

New Interconnection Policies Free The Grid While Providing For Stability



CALIFORNIA'S STORAGE MANDATE

**Get Ready For
California's Energy-
Storage Boom**

APRIL 2014

Improved Performance Assessment Leads To Greater PV Plant Bankability

Determining and evaluating system performance is critical to developing solar power plants as an asset class.

■ James Mokri & Joseph Cunningham

Traditional power generation plants enjoy one significant advantage over most renewable sources: Their annual production figures are in close agreement with their specifications as designed and built. Along with a hundred years of reliability data, banks, investors and secondary market financiers are confident in their cash flow projections for any proposed plant. This low-risk cash flow characteristic makes it relatively easy to secure financing.

If stakeholders of existing and future photovoltaic solar energy systems could offer financial institutions reliable system performance projections based on consistent historical data, as well as standard design, installation, commissioning, and operations and maintenance (O&M) procedures, performance guarantees would be more about proper execution rather than the financial stability of the entity standing behind the guarantee. In

this way, financing could become more readily available.

Many industry leaders have started asking these kinds of questions about solar PV bankability, and we are seeing many new efforts in this area. The National Renewable Energy Laboratory's (NREL) Solar Access to Public Capital is one such program. At the SunSpec Alliance, we have been taking a detailed look at how performance metrics may affect the financing process.

Halfway there

Finding the best way to measure physical quantities that the majority of society can agree upon has long been known to accelerate economic growth. Unfortunately, solar is not there - yet.

Monitoring companies are developing data analysis methods to process real-time data for their specific systems and performance metrics. However, a lit-

erature review of metrics in common use by companies found that various analytical methods are used to calculate the same metric, or one analytical method is used, with varied results due to the environment of the system. Both are problematical because they result in different interpretations.

For example, the commonly used metric of performance ratio (PR) - as defined by the International Electrotechnical Commission (IEC) standard IEC 61724 and NREL - may be appropriate for an annual comparison of systems with the same climates but is not appropriate for the shorter term or for system comparisons in differing climates. Specifically, if PR is used to evaluate a system in San Francisco compared to a similar system in Daggett, Calif., incorrect conclusions would be reached.

Using NREL's PVWatts calculator to represent an actual system, a 100 kW DC system in San Francisco with latitude tilt has a calculated PR of 0.73 with an output of 145,000 kWh/year, while a



Christina Stanevich
(800) 325-6745 or
(203) 262-4670, ext. 237
cstanevich@solarindustrymag.com

solarindustrymag.com/buyersguide

100 kW DC system in Daggett with latitude tilt has a PR of 0.69 with an output of 171,000 kWh/year. Even with a lower PR, the Daggett system has higher output and, therefore, higher performance.

If PR is used to make an investment decision in one of these systems - all other factors being equal - the investor would choose San Francisco with a lower return on investment (ROI) due to significantly lower annual energy production.

Determining the bankability of PV assets requires that investors understand the reliability of modeling and actual performance data in support of their investment decisions and how these are related to equipment, location, design, installation technique and O&M.

It would be desirable for stakeholders to have consistent definitions, methods and agreement regarding the objective of the metric. This would enable better classification of the performance of solar assets across technologies and locations. Consistent performance standards would also help streamline the bankability assessment for solar assets.

This SunSpec study identifies representative metrics in current use, summarizes the method and level of effort to calculate the metrics, reviews the objective of the metrics, estimates the metric uncertainty level, and recommends which metric is appropriate for which purpose/objective.

The four performance metrics employed in the study are as follows:

- Power performance index (PPI) of actual instantaneous kW AC power

output divided by expected instantaneous kW AC power output;

- PR with temperature-corrected final yield using weighted-average cell temperature. Note that PR is commonly defined without temperature correction;
- Energy performance index - system advisor model (EPI-SAM) of actual kWh AC energy divided by expected kWh AC energy as determined from an accepted PV model, such as SAM, using actual climate data and assumed derate factors; and
- EPI - regression of actual kWh AC energy divided by expected kWh energy as determined from a polynomial regression equation having coefficients determined from actual operating and climate data collected during the model "training" period.

Although this study was intended for metrics that apply to fixed, flat-panel PV module technology used on systems of greater than 100 kW (DC), the metrics are actually helpful for any fixed, flat-plate panel PV system size. Calculations were performed to evaluate the uncertainty range for various metrics. Data was obtained from existing systems that had weather stations and accessible data through online monitoring sites.

The objectives for performance assessment can best be summarized from an owner's perspective by questions that are often asked:

- How is my system, or a portion of my system, performing currently in comparison to how I expect it to perform at this point in its life?

- How is my system performing for both the short term and long term in comparison to how it is capable of performing with its given design, site location and baseline performance?
- How is my system performing over an assessment period in comparison to other, similar systems in similar or non-similar climates?
- How is my system performing compared to the last assessment periods? This trending model is useful for maintenance objectives.
- How can I develop metrics in support of an accurate prediction of future energy yield and ROI for reliable investment assessment?
- During commissioning, what metrics should be used to quickly validate system performance and to set a baseline for future performance assessments?

