PV SYSTEMS VALIDATION – THE REGIONAL TEST CENTER CONCEPT

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ABSTRACT

Regional Test Centers (RTCs) have been established by the U. S. Department of Energy (DOE) at three different locations to independently validate the performance and reliability of photovoltaic (PV) systems, particularly for emerging US manufacturers, and to develop standardized processes for PV systems validation procedures. These locations (Albuquerque, NM; Denver, CO; and Orlando, FL) were chosen in part due to their different climate conditions, which can have a significant effect on system performance, degradation, and durability. The RTCs will provide the land and electrical infrastructure required to install up to 300-kW system blocks for validation. More importantly, the RTCs will provide the expertise of DOE’s national laboratories to assess and validate the performance and initial reliability in such detail that manufacturers, integrators and the financial community will develop greater confidence in the bankability of these systems.

1. INTRODUCTION

The U.S. Department of Energy Solar Energy Technology Program (SETP) has established goals for solar-generated power to account for 15 to 18 percent of the United States’ electricity generation by 2030 and for costs of solar energy to decrease by 75% before the end of the decade. To accomplish these goals, DOE established the SunShot Initiative (SunShot) to support efforts by commercial organizations, academia, and the national laboratories to improve photovoltaic (PV) technologies and promote best practices that will contribute to helping DOE meet these goals. Achievement of these targets will encourage higher penetration of large-scale solar energy systems that would be cost-competitive with fossil fuel-based forms of energy production.

To define specific strategic initiatives for DOE to support, promote and meet these targets, DOE held the PV Manufacturing Workshop at Lawrence Berkeley National Laboratory (LBNL) on March 25th, 2011 (1). This gathering included executive level participants from small and large US companies as well as from venture capital
companies, large banks, state economic development agencies, insurance companies, and national laboratories. The focus of the workshop was on how to increase domestic manufacturing and create jobs in the US PV industry. One of the main findings of the workshop was that there is an urgent need to lower the perceived technology risk for PV systems deployment, and especially for new technologies. The DOE’s national laboratories were identified as a potential resource that could play an important role in increasing bankability of new technologies by leading a national effort in testing and validation of new PV concepts and projects.

Specifically, the participating banks and insurance companies expressed support for DOE and the national laboratories taking a lead role in defining the validation criteria for PV components (e.g., modules, inverters, etc.). Stakeholders expressed that validation efforts should be focused on larger systems that are more representative of system sizes that are being installed (MW rather than kW scale) and should occur across a variety of regions that encompass different climatic forces that lead to reliability and degradation processes. For example, regions identified as important to include for validation included a hot, dry region and a hot, humid region. Participants also expressed that product validation should consist of testing a statistically significant selection of modules tested both outdoors and in the laboratory for performance and reliability.

In response to the issues raised at the PV Manufacturing Workshop, DOE initiated a new program in June 2011 to develop three Regional Test Centers (RTCs) intended to supplement SunShot programs to help advance the DOE’s production goals and build stakeholder confidence in new and existing PV technologies and projects. The RTCs are part of DOE’s plans to accelerate the maturation of the U.S. PV industry into a reliable and robust energy production sector that will encourage greater private investment. DOE SETP has chosen to develop these capabilities initially in three locations: near Denver, CO at the SolarTAC facility, managed by the National Renewable Energy Laboratory (NREL) (Steppe climate); Albuquerque, NM at the National Solar Thermal Test Facility managed by Sandia National Laboratories (Sandia) (hot-dry climate); and Orlando, FL at the University of Central Florida managed by the Florida Solar Energy Center (FSEC) (hot-humid climate). These three locations were chosen because they leverage significant expertise and funding already invested by DOE in photovoltaic testing, research, performance model development and reliability. These RTCs will be centers to validate the performance of PV systems, verify and validate models used to predict performance, collect detailed operations and maintenance (O&M) data, and investigate the role of various environmental (climatic) factors on reliability, durability, and safety of PV technologies. The concept for these RTCs is that they will host identical PV systems (10 kW – 300 kW size) at each of the three sites.

