investor or owner of a large-scale PV system is rarely the generation of solar power. Therefore, the EPC contractor is asked to address the performance risk to help ensure that the system is operational for the long term. At the core of any successful guarantee is the idea that the project must be successful for its lifetime. It may sound simple, but very few construction projects have as much at stake. One of the keys to a successful guarantee is balancing the level of coverage with the cost of coverage.

Level of coverage. It is difficult to generalize about the level of coverage that is sufficient for debt and equity providers. Each unique deal requires an individual analysis. However, investors are generally hesitant to pursue projects that are perceived as risky. The challenge is to provide sufficient risk mitigation while still finding room for all of the stakeholders to make money.

Wrapping the necessary risks while providing a reasonable profit is harder than it sounds. The recent economic slowdown has substantially increased competition for large-scale solar development projects. The combination of investors' growing risk aversion and strong competition for PV projects is shifting the market to where investors insist on very robust guarantees. EPC providers are often left with the dilemma of either offering a strong performance guarantee or simply not doing the job.

Cost of coverage. The true cost of creating and maintaining a performance guarantee is not always disclosed in the EPC contractor's price for services. There are few risk-analysis tools or industry precedents available, so parties on all sides of the negotiating table are most likely guessing. The costs are sometimes rolled into the overall profit margin associated with the EPC contractor's portion of the project. When this is the case, it may appear from an accounting point of view that there are hidden costs in the project proposal. This can be a problem for the owner because hidden costs can negatively impact the project's ROI.

However, too much coverage can also reduce a project's ROI. In this case, the owner is getting too comprehensive a plan to cover the project's needs. One of the challenges is that big EPC providers are not organized to solve the small-scale and relatively high-frequency problems common to large-scale PV systems. Finally, monitoring, maintenance and reporting are not typically central to the business of an EPC contractor. Forcing EPC contractors to take on these risks can be expensive and may set the project up for financial failure.

The True Cost of Performance Guarantees

Pricing a performance guarantee can be very difficult. The challenge is to understand the risks and consequences of the system failing to perform. While large integrators may be able to contractually limit their liability, they may also be forced by the owner for commercial reasons to help resolve problems. A classic example is when a large integrator sells a project to an independent power producer (IPP) or non-utility generator, a transaction that may happen soon after the system is commissioned. The site host or energy off-taker may later tell the EPC contractor that the system is not CONTINUED ON PAGE 60

Brand recognition One challenge for contractors providing performance guarantees is that even if they are able to limit their exposure contractually, they may ultimately feel obligated to go beyond those minimum requirements to protect their reputation and brand.

Courtesy Cupertino Electric

performing as expected and service provided by the IPP is not fulfilling the customer's expectations. Regardless of whether this claim is valid, the EPC provider may feel obligated to help fix a system that it is no longer contractually responsible for.

Consequently, some EPC contractors offer only a 100% guarantee. They may feel that they cannot effectively limit their liability because their reputation is at stake. For example, if a project is extremely underperforming, the value of any damage to the company's brand may potentially be larger than the cost obligated by the guarantee. Therefore, the contractor provides comprehensive coverage regardless of any contractual obligation. This does not come free. In fact, larger EPC contractors may be forced by their internal structures and accounting methods to provide and charge for these larger guarantees.

RISK ASSESSMENT

The concepts of risk and risk mitigation are fundamental to the structure of PV performance guarantees. Risk is what shapes the language of performance guarantees and determines their inherent obligations. To illustrate the intricacies of performance guarantee negotiations, we provide three perspectives on the risks associated with PV projects—the financier's, the project developer's and the EPC contractor's.

The financier. Photovoltaic projects in the US are unique because they require someone to monetize tax benefits to make the projects work. This requires three distinct types of investment: debt (bank financing), tax equity and sponsor equity. A typical utility-scale PV project is financed using 50% debt, 30% tax equity and 20% sponsor equity, as shown in Chart 1. Note that debt and tax equity represent substantially more of the total capital input. This amount of money reduces the amount required from the equity investors, (those investors with an ownership stake in the project), and increases their returns.

As an example, imagine a project that costs $100 and returns $110. If the project is financed with sponsor equity, the equity investors get $10 on a $100 investment, which is a 10% return. However, the math looks quite different if the equity investors get $80 from the bank, and the bank asks for a $4 return. In this case, the bank gets a 5% return, which may be perfectly acceptable provided it is guaranteed to get its money back first. After the debt is serviced, the equity investors get the remaining $6. However, the equity investors put in only $20 ($100 – $80 from the bank), which means they are getting $6 in return for a $20 investment—a 30% return. In this manner, the equity investors are putting in less money and making a higher internal rate or return. In the US today, it is unlikely that PV project returns will be adequate for project sponsors without placing debt and increasing the equity returns.

Bank financing requires a lower rate of return because this debt is senior to sponsor equity, meaning it gets paid off first, and is therefore less risky. This makes debt prices less. Banks also take a much lower risk position by ensuring that there are cash reserves and high debt service coverage ratios. Especially in the wake of the 2008 financial crisis, banks are hesitant to assume unknown risks. Therefore, the bank must have another entity provide adequate coverage to ensure system performance.

The project developer tends to be a smaller, less established player compared to the bank or the EPC contractor. Therefore, the contractor is the natural performance guarantor for the bank. A large balance sheet and the proven ability to fix problems over a period of 5 or more years are essential. Someone must provide a solid and convincing story about the performance of the system to maximize the amount of debt and increase the equity returns. The strength and the structure are highly deal-dependent. While the bank may not be able to give a specific example of the terms required, it knows a good performance guarantee when presented with one.

The developer. The photovoltaic project developer is responsible for bringing together the five essential project pillars: real estate, interconnection, power take-off, permitting and financing. In the process, the developer attempts to assemble a comprehensive CONTINUED ON PAGE 62

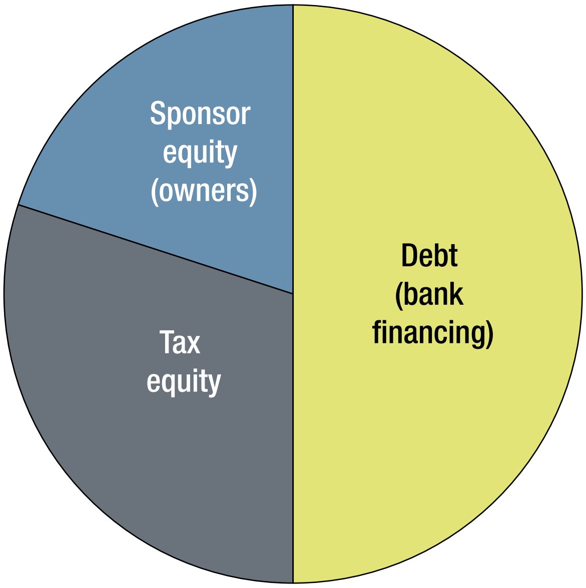


Chart 1 Large-scale PV systems in the US are typically financed using 50% debt (bank financing), 30% tax equity and 20% sponsor equity. Because they are able to put up less money, the equity investors are able to make the higher ROI required to make projects viable.

package that has a high chance of success with financiers. While large PV projects have some inherent risk, the developer is in a position to apply low-risk bank philosophy to mitigate it.

The developer generally finds it easier to work with the EPC contractor than with the bank. Bank financing tends to be somewhat binary: yes or no. EPC contractors, however, have a level of flexibility. They are motivated to find a performance guarantee that works. After all, if there is no guarantee, there is no project. In addition, EPC contractors are in a good position to own the performance risk. They design, build and commission the project, which limits or controls their exposure.

Performance guarantees need to be provided by an EPC contractor with sufficient experience and a sizable balance sheet. In European PV markets, EPC contractors provide very strong guarantees. This is in part due to the large size of European EPC providers; they can afford to provide strong guarantees. It is also true that EPC contractors are providing increasingly comprehensive performance guarantees as a means of differentiating themselves from the competition. While financiers are not always clear about a guarantee's requirements, a project without a performance guarantee almost certainly fails to find bank financing. A project without debt is simply not viable.

The EPC contractor. As a rule, EPC contractors are intimately familiar with evaluating contracts as they pertain to

> From the EPC contractor's point of view, a PV performance guarantee must be structured so that a relatively simple approach can be taken to assess the risk it is contractually obligated to assume.

getting things built. However, measuring plant performance over a long period of time and assuming responsibility for the possible associated damages is far from the norm.

The typical EPC contract has a definite beginning and end. For large-scale solar projects, this duration is usually a little over a year. PV performance CONTINUED ON PAGE 64

guarantee structures ask the EPC provider to extend contractual obligations for several times that duration. EPC contractors are accustomed to designing solar farms, building them, proving that they operate properly and then moving on to another project. In fact, all of the business structures for an EPC contractor—from design work through commissioning—are organized in this manner: beginning (the notice to proceed), middle (the work), and end (final payment and turnover). The PV performance guarantee is a distinct departure from this simple, predictable model.

While EPC contractors are not afraid of risk, they may not know how to evaluate or estimate it well. When this is the case, they are likely to evaluate project risk on the high side. EPC contractors can mitigate risk associated with system design and construction, but they cannot control the weather. Therefore, contractual conditions that assess damages based on climate data are often unacceptable to them.

