2009 BFRL Project Description

Project Title: Solar Photovoltaic Performance Measurements and Predictions

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BFRL Program: Healthy and Sustainable Buildings

Objective: To advance the measurement science needed to reduce the measurement uncertainty reported on solar photovoltaic modules and evaluate alternatives to the current, single point, rating method and test conditions.

Problem:

What is the problem? Solar photovoltaic modules are rated based on their maximum power output when subjected to a specific set of test conditions. This single-point rating is important because it provides a comparison basis between competing products, directly impacts the design of the installed PV system, is used to calculate efficiency, is often used as a basis for financial rebates or tax credits, and translates directly into system costs as the photovoltaic industry prices modules on a dollar per peak watt basis. In addition, because of the substantial role that photovoltaics play in achieving net zero energy buildings, accurate measures of their performance are of paramount importance.

Authenticated as part of the NIST USMS assessment[1], the accuracy and suitability of photovoltaic ratings are a current industry concern. Among the best photovoltaic manufacturers, uncertainties on silicon crystalline modules of ±8 % are quoted, "and historically PV manufacturers have consistently provided product at the lower end of this range."[1,2] In addition to the energy implications, this variability is financially significant because a 1 % change in rated output translates to 178 million dollars based on current market conditions.

Why is it hard to solve? Although testing may be done outdoors, convenience and speed dictate that all production photovoltaic modules are rated using some type of indoor solar simulator. Commercial solar simulators marginally approximate the desired spectral output of

[1] Alternative Energy/Photovoltiacs, An Assessment of the United States Measurement System: Addressing Measurement Barriers to Accelerate Innovation, Appendix B, Case-Study Measurement Needs: A Compilation, NIST Special Publication 1048, February 2007, p. 131.
[2] SPR-220 High Efficiency PV Module Specification Sheet, SunPower Corporation, San Jose, California, January 2007.

the sun and illuminate the test plane unevenly, with both spectral output and spatial uniformity gradually changing over time. Most solar simulators are flash type with flash durations typically lasting 10 ms or less. This short flash time does not result in the same specimen temperatures as seen in actual installations, a challenge in that photovoltaic performance depends upon temperature. Additionally, until recently, the short flash duration did not lend itself to alternative methods for simultaneously measuring irradiance and spectrum.

How is it solved today, and by whom? The measurement science has not been sufficiently developed to yield consistent photovoltaic power ratings with low uncertainties. ASTM and IEC standards exist that cover how to use a solar simulator and a reference device, either a calibrated module or a calibrated cell, to obtain the rating. The standards include performance requirements that the solar simulator must achieve, and offer approaches for adjusting the rating based on prior knowledge of the spectral responses of the reference device, the lamp source, and the test module. One of the largest sources of uncertainty is the reference device that provides the irradiance measurement.[3] Their traceability back to SI is dependent upon other photovoltaic artifacts, and their use in tests is often omitted due to the test burden. These reference devices are calibrated by a select few laboratories around the world that offer traceability back to SI units.

Why NIST? New measurement science that promotes more accurate performance ratings and facilitates increased third-party verification testing will enhance the competitiveness of the U.S. solar energy industry. More accurate, substantiated ratings will aid the industry's growth and reputation, thus better establishing the technology's status as a key component of net zero energy buildings. This work, therefore, fits in with the goals of the BFRL Strategic Priority Area in Measurement Science for Net Zero Energy, High Performance Buildings.

BFRL's current combination of outdoor and indoor test facilities and on-going collaborations with NIST experts in spectral and total irradiance measurements yield a unique set of resources for improving current test methods while also exploring alternative measurement technologies.

Approach:

What is the new technical idea? The idea is to use a high-speed spectroradiometer in place of currently used reference modules and reference cells when testing photovoltaic products. This instrument will allow simultaneous measurement of the solar spectrum incident on the module during the flash tests during which the module's electrical output is measured. The spectroradiometer will be used to learn the spectrum for each test (as compared to relying on some nominal value), should give a more accurate measure of total irradiance, and will more readily permit corrections to the standard test conditions (STC)[4]. Hurdles with implementing the new measurement science application, however, have to be overcome and its overall merit evaluated. The measurement uncertainty, time burden, and cumulative cost of using a spectroradiometer, as compared to using reference devices, are among the key delimiters.

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[3] Atmaram, G. H., "Photovoltaic Module Performance Certification," Proceedings of the 31st IEEE Photovoltaic Specialists Conference, pp. 1639-1642, Orlando, Florida, Jan. 3-7, 2005.