One objective of a performance assessment is to detect changes in system performance - usually decreases in performance - to allow the system owner to investigate and potentially perform cost-effective maintenance. This can be done best on a relative scale where the specific performance of the system is compared to itself, which reduces adverse effects of modeling input assumptions and uncertainty. However, the assessment also needs to include how well the system has performed on an absolute basis.

Another objective is to determine on an absolute basis if a new system - or an existing system having completed major maintenance - has instantaneous

power output and a zero- to 12-month energy output consistent with predictions by the design model. This is also considered a commissioning activity, and because there is no long-term operating data, the results are directly dependent on the validity of the model and input assumptions, which both increase uncertainty.

It should be noted that system performance is different from system value or system reliability. The performance of a system is indicated by the actual AC energy or power output relative to its as-designed or as-built capability. Deviations from 100% can be caused by many factors, including errors or incorrect assumptions during design, poor installation workmanship, equipment failure or degradation, and inconsistent metrics and methods of evaluation. The value of a system is related to the system lifetime cost relative to the AC energy output, often referred to as levelized cost of energy. Also, performance is different from reliability, although performance is dependent upon reliability.

A summary follows of some of the methods and descriptions developed in the study.

EPI-regression

The EPI is calculated using a polynomial regression analysis method to develop an equation relating to actual irradiance, temperature, inverter efficiency and other information relevant to the actual AC energy output at each sample time. Using this method in the first year will allow the system operator to set a

baseline equation for future evaluation. The following general equation has four unknown coefficients, and in principle, they can be determined with four equations. Deviations between the calculated expected AC output and the actual output are called residuals and are minimized as the model is improved with additional data over time.

A general regression equation is as follows, where "temp" is temperature, "irrad" is irradiance, and A-D are coefficients calculated by the regression analysis:

$$\text{AC output energy} = A + \text{temp} \times \text{irrad} \times B + \text{irrad} \times C + \text{irrad}^2 \times D$$

An advantage of using the regression analysis method is that an accurate PV model (e.g., SAM) and a correct derate factor are not needed.

The value for an EPI is calculated based on actual kWh (AC) divided by expected kWh (AC) from the regression model, using coefficients from actual hourly weather and hourly energy output data over the previous year.

Using the regression analysis method, the estimated daily energy can be calculated for comparison to the actual.

Using the general regression model and adding the inverter efficiency to the equation as a new parameter reduces the uncertainty. With this new parameter, the uncertainty with a global horizontal irradiance greater than 800 (W/m²) is 4.1%.

Quarterly data was also used to see

if any anomalies or trends existed. Quarterly data can be used to define a regression equation for a particular season. Further work is needed on this topic to fully assess its usefulness.

The same technique and method was used for 15-minute data. The reduction of averaging over a longer period of time (for an hour) was the motive for using 15-minute data so that there would be less averaging involved. For 15-minute data, there were more wild points to be considered; however, by taking into account more variables, 5% uncertainty was achieved.

The confidence level was increased by modifying the generic model described above to include more variables, where "temp" is temperature, "irrad" is irradiance, "inver" is inverter efficiency, "humid" is humidity, and A-H are coefficients calculated by the regression analysis:

$$P = A + \text{temp} \times \text{irrad} \times B + \text{irrad} \times C + \text{irrad}^2 \times D + \text{temp} \times E + \text{inver} \times F + \text{temp} \times \text{inver} \times G + \text{humid} \times H$$

Power performance index

The PPI is the instantaneous actual AC kW power output divided by the instantaneous expected AC kW power output. The instantaneous expected AC power depends on many factors, including the instantaneous irradiance and cell junction temperature; the module technology, including factory-standard test condition ratings; spectral and angular response; and the derate factors. The actual irradiance absorbed by the mod-

ule cells (referred to as “effective irradiance” by Sandia) can depend on a number of factors, including the plane of array irradiance just above the glass surface, incident angle, glass coatings, soiling, encapsulant, etc.

Methods of collecting data can be found in the complete study. A detailed PPI analysis could be performed using SAM or other PV design software to calculate the expected power output considering all relevant factors. The actual power is then compared to the resulting expected power in the PPI ratio.

Additional work is recommended to develop specific procedures for each of the metrics summarized above and for making software available for general use. Additional long-term data should be analyzed to investigate the ability of metrics to meet the stated purposes, and to determine best practices for obtaining reliable inputs with currently available industry products such as monitoring systems and IV curve tracers. An industry standard would also be useful to improve consistency in calculating and interpreting these performance metrics across the industry.

Incorporating these metrics into monitoring software can help automate data collection and metric calculations. This will also help with large amounts of data collected over longer periods of time to help further enhance these methods and to provide validation of the accuracy of the metrics and methods.

James Mokri is a professor of engineering at San Jose State University. Joseph Cunningham is director of operations at Centrosolar America and is active at SunSpec, working to develop PV performance modeling, measurement, troubleshooting and maintenance standards. He can be reached by email at joe.cunningham@centrosolar.com.