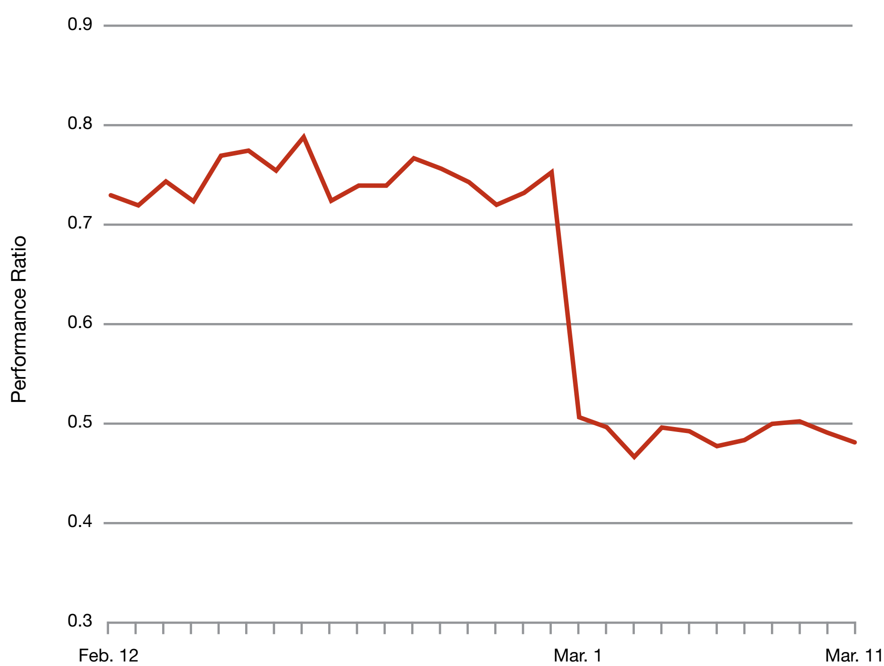
From the contractor's perspective, there is a nearly incalculable risk associated with quantitatively comparing site-measured system output data with historical data. In other words, they avoid putting themselves in the position of having to hit a MWh goal irrespective of the weather. They do not want to do this because they cannot predict the weather. If the assessed liquidated damages have anything to do with a less sunny year than normal, then a prudent EPC contractor is probably going to pass on the project. From the contractor's point of view, a PV performance guarantee must be structured so that a relatively simple approach can be taken to assess the risk it is contractually obligated to assume.

Concepts and Calculations

The complexity of PV performance guarantee approaches can sometimes overshadow the intent of the agreement. Performance guarantees should not be structured to sell projects; they should be structured to ensure that systems work as intended. It is critical that all parties understand their responsibilities. In other words, it needs to be clear what risks are being mitigated and by whom. The keys for successful negotiations are establishing clear rules, formulae and responsibilities; determining consequences of nonperformance; and limiting liability. As a general rule, the parties closest to the risk should be responsible for the risk.

It is also important to understand the constraints of the plant monitoring data. For example, most PV systems have a monitoring system that has technical restrictions on the type, accuracy and granularity of the data collected. This can directly affect the ability to calculate or prove system performance, or the methods used to do so. When making decisions about what to measure and how, it is advisable to get input from all team members responsible for these activities in order to accurately weigh the cost and benefit of monitoring, reporting and measurement validation. The degree to which a plant must be measured is analogous to the expectations of the performance guarantee. Nearly constant monitoring is required to keep everyone informed with the appropriate data. The owner, developer and contractor must know how the asset is performing in order to mitigate having to pay damages.

The duration of the guarantee can help reduce the administrative and payment risks associated with proof of performance. The longer the term, the more flexibility there is to cure or fix the problem; however, a longer term also broadens the contingent liability. It should be clear who requires or prepares documentation to determine if and how payout for damages is to be made. The beneficiary of the guarantee is typically the system owner but not always. Sometimes a third-party investor is the downstream beneficiary.



Performance ratio Because a PV plant's performance ratio is compensated for variables like irradiance, it is useful for comparing systems built in different locations or using different technologies. It can also be used to identify potential instances of or trends toward underperformance, whether occurring suddenly—as shown here—or developing incrementally over time.

Determining meaningful measures of performance is one of the most challenging aspects of contract negotiation. While there are many standard assumptions and models, the global financial markets have continued to tailor the required measures of performance for each set of underwriting needs. These underwriting needs are specific to local incentives, feed-in tariffs or tax equity. For the US, performance guarantees are generally governed by the need to leverage the 5.5 years of potential tax recapture allowed under the Investment Tax Credit and ensure acceptable debt service levels.

One of the first steps in contract negotiations is to establish some common definitions. These definitions ultimately determine the basis of measurement, which can be thought of as the hardware, software and numbers that need to be gathered in order to fulfill the performance guarantee. The most commonly used terms or concepts are specific production, performance ratio, temperature compensation and irradiance compensation.

Specific production. The *specific production* or *specific yield* of a system is a modules-to-meter performance metric. It is the ratio of energy produced by the system (MWh_{AC}) to the nameplate rating of the modules ($MW_{DC\text{-}STC}$), which is usually expressed as MWh/MW. Specific production is a good way to compare various PV technologies because it basically predicts the system output of a specific technology within a given climate. In any case, the predicted result is typically based on hourly PV simulations using known system design parameters. The actual production measurement in the field can be taken at many points throughout the system, but it is typically taken at the production meter, which is located at or near the point of common coupling or utility interconnection point.

A good performance guarantee helps identify and fix problems: When a PV system fails to perform as expected, there can be mutual agreement about the cure, and action can be taken to get it fixed.

The basic formula for specific production is shown in Equation 1:

$$\text{Specific production} = MWh_{AC} \div MW_{DC\text{-}STC} \quad (1)$$

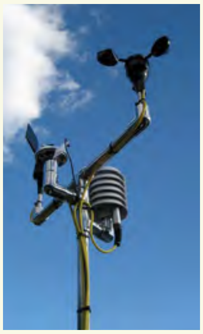
As long as the methods used to determine the numerator and denominator are mutually understood, this index can be a very good starting place for PV performance guarantee negotiations. Of course, specific production is only an indication of relative system performance and depends on a host of parameters. Failing to reach a specific production goal usually indicates a poorly performing system, but it does nothing to help identify or fix problems. Understanding these limitations is key to properly using this index.

Performance ratio. The most widely used and accepted index of PV system performance is the *performance ratio*. This ratio separates out the uncertainty and variability of irradiance and is intended to normalize out weather factors to produce a consistent measure of system performance. It is therefore a useful equivalent for comparing PV plant performance regardless of technology or location. As such, it is CONTINUED ON PAGE 68

Guidelines for a Successful Performance Guarantee

General recommendations:

- Write the terms and conditions with input from all parties.
- Establish a mutually agreeable basis for measurement that identifies the data to be measured, as well as the hardware and software required.
- Identify the monitoring hardware and software needed to ensure equitable measurement.
- Establish co-ownership of plant metrics.
- Design the PV performance guarantee contract to ensure that performance is maintained over the project lifetime.
- Establish firm dates and durations for O&M and guarantee phases.



Shawn Schreiner

Monitoring It is important that all parties engaged in a performance guarantee are in agreement about what data is to be collected, how it is to be collected, and what the limitations are due to measurement accuracy or method. A recalibration schedule should also be part of the agreement.

For the developer or owner:

- Keep the end in mind: It is essential to understand the true risks that need to be managed; those closest to the risk should manage the risk, and that may very well be the owner.
- Do not ask for a performance guarantee for its own sake; it is essential to structure agreements to solve problems, such as plugging gaps in coverage.
- Negotiate with the financier to find a balance for the ownership of risks.
- Keep in mind that managing a PV performance guarantee takes time and money; clear and simple structures work best.

For the financier:

- Take time to understand the terms of the warranties for major components.
- Be willing to pay for the performance guarantee because it adds value.
- Remember that performance guarantees are intended to ensure that systems perform, rather than to provide a mechanism for collecting payout damages.
- Understand that ultimately it is the knowledge, experience and solvency of the EPC and O&M contractors that is being counted on to keep the system producing.

For the EPC contractor:

- Understand the terms of the warranties for major components and fold them into the PV performance guarantee contract terms in full; do not promise more than the manufacturers do.
- Only agree to back up agreements from the manufacturers within the scope of the supply agreement and make sure to have the contractual authority to insist on corrective action.
- Perform accurate, detailed system simulations and agree with the client on the contract terms based on the modeled system.
- Do not guarantee the weather; be careful to avoid contracts that quantitatively tie damages to historical weather data.
- Pursue an arrangement that incentivizes meeting and exceeding performance expectations by trying to write incentives into the contract. ●

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$$PR = (E_{ACTUAL} \div E_{IDEAL}) \times 100\% \quad (2)$$

where E_{ACTUAL} is the amount of energy that passes through the custody meter over a given period of time, and E_{IDEAL} is the amount of energy that would be ideally expected, after correcting for temperature and irradiance.