2. PV SYSTEMS VALIDATION

There are many reasons why systems could perform differently at different sites (solar resource, environmental conditions, etc.). One of the objectives of the validation work is to measure and document these differences with the goal of improving industry’s ability to predict the output of new technologies regardless of where they are deployed. Detailed performance monitoring is essential to ensure that the performance and reliability modeling tools used by industry and by independent engineers to assess bankability are able to predict power and energy output from such systems for any location over time. Detailed monitoring also enables early detection of module degradation, infant mortality failures, and early indicators of potential failure modes. The RTCs will draw on many years of experience with installing and validating renewable energy systems with industry partners, to lead the analysis of data gathered, and to assess the initial durability and reliability of the systems.

The validation plan developed by the RTC team is based on the testing and monitoring required to develop a technical data set to support bankability; the data and processes needed to develop standards and guidelines for performance validation, performance model validation, monitoring practices in the field, and data filtering; and the process for validating the test systems.

The validation plan is set up to assess all aspects of a PV system throughout its lifetime. It is organized into four main areas:

1. Design Evaluation and Acceptance Testing (Commissioning)
2. Performance and System Monitoring
3. Analysis and Modeling
4. Reliability and Safety

2.1 Design Evaluation and Acceptance Testing

PV system designs can vary significantly due to the variability in component characteristics, technology choices, and site specific factors. Activities that aim to validate a PV design to increase investor confidence include ensuring that the design is well documented, meets applicable codes, and the energy production from the system has been predicted in an acceptable way, using appropriate models and data. In order that performance
can be predicted accurately, it is essential to fully understand the ability of the manufacturer to characterize its products (e.g., module) and the capability of modeling software to represent these performance characteristics. Once the plant is built, it is important that the installation can be verified and that all components in the system are operating properly. The RTC team will work with the partners to verify the systems are designed and built to specifications. The RTC team will be responsible for independently testing a statistically significant sample of modules indoors and outdoors to verify the module manufacturer’s data set and power distribution provided.

2.2 Performance and System Monitoring

Each of the RTCs will use the same (or equivalent) metrology equipment, baseline test equipment for assessing module and string performance, and equipment for periodic testing in the field. In addition, there will be a recommended data monitoring system for collecting field performance data.

Each system will be monitored to detect component and system failures as well as to validate that the various components or parts of the system behave consistently and predictably.

At the top level, output power from each full system will be monitored at near real time. Monitoring at this level captures electrical performance of the entire system and will include monitoring on the AC and DC sides of the system relative to weather data recorded from a research grade meteorological system.

Monitoring at lower levels in the system (e.g., subarray, string, or even module) provides more detailed information about how consistently each part of the system is performing. Figure 1 shows an example of monitoring data at the string level. It demonstrates how monitoring data can help to identify problems. Data obtained at this lower level is especially useful for identifying component failures and problems, uneven soiling and possibly even degradation. For example, if a system is monitored at the string level, output from each string will be compared by normalizing output (e.g., by DC capacity).

Monitoring at points internal to the system (e.g., subarray, string, module) captures the DC electrical performance at the component or subsystem level but also costs more to implement and maintain. The RTCs will work with the specific RTC partner to define the appropriate level of monitoring. At a minimum we recommend monitoring 10% of the strings in the system.

Fig. 1. AC power vs. string-level DC power for three months. Different colors differentiate the strings and, in this case indicated a hardware failure in the DC monitoring system. The dashed line indicates 100% inverter efficiency.

The performance and inspection data will be summarized and shared with the RTC partners quarterly and will include monthly irradiance and power over time and monthly performance ratios. Figure 2 shows a plot of system power as a ratio to direct normal irradiance (DNI), demonstrating the uniformity of the system response to irradiance. Daily plots with daily profiles (calendar view) are also useful for comparing the performance over the month (Figure 3).

Fig. 3. Summary of a data set presented as a ratio of power to DNI.
4 Comparisons between predicted and measured data will be performed. This comparison can be done at a number of different levels.

a. Compare power and total energy produced over a given period.
b. Calculate a model residual (modeled quantity – measured quantity) and evaluate whether this “error” exhibits any systematic patterns (e.g., are residual errors correlated with other variables such as irradiance and temperature?). Such correlations can suggest possible model improvements and/or problems with the PV system or components. Figure 4 demonstrates an example of calculating residuals (2).

Fig. 4. Residual analysis plot showing the effect of irradiance on the accuracy of the model. The center plot demonstrates this model has a bias based on irradiance.

The goal is to share what is learned with the public with regard to analyzing the results of each test sequence. This may be in the form of protocols and procedures, or as reports based on aggregated data. Where appropriate, the RTCs will use existing standard test protocols. However, many areas of validation are currently not standardized. For these areas, the RTCs will write the protocols and update them based on results from the first installations.