[4] Standard Test Conditions are 1000 W/m^2 irradiance, spectrum associated with Air Mass 1.5, zero angle of incidence, and a photovoltaic module temperature of 25˚C.

The CEC[5] and the Department of Energy[6] are among a constituency that seeks alternatives to the current maximum power ratings. One hurdle is the lack of data on how well or poorly solar simulators can generate irradiance levels lower than 1000 W/m^2. The degree to which module temperature coefficients can be determined indoors and how they compare to coefficients determined outdoors is also under-reported. NIST will use existing facilities to quantify typical solar simulator performance for a range of operating conditions. Computer modeling will provide insight into options for predicting performance for representative days or a typical year.

A novel idea to make a tunable, LED-based light source that can replicate the sun's spectrum is proceeding. BFRL staff act as the primary technical monitor for this SBIR Phase II project. When available, this device will be evaluated by NIST.

Why can we succeed now? Because of advances in the last few years, the fastest commercial spectroradiometers can now measure the spectral energy generated by a light source over the same millisecond-level time interval that is used for obtaining a photovoltaic module's power output. An in-depth evaluation of simulator performance using an integral, high-speed spectroradiometer versus that when using current ASTM test methods is possible because of the versatile, state-of-the-art solar simulator that NIST now operates. To respond to the growing interest in measuring panel power output over a broader range of conditions, NIST can tap its extensive accumulated database on measured installed performance and expand its modeling work to address possible alternatives (e.g., ratings for representative days or over a typical year).

What is the research plan? Tests using a high-speed spectroradiometer will fully quantify the potential of this measurement science technology as an integral part of a solar simulator test facility. Ways to best trigger and synchronize the spectroradiometer with the stand-alone equipment of the NIST and (at least) one other type of solar simulator will be explored. A customized LabVIEW program will be developed to allow flexibility for using and evaluating different calibration, data collection, and data reduction modes. These findings, along with those from parametric tests conducted to identify where the current industry test methods that use reference modules or reference cells can be improved, will be shared with manufacturers and members of ASTM E44.

BFRL plans to visit at least three test facilities (e.g., manufacturers, third-party test lab) to evaluate these spectral and irradiance uniformity measurement techniques on a range of solar simulator(s). BFRL will work with those facilities to compile data on the performance of a range of solar simulators. Information on each test facility's chosen test method, the degree of adherence to that method, and any in-house test protocols will also be logged.

The performance of the BFRL solar simulator will be evaluated according to IEC Standard 60904-9, and its components will be recalibrated to help create a historical record of the facility. BFRL will co-author a paper with members of the Physics Laboratory that describes this process.

BFRL will investigate the ability to use its solar simulator to make performance measurements at irradiance levels lower than those specified at Standard Test Conditions (1000 W/m^2). The

[5] California Energy Commission
[6] Chalk, S. and Kimbis, T., "The Federal Perspective: A National PV Standard Will Benefit Industry and Consumers," Solar Today, March/April 2007.

impact from using an inline spectral filter along with options for testing at elevated module temperatures will be explored. These measurements will be compared with power outputs derived from outdoor measurements. The focus will remain on solar photovoltaic modules having silicon crystalline cells.

BFRL has collected several years' worth of installed performance data on different building integrated photovoltaic (BIPV) products for wall and roof applications. BFRL will organize and archive these data in a format that is readily usable to computer modelers. BFRL will use the data to evaluate at least two computer models that can be used for predicting installed performance, focusing in FY09 on BIPV roofing products. This work benefits architects and building designers interested in making informed decisions on potential BIPV installations and complements the pursuit of PV ratings based on typical annual or daily operation.

Recent Results:

- *Output*: Fanney, A. H., Dougherty, B. P., and Davis, M. W., (2008) "A Comparison of Predicted to Measured Photovoltaic Module Performance," Awaiting publication in the ASME Solar Energy Engineering Journal.
- *Output*: Dougherty, B. P., "Rated Versus Installed Performance of Building Integrated Photovoltaic Products," ASHRAE Seminar Presentation, June 2008.
- *Outcome*: Outside entities (e.g., Natural Resources Canada, University of Wisconsin) are using NIST BIPV performance database to evaluate computer models.
- *Output*: Design, fabrication, and operation of the BIPV Roofing Test Facility[7], and the BFRL Long-Pulse Solar Simulator.

Standards and Codes: Project results will be presented during the next revision of ASTM Standards E927 and E1036. Brian Dougherty is a member of ASTM Technical Committee E44.

[7] See http://www.bfrl.nist.gov/863/bipv/Facility.htm