Like an availability guarantee, which promises system or component uptime, a performance ratio guarantee requires a high level of service response. When both are provided as part of a performance guarantee contract, the EPC contractor ensures that the components work as described and that the system performs at the guaranteed level of effectiveness. The addition of an availability guarantee to a performance guarantee means the PV performance guarantee sponsor (the EPC contractor or developer) takes a more active role in plant management, helping to ensure total system performance even in the event of major component failures. This layered approach works well if there are several sub-metered production obligations or if the overall project includes systems across several sites.

Temperature compensation. Typically, the sponsor and the bank take the weather risk. More sophisticated contracts attempt to account for the performance risk associated with higher-than-average annual temperatures. While this is a more thorough method of assessment, a drastically different average temperature profile is unlikely during the term of a performance guarantee. Temperature fluctuations are typically within a few degrees Celsius. Therefore, the risk of temperature is inconsequential compared to the weight of solar irradiation. It is often expedient to simplify the documentation and limit metrics to include only solar input.

While temperature compensation tends to add complexity, module suppliers and EPC contractors wanting to limit risk may insist on it. In fact, some guarantors take a fundamental position to not guarantee weather impacts. If this is the case, Equation 3 can be used to calculate the temperature-corrected nominal plant power (P_{TC}):

$$P_{TC} = [1 + \gamma \times (T_{MOD} - 25°C)] \times P_{STC} \quad (3)$$

where gamma γ is the thermal coefficient of power from the module specifications, T_{MOD} is the module temperature and P_{STC} is the system capacity value at standard test conditions. Calculating the system capacity value can be as simple as using the nameplate dc system capacity. However, some procurement contracts allow for a wide variation in module power tolerance. Therefore, flash-test data or other factory or field measurements may more accurately reflect the size of the generator installed.

Irradiance compensation. The next challenge is to determine the measurement and verification methods used to account for variable site irradiance. Standard test conditions, of course, are based on an irradiance of 1,000 watts per square meter. In the field, the available solar power (irradiance) in the plane of the array is variable between 0 and perhaps 1,200 watts per square meter and is constantly changing.

While this complicates performance verification, expected PV system output power is directly proportional to solar irradiance, which is the input-power source. Therefore, as measured solar irradiance in the plane of the array changes, the output power of a PV plant should change proportionally. This means that the temperature- and irradiance-corrected expected PV system output power ($P_{EXPECTED}$) can be derived from the temperature-corrected nominal plant power (P_{TC}), as calculated in Equation 3, by multiplying the latter by the normalized solar irradiance, as shown in Equation 4:

$$P_{EXPECTED} = P_{TC} \times (G_{POA} \div 1{,}000 \text{ W/m}^2) \quad (4)$$

where G_{POA} equals the measured solar irradiance in the plane of the array.

When managing a large PV asset, verifying power instantaneously is generally less informative than verifying energy production over time. For example, one might want to characterize the daily, monthly or lifetime performance ratio for a PV power plant. As shown in Equation 2, this is a function of the actual energy measured at the revenue meter and the ideally expected amount of energy after temperature and irradiance compensation. This can be accomplished in two steps: determining the available irradiation and solving for the temperature- and irradiance-compensated ideally expected energy.

The first step is to determine the *irradiation,* the solar energy, available at the point of measurement. In *Photovoltaic Systems Engineering,* Robert Messenger and Jerry Ventre explain, "Since energy is power integrated over time, irradiation is the integral of irradiance." In this context, the verb "to integrate" is just a fancy way of saying "to sum up." In other words, available solar energy is the sum of all the little bits of solar energy, which might be measured in 1-second, 1-minute or 15-minute increments, added up over some interval (hour, day, month, year, etc.). While this can be expressed as a sum equation, the integral is shown in Equation 5:

$$H = \int G_{POA} \, dt \quad (5)$$

In this formula, H equals the irradiation or solar energy at the point of measurement. As was CONTINUED ON PAGE 70

the case in Equation 4, G_{POA} is the irradiance or solar power in the plane of the array. This needs to be multiplied by an increment of time in order for power to result in a unit of energy. This increment of time is shown in the equation as dt, which represents a change in time, the smallest increment being measured. It is most common for this to be a 15-minute interval, as this simplifies the math and data collection. The irradiance in the plane of the array is averaged over a 15-minute interval, and then all of these tiny 15-minute bits of energy are added together to determine the total irradiation in the plane of the array over a longer interval of time.

The second step is to use the solution from Equation 5 to solve for the temperature- and irradiance-compensated ideally expected energy (E_{IDEAL}), which might look like Equation 6:

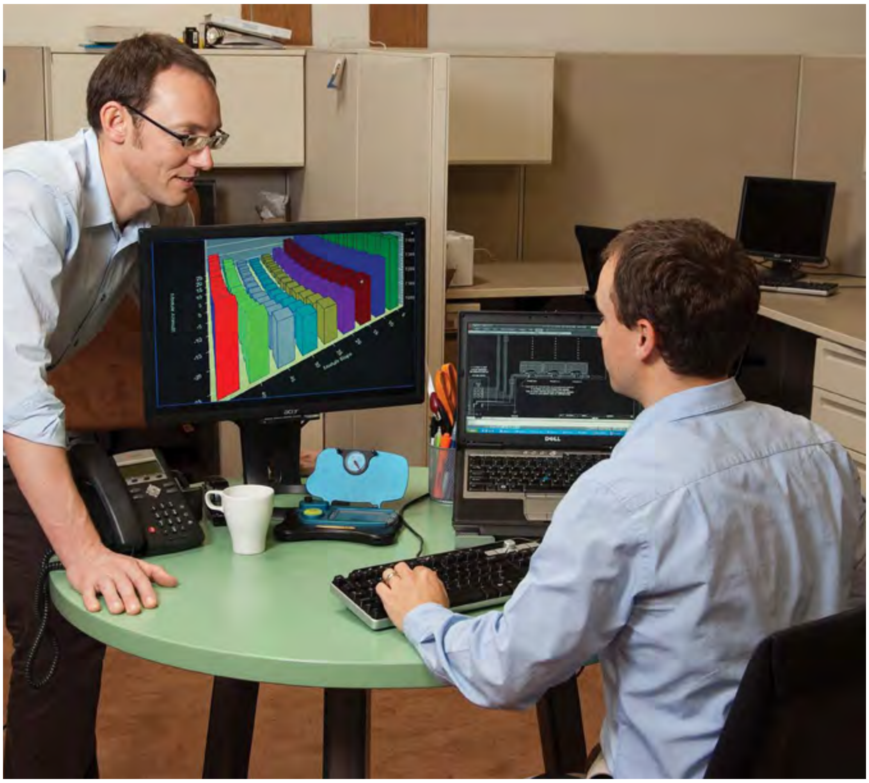
$$E_{IDEAL} = (H \div 1{,}000\ W/m^2) \times P_{TC} \qquad (6)$$

Dividing the solution found in Equation 6 into the actual measured energy over an identical period of time determines a PV system's performance ratio, as described in Equation 2 (p. 68). This index allows for the comparison of PV plants across different sites, regardless of the PV technology. It is obviously important to choose units and metrics that match the measurement equipment and resolution of data.

These formulae help to give guidance as to who should hold the risk, the EPC contractor or the project sponsor. The key to using these equations is to know their limitations, which are a function of overall project design and measurement accuracy. The results are not intended to be exact, but rather to be very close approximations given the instrumentation options. Furthermore, accurately measuring and correcting for temperature and irradiance is a powerful tool for determining system health. When combined with other plant measurements, temperature and irradiance information are useful as both troubleshooting and revenue-estimating tools.

GUIDELINES FOR MEASUREMENT, ACCURACY AND PROOF

Measurement is the backbone of a solid performance guarantee. Sometimes the performance of the meter and data acquisition system can be more important than the actual system performance. If it matters to the contract, and if it determines assessed damages, then it has to be measured and reported accurately and often. Good plant measurements lessen the challenges associated CONTINUED ON PAGE 72



Fred Speiser

Production modeling The performance assumptions underlying performance guarantee contracts must be supported by accurate and detailed system simulations that all stakeholders have reviewed and agreed on.

with verifying that performance guarantees are met or enforcing the contract terms when they are not.

Instrumentation and accuracy. All performance guarantees have to be definitively measurable. The value of the measurement is directly proportional to all parties' confidence in how it is measured. Instrumentation and accuracy should be explicitly addressed in the contract documents. A rigorous recalibration schedule is also vitally important to the agreement to help mitigate measurement errors.

Measured quantities. All parties have to agree on the measured quantities that ultimately represent the contract terms and conditions. If a contract specifies dc losses, for example, then the equipment needs to be in place to reliably and accurately measure the compliance of the dc system parameters. If there is an inverter efficiency guarantee in place, then third-party monitoring of dc input and ac output at the inverter is required at additional expense.

Identifying low performance. The PV performance guarantee terms must ensure that all relevant aspects of plant performance are quantifiable so that any deliberation as to the claim of low performance can be assessed immediately, beyond a reasonable doubt, and the magnitude of the shortfall can be specifically quantified. In the grand scheme of things, performance guarantees should prevent a PV system from persistently underperforming. Small differences between expected and actual output values are hard to justify, especially when it comes to assessing damages. A good performance guarantee helps identify and fix problems: When a PV system fails to perform as expected, there can be mutual agreement about the cure, and action can be taken to get it fixed.