The RTCs will develop standard data analysis packages based on the technical bankability requirements. This

2.3 Analysis and Modeling

For a PV technology to be “bankable” it must be predictable so that investors understand how the systems will function in a variety of environments and climates. The RTCs will provide a unique opportunity to test the ability of selected performance models in three distinct environments. Since performance models require sets of calibrated coefficients in order to run, it will be important to maintain a separation between calibration and model evaluation (and validation) activities.

A modeling analysis of a system’s performance will be done at regular intervals and will be reported to the partner. For each interval, the analysis will follow a series of steps:

1. Weather and performance data will need to be filtered to remove outliers and problematic data that cannot be explicitly represented in the model and will be rigorously documented (e.g., operational events, component failures, snow, etc.).
2. Model will be run to predict quantities of DC and AC power, module temperature, and DC voltage.
3. Both measured and modeled quantities will be used to calculate energy, energy yield (kWh/kWp), performance ratio (PR), AC efficiency, and power rating.

Fig. 3. Example “Calendar” plot comparing measured PV output power (black) and modeled PV output (red) for a fixed tilt system in Albuquerque. Data are 2-min averages.
information will be used to determine modeling uncertainties as well as performance issues, and to support the development of standardized methods for validating performance prediction algorithms. If the systems are under test for three or more years, the RTCs will have the opportunity to assess and quantify system losses such as soiling, degradation rates, module mismatch, and field failures, which will be tracked in an operations and maintenance database.

2.4 Reliability and Safety

Validating the reliability of a PV system is an important attribute that investors consider. Product design or manufacturing flaws may not be evident initially. The RTCs will perform a series of periodic tests and inspections over the deployment period of nominally three years to identify any failures, concerns, or leading indicators of any reliability or safety problems that may occur in the future. Periodic testing may include: current-voltage curve traces in the field at the string and/or module level; flash testing a subset of modules using a module-scale solar simulator; infrared and electroluminescence imaging; and digital photographs. In addition, all maintenance events (scheduled and unscheduled) will be logged along with any energy lost due to system downtime.

3. Partnering with the RTCs

There are two types of partners expected to work with the RTCs: system designers (e.g., integrators, utilities, or integrated teams along the value chain) and module manufacturers. In each case, the RTCs will work with the partner prior to installation to ensure all regional requirements are understood, and to determine the best level of monitoring and the optimal validation process for that partner’s technology and system design. For example, if a partner is interested in installing high concentration photovoltaic systems, the RTCs would recommend adding tracking error monitors to a subset of the trackers.

For system designers we anticipate the partner will design, procure and install systems at each location, in the 50 kW – 300 kW range, representing a typical block size for a commercial or utility scale installation. For module manufacturers, each partner may provide 10 kW – 50 kW worth of modules to each RTC. The RTC team will work with an integrator and local installers to design the systems, procure the balance of systems components, and install the systems.

In each case, the RTCs will provide the baseline monitoring equipment and will perform all testing and analysis associated with the validation work. In addition, partners will receive regular reports as outlined in section 2. Data ownership will be negotiated with each partner. It is anticipated that each partner will have primary ownership of the data, and that the RTCs will use the data to develop the standards and protocols discussed above and to publish results in a normalized or aggregated format. Partners will be able to share their results with independent engineering firms, financing firms and insurance companies in support of bankability assessments. Data sets and analyses will only be made publicly available if agreed to by the partner.

Due to the existing capacity of 1 MWac at each location, there will be a limited number of partnerships of each type allocated. DOE SETP and the RTC team will be responsible for developing the acceptance criteria and DOE will be responsible for selecting partnerships.

4. Summary

The RTCs have been established by the DOE to independently validate the performance and reliability of PV systems. The RTC team has developed a baseline validation and analysis plan to assess the performance, initial reliability, and predictability of these systems. The validation and analysis processes will be applied to systems from partners selected by DOE and the processes will be continuously improved. The goal of the RTCs is to create and substantiate protocols and standards for module and systems validation, and to implement these such that manufacturers, integrators and the financial community will develop greater confidence in the bankability of these systems.

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6. References

(1) Executive Summary of the PV Manufacturing Workshop held March 25, 2011; http://www1.eere.energy.gov/solar/sunshot/m/past_workshops.html#PV