Administration. Performance guarantee mechanisms always require documentation and proof for damage payment. Unfortunately, this documentation and proof process may incur excessive administrative costs. It is not uncommon for the cost of annual reporting to exceed actual damages. Some of these guarantees with cumbersome administrative requirements have clearly been negotiated with business development teams in isolation from the execution teams that do the actual work. These counterproductive guarantee terms seem to be extending further into the future, which can create decades of form filing that has little to do with keeping systems operational.

Deciding on the Details

In Part 2 of this article, we outline the major approaches to proof of performance. These different warranty or guarantee approaches ultimately determine what PV system performance measurements are required. We discuss the hardware required for the collection of plant metrics, as well as how the variables being measured actually impact plant performance and the verification thereof. We also examine the basic elements of a typical performance guarantee and what to look for when evaluating guarantee structures.

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Resources

Photovoltaic System Engineering, Roger Messenger and Jerry Ventre, CRC Press, 2000

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Turning on the Heat

Solar Thermal System Commissioning

By Justin Weil and Patrick O'Boyle

Low natural gas prices and lack of public awareness of solar thermal technologies are the two most oft-cited barriers to significant expansion of the industry within the US. Unlike photovoltaics, which is relatively well known and certainly well publicized, solar thermal continues to be an esoteric segment of the solar technology spectrum.

While the activities of the solar thermal industry cannot impact the price of natural gas, the technology's public profile can be greatly improved with the deployment of high-performance solar heating systems that meet customers' expectations. Professional commissioning ensures long-lived, reliable and efficient installations. These systems, along with public outreach and education, are the keys to widespread solar thermal application awareness and acceptance.

THE IMPORTANCE OF COMMISSIONING

Picture the solar thermal installer in a mechanical room, deep in the bowels of a massive commercial building. After

months of hard work, a new solar heating system is nearly complete. The copper pipes have long since been roughed in, insulated and jacketed. Long banks of flat-plate collectors fill the roof, mounted on a properly engineered, secured and flashed racking system. In the mechanical room, the solar storage tanks are strapped in and full of water. The pumps, flow meters, sensors, and control and monitoring systems are wired up and plugged in. Commissioning, the official start-up of the new system, is the last major procedure to complete. Considering the overall scope of a project, commissioning does not take a significant amount of time, but doing it right is vital to the performance, longevity and value of the system.

As with solar thermal system design, project commissioning requires various levels of sophistication. For a residential application, it may be a simple procedure, while an industrial project may take several days. Residential domestic hot water systems, generally comprising four or fewer collectors, are the least complicated. Commercial and industrial systems that provide heat for applications such as process heating can include hundreds of collectors. Commissioning these systems

Shawn Schreiner (2)

System scale Commissioning procedures and documentation become more complex as project size increases. Commercial and industrial systems, such as this 40-collector installation (two arrays shown) by SunWater Solar, can take multiple days to commission and require customized, project-specific commissioning protocols and documentation.

is complex and time-consuming. Combi systems that provide heat for multiple loads and processes are typically the most difficult to commission. The wide variety of system types and elements means that a separate commissioning procedure must be developed for each application.

Some elements are common to commissioning each of these system types. In this article, we focus on the systems that we most often commission: commercial-scale active closed-loop glycol systems that provide domestic hot water to the facility. In the end, the goal is the same: to ensure that the solar thermal system remains in use for decades to come and performs optimally. After commissioning, the system is no longer a work in progress, but a work completed.

WORST-CASE COMMISSIONING SCENARIOS

Failure to commission solar thermal systems properly can have drastic consequences including property damage, injuries and delays in payment. Failed commissionings also damage the reputation of the installer, the technology and the industry as a whole. Over the course of many years in the solar thermal business, professionals have encountered all manner of commissionings gone wrong. Before we tackle specific procedures and approaches, here are some real-world examples where proper system commissioning would have saved installers time and money, and, in one case, would have prevented an injury.

Leaving a system manually on. One case involved a large commercial system with an unpressurized storage tank. At start-up, the system seemed to be functioning properly. The pumps were on and appeared to be operating normally during the sunny day that the commissioning took place. In reality, one of the sensors had failed and the system control was programmed incorrectly, bypassing the high temperature setpoint limit. The result was that the pumps were locked in the On position. After the installer left for the week, the unpressurized storage tank began to overheat. It got so hot that the mechanical room turned into a steam room. When a maintenance man grabbed the door handle to enter the room later that week, he suffered second-degree burns to his hand. The room's walls were destroyed and the entry door was warped from the heat.

Skipping a final pressure test. After pumping 100 gallons of a propylene glycol mix into an 80-collector commercial system, a commissioner climbed to the roof to check the collectors. He found that solder joints on several air vents had failed and that a drain valve had been left open. The roof was badly stained, and the propylene glycol was a total loss, having been discharged into the storm drain. The system had been pressure tested and precommissioned 4 months before that, but had been drained and left to stagnate while the building construction was finished. By the time the second and final commissioning took place, numerous weaknesses in the system became apparent.

Leaving a tank empty. While commissioning a commercial system, the commissioner failed to ensure that there was water in the solar storage tank. He therefore did not realize that a clog in the piping was preventing water from entering the tank. When the system was turned on, heat came from the solar collectors and the commissioner figured he was done. Unfortunately, the domestic-side pump was burned out by the next day.

Leaving water in collectors. One two-collector residential system installed in a high-altitude location was commissioned with water and left unused for several weeks until the project could be completed. An unexpected cold snap hit in late spring, and sure enough, the water froze. Not surprisingly, the system was nonfunctional. When installers responded to the service call, they discovered that the collectors and copper piping had cracked and broken.

Each of these scenarios could have been avoided if detailed, well-organized commissioning procedures and documentation requirements had been in place.

WHO COMMISSIONS?

Solar thermal systems are mechanical in nature and can be very temperamental, especially just after installation. An

CONTINUED ON PAGE 78

Shawn Schreiner

Commissioning team The installation foreman typically commissions solar thermal systems. For commercial applications, it is common to have two individuals on site. The primary commissioner works in the mechanical room, and a second team member is stationed on the roof. Here, Sean Speagle, project manager from SunWater Solar, visually inspects pipe jacketing and roof flashing details.

experienced professional who knows what to expect should be in charge of a system's commissioning. Commissioners should be competent, unhurried and completely prepared on commissioning day. Taking the time to make sure that everything is perfect pays dividends in the reduction of service calls alone. Mistakes or overlooked items during commissioning can damage the system, incurring additional costs.

The installation team foreman usually commissions solar thermal systems, although engineering firms and consulting companies sometimes employ commissioning agents to handle the procedure. Ideally, the commissioner should already be familiar with the system, including both design and installation details. During the current solar thermal renaissance, however, this is not always the case. Most independent commissioning agents rely on the integrator to provide commissioning guidelines, checklists and confirmation of their findings.

One person is usually sufficient to commission a residential system, but for commercial and industrial systems, there should be at least two individuals on site. While the primary commissioner remains in the mechanical room, the second person is stationed on the roof, where he or she can check for leaks, open and close ball valves, balance flow through the arrays, vent air, listen for the sound of fluid moving through the collectors and make adjustments as needed. The commissioning team should remain in voice communication via radios or cell phones as the procedure is carried out.

It is always best to commission a solar thermal system on a sunny day. Heat exchange occurs best when the system is working at maximum capacity and liquids are moving freely through the system. Just as it is easier to diagnose a sick patient when the illness is most intense, powering up a solar thermal system on a sunny day allows the commissioner to put the system through its paces under strenuous conditions. However, collectors should be filled early in the day before they get too hot.

COMMISSIONING SCHEDULE

Solar thermal commissioning, particularly of a commercial or industrial system on an occupied building, should be timed according to when hot water is needed. Commissioning can occur soon after the system is installed. New construction projects, however, may require two commissionings: one to ensure that the system is operational and the second to enable the system to start heating water.

For new construction projects, the first commissioning occurs soon after installation is complete. Commissioners pump water into the system and run through the checklist of commissioning procedures to ensure that all system components are functioning properly. After this initial testing is complete, water should be drained from the system, air vents should be opened and collector temperature sensors should be removed. Draining and venting the system is critical. If occupants do not move into the new building for weeks or months, any fluid left to stagnate in the system can cause problems. Glycol, if left to cook in a stagnant system, may break down, greatly reducing the time before the fluid must be replaced. Sensors and air vents can also fail from overheating if left operational on a stagnant array.

Shawn Schreiner

Existing systems For both new and retrofit commercial-scale applications, the integrity of the gas or electric water heating equipment should be verified by a mechanical/plumbing contractor before the solar thermal system is commissioned.

At the second commissioning of a system built for new construction, the fluids are refilled and everything is checked again. At this point, the system is fully operational. Commissioners can walk away knowing that the system has been double checked and is now providing occupants with solar-heated water.

TYING INTO EXISTING EQUIPMENT

Except for stand-alone applications, all solar thermal systems are supplementary in nature since they feed solar-heated water to existing equipment. That equipment may be as basic as a 40-gallon electric water heater in a homeowner's basement, or as complex as a series of industrial boilers heating tens of thousands CONTINUED ON PAGE 80

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of gallons of water a day for a factory. Regardless of its size or complexity, the existing water-heating system must be functioning properly before commissioning a solar thermal system that is connected to that equipment.

Unlike PV systems that tie into the electrical grid, a solar thermal system ties into a complex mechanical system and its related equipment. It is much harder to troubleshoot problems on the solar thermal side if there are doubts about the integrity of the existing water-heating equipment.

If you are unsure about the equipment that the system is integrating with, get an expert to verify that it is functioning properly. At the very least, check the existing system for leaks, check the controls for faults, confirm the flow of existing pumps and test the system under a load before the solar thermal system is commissioned.

For new construction projects, it is best to have the gas or electric water-heating equipment commissioned and operational several days before the solar thermal system is brought on line. Allowing the mechanical and plumbing contractors to commission their systems enables them to sort out any kinks without the distraction of the solar heating system. It also minimizes finger pointing if their systems perform inadequately and the building is not getting sufficient hot water.

GLYCOL: THE POINT OF NO RETURN

Propylene glycol, or *solar fluid,* as it is often called, is the lifeblood of active closed-loop glycol systems. Due to the cost of glycol and the care that must be taken when handling it, charging a system with glycol is best done once and done correctly. Commissioning a closed-loop system needs to be carried out in the proper sequence (see page 86). Once glycol is pumped into the system, there is no going back without considerable difficulty and likely extra expense.

Glycol should not be added until system installation is complete, including wiring of electronic components. The domestic hot water side must be running and fully tested. The solar tanks must be full of water and all piping must be thoroughly flushed and disinfected if required. Most importantly, commissioners must be 100% confident that the system is free of leaks. Air or water should already have been used to pressure-test for leaks in the solder joints and other connections. Nothing spoils a commissioning like glycol leaks, which can be expensive, considering the $20–$40 gallon cost of the fluid. Finally, pools of leaked glycol cooking on a sun-baked roof leave behind stains and sticky puddles of congealed goo that are not fun to clean up.

Shawn Schreiner

Point of no return Commissioning an active closed-loop glycol system needs to be methodically carried out in the proper sequence. Once glycol is added to the system, there is no going back without considerable difficulty and expense.

Before reaching this point of no return, commissioners should double check that they are using the manufacturer-recommended glycol type and that it is diluted properly. A 50/50 glycol-water mix is standard, although increasing the water content to 60% or even 70% is permissible in areas where freezing temperatures are extremely rare. Follow the manufacturers' temperature-to-ratio chart and make a mix that suits the climate. You will need a glycol tester in order to achieve the proper mixture ratios when combining glycol and water. Be sure to check the final mix by removing a small amount from the collector loop after charging is complete.

Open-loop or drainback systems do not require this point-of-no-return warning that closed-loop glycol systems do. The systems can be easily emptied and recharged if necessary. The water from an open-loop or drainback system, unlike glycol, can simply be directed down a floor drain and the system can be refilled if leaks or other problems are discovered during commissioning.

Equipment for Commissioning

Commissioning must be well planned, and part of that planning process is making sure that the commissioners are armed with all the necessary equipment. The following checklist is valid for residential, commercial and industrial systems, and includes specific items for commissioning active closed-loop glycol systems.

Charging station. The central tool in commissioning a propylene glycol system, the charging station allows you to pump a system full of a glycol mixture and purge unwanted air. Have extra hoses and buckets on hand in the mechanical room to direct water down drains or into jugs and catch leaking or spilled fluids.

Glycol. The food-grade propylene glycol that flows through active closed-loop solar thermal systems is typically diluted with water to reach a 50/50 solution.

Glycol tester. This tool is vital when diluting propylene glycol with water. The tester provides an accurate reading on the glycol-to-water ratio, a metric required on the commissioning checklist.

Camera. Take pictures of everything, especially equipment or installation details that present problems during the commissioning. Thorough documentation gives you a leg up if further troubleshooting is required.

Digital multimeter (DMM) with ac voltage and ohm functions. A DMM is required to test and verify pump and control voltage and sensor resistance values.

Voltage detector. Handy for quick checks, a voltage detector can determine if power is being supplied to various electrical components in the system.

Circuit setter/pressure differential read-out kit. This kit allows you to balance the flow on systems that have circuit setters.

Temperature meter with pipe sensor attachment. This tool makes it quick and easy to get a temperature reading on any pipe in the system.

Hand tools. At a minimum, you need wrenches to tighten hoses and screwdrivers for opening control panels.

Ladders. Stepladders are handy for getting above a wall-mounted pumping station or checking the solder joints on ceiling-mounted pipes. Extension ladders may be required for roof access.

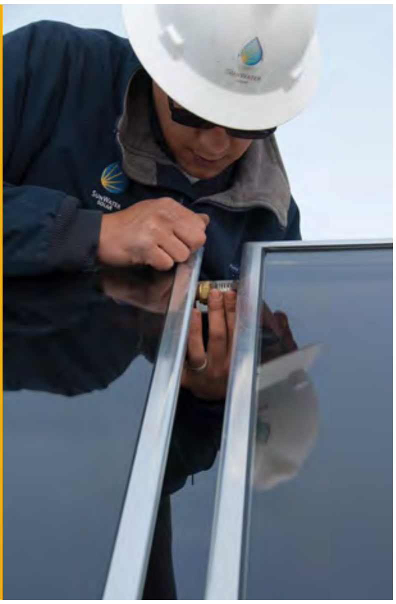
Harness. Safety equipment is usually required for anyone working on the roof of a commercial building and is definitely needed when working on pitched roofs. ●

THE COMMISSIONING PROCEDURE

A solar thermal system generally lasts 25 years or longer, starting the day it is commissioned. Methodically completing and documenting each step of the commissioning process outlined here helps ensure that the system functions properly and meets your customers' expectations for years to come.

Various types of documentation must be on hand during commissioning. First, and most important, is the commissioning checklist, which serves as a step-by-step guide to starting up the system. Even the most seasoned solar thermal installer needs such a checklist. Companies that frequently commission systems usually keep separate checklists for residential, commercial and industrial systems, as there are procedural variations for each system type. Original and as-built design documents, and equipment specification and installation manuals should also be on-site during commissioning.

Perform a visual check. Begin the commissioning process by looking over the entire system, from the CONTINUED ON PAGE 84



System piping During commissioning, piping should be visually inspected and pressure-tested, and the results should be documented and included in the commissioning report. Items on the checklist include collector-to-collector connections, pipe support, jacketing and valve location, orientation and direction.

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roof to the mechanical room, to make sure that all work has been completed properly and according to the system design. It is useless to begin the commissioning process if something is clearly wrong and the system cannot be started up.

Review the system piping.

- ❏ Check that all piping, gauges and valves are per design.
- ❏ Check that the pipes are supported properly.
- ❏ Check the pipe insulation and jacketing.
- ❏ Check that pipes are labeled correctly.
- ❏ Check that the valves and gauges are installed in the proper location, orientation and direction.
- ❏ Check that pressure and temperature relief valves are installed in the proper locations to protect the components if conditions exceed maximum operating ranges.
- ❏ Check the collector connections.

Evaluate the roof work.

- ❏ Check that the collector mounting is complete and that all hardware is tightened.
- ❏ Check that mounting and piping is properly flashed and correct roofing practices were used for the building's specific roofing system.
- ❏ Confirm collector orientation and angle per design.

Verify the system's electrical wiring.

- ❏ Confirm that all system wiring is per design.
- ❏ Check that the system has overcurrent and surge protection.
- ❏ Check that wire sizes are correct.
- ❏ Confirm that a sufficient motor starter is installed for systems with 3-phase pumps.
- ❏ Check that all wiring is terminated correctly, including polarity.
- ❏ Check that the required conduit is used and properly supported.
- ❏ Check that the sensor wiring is secure and protected from UV.

Pressure-test the system. The installers should have pressure-tested the system with air or water prior to commissioning. The *2009 Uniform Plumbing Code* requires that piping be hydrostatically tested to 100 psi or twice its operating pressure, whichever is greater. It is wise CONTINUED ON PAGE 86

Glycol Charging Sequence

1. Fill the domestic-water side of the heat exchanger. For systems that use heat exchangers immersed in the tank, be sure the tank is full of water. For systems with external heat exchangers, be sure the water side of the heat exchanger is flooded.
2. Precharge the solar loop expansion-tank pressure per the design specifications.
3. Close all the drains and air vents on the roof.
4. Calculate the amount of glycol needed. Add the volume of fluid in the piping, in the collector field (consult manufacturer) and in the heat exchanger, or fill the system with water and measure the volume when drained. (The latter option should be used only if the system design allows it to be drained completely.)
5. Mix the required amount of glycol (if not using a premixed product). Use purified water if the tap water in the area is suspected to be of poor quality. If water quality is unknown, it should be analyzed by a qualified water-testing provider.
6. Connect the charging pump to charging ports on the collector loop so that the charging pump is flowing in the same direction as the collector-loop pump.
7. Close the charging-diversion valve, which is typically a ball valve between the two charging ports that forces the water through the loop.
8. Fill the charging pump reservoir or insert charging hoses into the bucket or barrel containing glycol.
9. Turn the charging pump on.
10. Turn the collector loop pump on.
11. Continue to fill the reservoir with glycol mix as needed.
12. If the system has multiple arrays, close all arrays but one and allow the glycol to flow for 2 minutes or until air is purged. Proceed similarly through all arrays. Once each array has been fully charged, open one array at a time until all arrays are open.
13. Allow the system to flow until all air is purged. Manually bleed off air periodically throughout the commissioning process.
14. Close the charging port that is returning to the reservoir.
15. Continue to inject glycol into the loop with the charging pump until the desired pressure is reached.
16. Close the final charging port.
17. *Immediately* turn off the charging pump. ●

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Control verification Temperature sensors should be tested and the reading should be compared to the reading at the control unit. All control functions and relay operation should be verified, and system control programming reviewed and documented.

to pressure-test again on commissioning day, especially if the system has been unused for a period of time.

Follow the correct glycol charging sequence. Detailed, step-by-step instructions for glycol charging are included in the above sequence. If you are charging the system on a warm day, be cautious not to close off an array full of liquid for any longer than is necessary. If the fluid in the array boils, the pressure can skyrocket and damage the system, perhaps blowing off pressure-release valves.

Verify system control.

❏ Test sensors by using a temperature meter to measure temperature at the sensor location. Confirm that it matches the sensor reading on the control. Using an ohmmeter at the solar control, test the resistance through the sensors. Look at a resistance-to-temperature chart and confirm that the measured resistance matches the actual temperature where the sensor is located.

❏ Verify that the control functions or relays are operating correctly. Is the system operating when the design differential is met? Change the high-temperature limit to below the current temperature of the storage tank and confirm that the CONTINUED ON PAGE 88

pumps turn off. You might need to artificially heat or cool sensors to confirm they are operating properly.
- ❏ Program the system control to achieve the desired sequence of operation per design.
- ❏ Record all settings.

Check and record flow rates.
- ❏ Check the collector pump-loop flow.
- ❏ Check the domestic pump-loop flow.
- ❏ Calibrate the arrays if they are fitted with circuit setters or flow meters. When balancing arrays, it is important to note that the fluid flow changes as each array is balanced. Restricting one array often adds more flow to another. Refer to the balancing valve manufacturer's instructions for directions. It may take several passes to correctly balance the arrays.

Calibrate valves and sensors.
- ❏ Calibrate the tempering valve and record the setting.
- ❏ Calibrate the temperature and pressure sensors as required.

Check labeling, postings and owner's manuals. One of the most common causes of a solar thermal system's premature death is the facility's service technicians' failure to understand how the solar thermal system integrates into the existing water heating system. In extreme cases, this can lead to the solar system being bypassed and rendered useless. Proper labeling, along with posting product information, solar contractor contact information and schematics, greatly reduces this risk. A system diagram must be posted near the solar equipment, along with a valve chart and shutdown procedures. All diagrams should be laminated. Pipes and each piece of equipment should be labeled per the schematic. Valves should be labeled per the valve chart. Owner's manuals should be posted and easily located.

For closed-loop systems, labels reading *Propylene Glycol* should be affixed to the solar loop. Many building departments also require labels on the heat exchanger that clearly state whether it is single or double walled.

Check the monitoring system. Monitoring systems allow installers and system owners to conveniently keep close tabs on system performance and production. Web-based monitoring provides maintenance staff and system installers with real-time system performance and production data to confirm system operation and productivity without a site visit. Some products feature alerts that allow installers to proactively address malfunctions, such as burned-out pumps or failed sensors. Monitoring systems typically require Internet connectivity, which can involve the installation of a router and Ethernet cable.

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Labeling In glycol-based systems, labels reading *Propylene Glycol* should be affixed to the solar loop. In addition, many building departments require labeling on the heat exchanger that indicates whether it is single or double walled.

FACILITY STAFF TRAINING

Training plays a vital role in commissioning. It provides an opportunity to raise the profile of solar thermal technology, educate potential solar thermal advocates and perhaps win more jobs with the client. Contracts often require solar thermal companies to educate maintenance staff and other on-site personnel on system operation, shutdown and troubleshooting. Take this occasion to get people excited about solar thermal and encourage system owners to publicize their adoption of the technology.

The training briefing usually takes place soon after the system is commissioned. Begin the CONTINUED ON PAGE 90


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

training session with an overview of how solar thermal and PV systems differ, as the two are often confused. During the training, point out where the system documentation is located (typically in the mechanical room). Thoroughly address system maintenance and at what intervals maintenance should be performed. Remember, facility maintenance staff often consider a solar thermal system to be just another thing that is going to break down and cause them trouble, and some maintenance personnel may opt not to be responsible for maintenance at all. Ask questions of the staff to get a feel for how much assistance they want with system maintenance. Record your findings and relay a summary to the service manager. Make sure to allocate sufficient time for the training session and stay on site until you have answered everyone's questions.

INTERNAL DOCUMENTATION AND THE COMMISSIONING REPORT

Internal documentation serves as a record of the entire commissioning process. The commissioner's handwritten notes can prove invaluable in troubleshooting any future malfunctions. The make, model and serial numbers of system components should be recorded. This information will be needed if components fail during their warranty period. This documentation also identifies who commissioned the system, the date of commissioning and any issues encountered during the process. Commercial building owners may demand a copy of items from this documentation along with the commissioning report before releasing final payment.

Original and as-built design documents are also important to the commissioning process. The commissioner must carefully compare every aspect of the as-built system to the original plans to determine design conformance. Record any discrepancies. The sizes of piping and tanks, the placement of valves and the collector layout are just a few of the features that must be double checked. All discrepancies or changes should be noted and documented.

In addition to the commissioning report, supplementary documentation should be provided. Requirements vary according to system owners' wishes, but generally include product manuals, as-built drawings, system shut-down procedures, valve charts and contact information for service companies. These materials are useful to any maintenance or repair personnel who need to service the system. One full set of documentation is left in the mechanical room, with items such as the valve chart and shut-down procedures laminated and posted in plain view. Additional sets of documentation should be handed off to the system owner. CONTINUED ON PAGE 92

Follow-up Solar thermal system malfunctions can easily go unnoticed because backup heating systems will typically continue to supply hot water to the facility. Therefore, a commissioning follow-up should be scheduled 30 to 60 days after the initial commissioning to ensure that the system is operating as intended.

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COMMISSIONING FOLLOW-UP

Commissioning is complete when the lead commissioner is satisfied that the system is up and running properly. That said, solar thermal professionals should always follow up 30 to 60 days after commissioning to ensure that the system is still operating smoothly. No news is good news, but do not assume that an absence of complaints from the client always indicates a flawlessly functioning system.

Malfunctions in the solar thermal system may go unnoticed. Because an electric or natural gas water-heating system nearly always backs up a solar thermal system, clients always have hot water. If a pump or control unit in the solar thermal system fails, for example, owners may not realize for weeks or months that something is amiss. Homeowners, as well as finance departments that pay the utility bills for commercial or industrial buildings, may not know how much energy savings to expect and therefore could not know that a newly installed solar thermal system is underperforming. Unlike PV systems, where production is clearly indicated on utility bills that show how much energy the system is producing, utility bills do not show solar thermal system production. In addition, solar thermal system production is hard to quantify by looking at gas bills alone since the gas portion of the bill is often accounting for numerous gas-powered appliances.

CONCLUSION

For installers, the two best days of a project are typically the first day on the job when the build plan is made and the day that the new system is fully commissioned. The difficulties that so often occur in between—leaks, parts runs, scheduling delays, inspections—can be chalked up to experience if the commissioning is flawless. Commissioning day is your chance to close out the job on a high note. After the system is charged, there is nothing more satisfying than spending some time watching it run, fine-tuning the control settings and admiring your handiwork.

Commissioning is also an opportunity to take photos of the completed system for use in case studies and other marketing efforts. Avoid the urge to set and forget the system and move on to the next job without taking steps that enable you to showcase your hard work. Your business benefits, as does the solar thermal industry itself. Publicizing solar thermal technology is a responsibility shared among solar thermal installers, integrators, equipment manufacturers and resellers. Do your part by commissioning the right way every time and showing the world that you have done so.

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Raghu Belur, Enphase Energy

Establishing a New Product Class

In March 2006, Raghu Belur and former Cisco colleague Martin Fornage launched Enphase Energy. Since then, Enphase has proven the viability of microinverter-based PV systems and brought the benefits of module-level dc-to-ac conversion to the industry. An analysis of CSI data revealed that, in 2010, Enphase microinverters held more than 13% of the market share in residential installations with capacities up to 10 kW, up from 5.3% in 2009. For small commercial systems ranging from 10 to 100 kW, Enphase secured 9.3% market share in 2010, up from just 3% in 2009. Enphase has shipped more than 500,000 units to date, and it has announced plans to triple production capacity by year-end 2011. Raghu holds an MS in electrical engineering from Texas A&M University and an MBA from the Haas School of Business.


Courtesy Enphase Energy

Raghu Belur, VP of products, Enphase Energy
Best practices from the telecom industry provided a foundation for Raghu's successful development of the Enphase microinverter system.

SP: What drove you to transition from the computer networking and telecommunications industry to solar, and how did your past experiences assist in the successful launch of Enphase Energy?

RB: Martin and I were working on high-efficiency power-supply technology and advanced communication systems for telecommunications equipment when Martin decided to buy a PV system for his home. Upon seeing the inverter equipment used in PV systems, we immediately thought we could create a better solution. Specifically, if we could design an inverter at the individual module level, we could use low-voltage, low-power technology and semiconductor-based designs to increase performance, reliability and intelligence, while at the same time create a path to continued cost reduction. Essentially, we saw the opportunity to bring some of the concepts of Moore's law to PV inverters. [Moore's law identifies a long-term computer hardware trend where the number of transistors that can be placed inexpensively on an integrated circuit doubles approximately every 2 years.]

SP: In the late 1990s, microinverter products from NKF Electronics and Ascension Technologies failed to gain acceptance in the PV marketplace. From a product engineering perspective, what enabled Enphase to succeed where earlier attempts had failed?

RB: In trying to understand why past technologies had not succeeded, we concluded that they had failed in four key areas: efficiency, reliability, cost and lack of a systems-level approach. The main cause of all these problems was that product developers were attempting to follow the designs of existing central inverters, with the intention of simply making them smaller. Martin and I knew this wouldn't work, so we built a microinverter from the ground up, integrating cutting-edge power electronics with digital control and intelligence. We also took a different approach by thinking at the system level—every microinverter would incorporate built-in data acquisition and networking technology to make the whole array smarter and more connected. We've devised ways to use automotive- and military-grade semiconductors and components in our system without dramatically affecting its cost or size. Our semiconductor-based approach provides a significant advantage over central inverters. We can build more reliable systems and simultaneously increase functionality and lower costs.

SP: Many PV integrators view microinverters as a solution for residential and small commercial installations but not for larger commercial projects. Are you developing products for the commercial sector?

RB: The majority of our installations are residential and small commercial. However, we are seeing significant demand for larger commercial installations as system integrators see the improvements that microinverters deliver to ROI. We are very focused on increasing our presence in this market through further innovations CONTINUED ON PAGE 96

targeted at the needs of large commercial systems. Our system-level approach means that we develop completely integrated solutions. This calls for both hardware and software advancements for large commercial installations. On the hardware side, we will be releasing our 3-phase 480 V product soon, which allows for larger branch circuits and greater BOS savings. The software component is critical as well because commercial systems require different capabilities, including support for O&M, reporting and system analytics.

SP: Does Enphase have specific programs or training to assist integrators in deploying microinverters into larger commercial systems?
RB: Yes, we are building our staff specifically for commercial projects, and it's one of our fastest-growing areas. Today we work with our installer partners during all phases of site development, from technical support during presales to detailed review of line drawings. We also have dedicated sales staff on both coasts focused on large commercial integrators and EPCs. Soon we will be introducing targeted training materials such as best practices for commercial-scale microinverter system design and installation.

SP: As new equipment, including dc optimization products, continues to enter the market, what are Enphase's strategies for differentiation and maintaining a market edge?
RB: We really don't see providers of dc-to-dc electronics as direct competitors. Our goal is to replace central inverters for a whole range of performance, reliability and system design issues, and dc-to-dc electronics are effectively an add-on to central inverter systems. Meanwhile, our installers tell us that dc-to-dc electronics add a whole new set of issues, such as system installation complexity and cost. While the entire industry is focused on driving down BOS costs by making PV systems simpler to install, it seems that the increased cost and complexity of a central inverter with dc-to-dc optimization is not justified in residential or commercial installations. We believe that microinverters are a true alternative to central inverters, and we're focused on making them better, simpler and more cost effective.

SP: PV array safety and fire hazards have become widely discussed topics, especially with the addition of arc-fault protection to Article 690 of the 2011 *NEC.* Enphase products will be exempt from these requirements due to low dc operating voltages. From your perspective, how will the new *NEC* arc-fault requirements impact the industry?
RB: The inherent safety advantages of all-ac systems benefit installers, homeowners and firefighters. For this reason, we see the safety of microinverters as equally important as all their other advantages. We agree with the NFPA's decision and feel that arc-fault requirements should absolutely be in place to ensure a minimum level of public safety. In my opinion, this is a nontrivial and critical problem to solve. It's difficult to predict the impact of the new requirements because the enforcement of the *NEC* depends on the jurisdiction and the discretion of individual inspectors.

SP: Enphase recently announced a major distribution agreement with Siemens, one of the world's largest suppliers of building technology products. The cobranded inverters will be rolled out this summer. Are additional agreements with other electrical product suppliers on the table?
RB: We are very enthusiastic about the agreement with Siemens. As the solar industry continues to grow, new installers will enter the market—and these new installers will most likely come from the ranks of master electricians. When we signed the Siemens deal, we already had relationships with a number of mainstream electrical distributors with portfolios of solar products. However, this is our first agreement that includes product cobranding. As Siemens introduces solar to a new set of electrical contractors, we will continue to focus on supporting our solar installers as we develop additional markets.


Courtesy Enphase Energy

Designing for manufacturability One of Raghu's primary objectives was to develop an extremely reliable microinverter that could be produced via a highly automated manufacturing process.

SP: Finally, the million-dollar question: Enphase announced the development of a new platform for microinverters at SPI 2010 in Los Angeles last October. The platform was developed to enable direct inverter/module integration. Can you share any module partnership details and expected release dates?
RB: We are excited about the anticipated transition to ac modules, which we believe will have a substantial impact on the solar industry. As such, its success requires tight collaboration with our PV module partners and new design elements on the back of the modules for highly reliable electrical and mechanical interconnection. Our next generation microinverter platform, coming out in June or July, combines the proven field reliability of our products with an enclosure design that allows for direct integration into the module. We have announced partnerships with Canadian Solar, Suntech Power and Upsolar, and we have several other module partners committed to working with us. We expect to provide formal release timelines with our partners in the coming months.


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erenewableresource.com

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Fremont
bootsontheroof.com

Colorado

Solar Water Pumping
Solar Energy International
Jun 4 – Jun 5
Paonia
solarenergy.org

Off-Grid Systems for Remote Locations
Buckville Energy Consulting
Jun 5
Fort Collins
sustainableliving association.org

Grid-Direct PV Design & Installation
Solar Energy International
Jun 6 – Jun 10
Jul 11 – Jul 15
Paonia
solarenergy.org

Grid-Direct PV Lab Week
Solar Energy International
Jun 13 – Jun 17
Jul 18 – Jul 22
Paonia
solarenergy.org

Battery-Based Design
Solar Energy International
Jun 20 – Jun 24
Paonia
solarenergy.org

Battery-Based PV Lab Week
Solar Energy International
Jun 27 – Jul 1
Paonia
solarenergy.org

Women's Grid-Direct PV Lab Week
Solar Energy International
Jul 4 – Jul 8
Paonia
solarenergy.org

Grid-Direct Design & the *NEC*
Solar Energy International
Jul 11 – Jul 15
Carbondale
solarenergy.org

Grid-Direct PV Design & Installation
Solar Energy International
Jul 18 – Jul 22
Boulder
solarenergy.org

Florida

Installing PV Systems
Florida Solar Energy Center
Jun 6 – Jun 10
Cocoa
fsec.ucf.edu

PV Design & Installation
US Solar Institute
Jun 13 – Jun 17
Jul 18 – Jul 22
Fort Lauderdale
ussolarinstitute.com

Solar Installer Training
ONtility & Miami Dade CC
Jun 20 – Jun 24
Miami
ontility.com

2011 *NEC* for PV
UL University & NFPA®
Jun 21
Fort Lauderdale
uluniversity.us

Advanced PV Installation
US Solar Institute
Jun 27 – Jul 1
Fort Lauderdale
ussolarinstitute.com

Georgia

PV Design & Installation
Solairgen
Jun 6 – Jun 10
Dahlonega
solairgen.com

PV Technical Sales Exam Prep
Solairgen
Jun 23 – Jun 24
Dahlonega
solairgen.com

Louisiana

PV Technical Sales
ONtility
May 31 – Jun 3
New Orleans
ontility.com

Massachusetts

Solar Domestic Hot Water for Installers
AltE U
Jun 20 – Jun 24
Hudson
altestore.com

Solar Water Heating Design & Installation
AltE U
Jun 22 – Jun 24
Hudson
altestore.com

PV System Installation Certification Exam
UL University
Jun 10
Jul 15
Research Triangle Park
uluniversity.us

New Jersey

Master Certificate in Renewable Energy
Boots on the Roof
Jun 6 – Jun 24
Newark
bootsontheroof.com

PV Boot Camp
Boots on the Roof
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Newark
bootsontheroof.com

New York

PV Design & Installation
SUNY Delhi
Jun 6 – Jun 10
Delhi
delhi.edu/bcs

Advanced PV Systems
SUNY Ulster
Jun 21 – Jun 22
Kingston
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PV Design for Engineers
SUNY Ulster
Jun 23
Kingston
sunyulster.edu/ce

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Jun 27 – Jun 29
Kingston
sunyulster.edu/ce

North Carolina

PV System Installation
UL University
Jun 6 – Jun 10
Jul 11 – Jul 15
Research Triangle Park
uluniversity.us

Pennsylvania

2011 *NEC* Code Changes for PA
Electric Education Center
Jun 7
Bensalem
electriceducationcenter.com

Project Cost & Risk Management
School of Business, Saint Francis University
Jun 14 – Jun 16
Loretto
francis.edu/recertificate.htm

Texas

Solar Thermal Training
ONtility
Jun 15 – Jun 17
Houston
ontility.com

Utah

PV Systems
Salt Lake Community College
Jul 5 – Aug 4
Salt Lake City
slcccontinuinged.com/solar

Online

Allied American University
allied.edu

Allied Schools
training4green.com

ONtility
ontility.com

Solar Energy International
solarenergy.org

Solar Living Institute
solarliving.org

Solar Training School
solartrainingschool.com

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RESCO ENERGY

LoyaltyOne, Mississauga Call Center

Courtesy RESCo Energy (3)

Overview

DATE COMMISSIONED: February 2010

INSTALLATION TIME FRAME: 180 days

LOCATION: Mississauga, Ontario, 43.6°N

AVERAGE SOLAR RESOURCE: 3.8 kWh/m²/day

RECORD LOW/AVERAGE HIGH TEMPERATURES: -22°F/80°F

ARRAY CAPACITY: 156.6 kW

AVERAGE ANNUAL AC PRODUCTION: 160 MWh

LoyaltyOne, owner and operator of the AIR MILES Reward Program, engaged RESCo Energy to design and build a solar system on a call center facility that was already under construction. The building's core and shell were designed to LEED Silver requirements, and the interior was designed to LEED Gold standards. LoyaltyOne decided to add a PV array eligible for feed-in tariff (FIT) rates through the Ontario Power Authority. Connection to the grid and receipt of a FIT contract occurred in early 2010. This was the largest PV array in Ontario's FIT program at the time of commissioning. RESCo provided all design, permitting, project management, installation and commissioning services for the system.

When LoyaltyOne approached RESCo, no one in Canada had taken on a project of this scale. The Electrical Safety Authority (ESA) was just beginning to learn about large grid-connected PV arrays. RESCo worked collaboratively with the ESA and utility officials on the specifics of the project through a series of meetings. These meetings served to help the project as well as increase the knowledge about solar within Ontario. RESCo worked collaboratively with the entire team, including all subcontractors, to ensure that the project was completed on schedule, on budget and at a high level of quality.

The array employs two solar technologies combined to provide both solar electric and solar heat to the building. In addition to the PV array, four 4 x 10 solar thermal collectors deliver approximately 34% of the required hot water load. Approximately 90% of the PV modules are situated on the roof of the building. The remainder of the modules and the solar thermal collectors are integrated into a custom carport that is reserved for

low-emission–vehicle parking. The inverters are integrated into the employee's staff room alongside a standalone kiosk to engage staff and visitors.

The construction of the building core was mostly complete when RESCo began designing the array. This posed challenging space constraints as the building had very little capacity for solar on the roof. Working with an integrated and collaborative team, RESCo was able to provide a unique solution that added no additional loading to the roof deck. This required a custom flat-mounted system that tied the PV racking system directly into the building's underlying structural support columns, suspending the solar array above the roof. Multiple sections were placed to help distribute the weight of the array over the building's support columns. This reduced the power density but allowed the building's core design to remain unchanged.

"This building was not designed for a solar array on the roof and as such caused some challenges during the planning stages. Our team had to get creative. We worked closely with the teams from LoyaltyOne and Bentall L.P.—the building owner—to provide a solution that met the needs of the landlord, tenant and contractors after the building construction had begun. The result is one of the largest rooftop arrays in Canada, on a building that was never designed to support a solar array."

–Fidel Reijerse, president, RESCo Energy

Equipment Specifications

MODULES: 764 (48 carport, 716 rooftop) Sanyo HIT Power 205N, 205 W STC, +10%/-0%, 5.05 Imp, 40.7 Vmp, 5.54 Isc, 50.3 Voc

INVERTERS: 3-phase, 120/208 Vac service w/ 22 inverters: four SMA SB 5000-US, 5 kW, 600 Vdc maximum input, 250–480 Vdc MPPT range; three SMA SB 6000-US, 6 kW, 600 Vdc maximum input, 250–480 Vdc MPPT range; 15 SMA SB 7000-US, 7 kW, 600 Vdc maximum input, 250–480 Vdc MPPT range

ARRAY, FLAT ROOF: Eight modules per source circuit on two SB 5000-US inverters (1,640 W, 5.05 Imp, 325.6 Vmp, 5.54 Isc, 402.4 Voc), three circuits per inverter (4,920 W, 15.2 Imp, 325.6 Vmp, 16.6 Isc, 402.4 Voc); nine modules per source circuit on 12 SB 7000-US inverters (1,845 W, 5.05 Imp, 366.3 Vmp, 5.54 Isc, 452.7 Voc), four circuits per inverter (7,380 W, 20.2 Imp, 366.3 Vmp, 22.2 Isc, 452.7 Voc); 10 modules per source circuit on three SB 7000-US inverters and three SB 6000-US inverters (2,050 W, 5.05 Imp, 407 Vmp, 5.54 Isc, 503 Voc), four circuits per SB 7000-US (8,200 W, 20.2 Imp, 407 Vmp, 22.2 Isc, 503 Voc) three circuits per SB 6000-US (6,150 W, 15.2 Imp, 407 Vmp, 16.6 Isc, 503 Voc)

ARRAY, CARPORT: Eight modules per source circuit on two SB 5000-US inverters (1,640 W, 5.05 Imp, 325.6 Vmp, 5.54 Isc, 402.4 Voc), three circuits per inverter (4,920 W, 15.2 Imp, 325.6 Vmp, 16.6 Isc, 402.4 Voc)

ARRAY INSTALLATION: Conergy Suntop rails supported by custom framing on flat roof, 180° azimuth, 0° tilt; Conergy Suntop rails supported by custom carport, 151° azimuth, 35° tilt

ARRAY STRING COMBINER/S: Midnight Solar MNPV6

SYSTEM MONITORING: Sunny Boy Portal


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Projects

NW PHOTON ENERGY
CherryWood Village Retirement Community

Overview

DESIGNER: John Stimac, system designer, Renewable Energy Associates, renewableassociates.com

LEAD INSTALLER: Guy Anderson, project manager, NW Photon Energy, nwphotonenergy.com

DATE COMMISSIONED: February 2011

INSTALLATION TIME FRAME: 35 days

LOCATION: Portland, OR, 45.5°N

AVERAGE SOLAR RESOURCE: 3.73 kWh/m²/day

HIGH/LOW DESIGN TEMPERATURES: per solarabcs.org/permitting/map: 89.6°F/17.6°F

ARRAY CAPACITY: 92.4 kW

AVERAGE ANNUAL AC PRODUCTION: 88,660 kWh

Equipment Specifications

MODULES: 420 Schuco MPE 220 PS 092, 220 W STC, +5%/-0%, 7.38 Imp, 29.7 Vmp, 8.12 Isc, 36.77 Voc

INVERTERS: 3-phase, 120/208 Vac service, 12 SMA SB7000-US, 7 kW, 600 Vdc maximum input, 250–480 Vdc max MPPT range, 208 Vac output

ARRAY: 12 modules per source circuit (2,640 W STC, 7.4 Imp, 356 Vmp, 8.1 Isc, 442 Voc), three circuits per inverter on 11 inverters (7,920 W STC, 22.2 Imp, 356 Vmp, 24.4 Isc, 442 Voc), two circuits on one inverter (5,280 W STC, 14.8 Imp, 356 Vmp, 16.2 Isc, 442 Voc)

ARRAY INSTALLATION: built-up asphalt flat roof, Schuco SolarEZ Mounting System, 211° azimuth, 7.5° tilt

ARRAY STRING COMBINERS: SMA inverter-integrated combiners and disconnects, 15 A fuses

SYSTEM MONITORING: SMA Webbox

Courtesy Renewable Energy Associates (2)

CherryWood Village Retirement Community is a 318-unit senior living facility located in Portland, Oregon, and owned by Generations LLC. It is the first such facility in Portland to utilize solar power. The 92.4 kW PV system, one of the largest in the metropolitan area, is expected to cut the facility's annual electric bills by 25%.

Due to the building's many architectural features and obstructions on the roof, it was necessary to create a full 3-D drawing after doing the roof shade analysis. The module layout had to be carefully planned around the rooftop features. Upon further review by a structural engineer and the roof truss manufacturer, the preliminary design of 150 kW was reduced to 92 kW due to loading restrictions. In addition, the new Oregon Solar Installation Specialty Code and strict AHJ requirements regarding wind loading ruled out a ballasted racking system. This resulted in over 800 4-feet-on-center penetrations in the built-up asphalt roof to accommodate the racking system. A professional roofing company sealed the penetrations.

The Schuco ezRail Mounting System is paired with custom tilt-up legs to accommodate varying roof slopes. Wiley Electronics WEEB clips ground the Schuco modules. The source circuits are routed through one NEMA 3R junction box, allowing a single conduit run off the roof and into wireways connected to the inverters.

"We are excited about the end result of the CherryWood project. Since the array can be seen from some of the residences, aesthetics and array placement were important considerations. The close communication with the building owners, architect and residents helped make this a highly successful project."

—Kirk Cameron, founder, NW Photon Energy

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