A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

Innovation for Our Energy Future

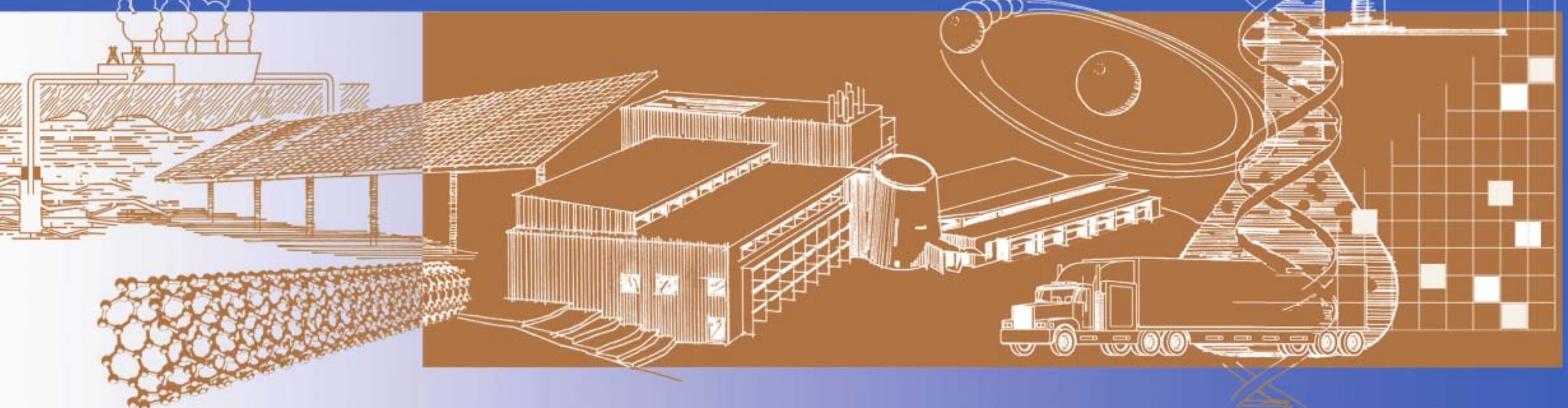
# PV System Performance and Standards

C.R. Osterwald

*Conference Paper*
**NREL/CP-520-38932**
**November 2005**

*Presented at the 2005 DOE Solar Energy Technologies Program Review Meeting*
*November 7–10, 2005*
*Denver, Colorado*

NREL is operated by Midwest Research Institute ● Battelle Contract No. DE-AC36-99-GO10337



Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

# PV System Performance & Standards

C.R. Osterwald
National Renewable Energy Laboratory, Golden, Colorado, carl_osterwald@nrel.gov

## ABSTRACT

This paper presents a brief overview of the status and accomplishments during fiscal year (FY) 2005 of the Photovoltaic (PV) System Performance & Standards Subtask, which is part of the PV Systems Engineering Project (a joint NREL-Sandia project).

## 1. Objectives

The objectives of this project, as stated in the FY 2005 Solar Program Annual Operating Plan (AOP), are to provide "…PV emerging-technology, small grid-connected, system performance and reliability data, analyses, and characterizations to the Solar Program and to the participating industry partners."

## 2. Technical Approach

Long-term testing of prototype modules in small systems, both grid-tied and stand-alone, provides information about reliability and performance on statistically significant numbers of modules. Development of PV consensus standards is supported through several subcontracts as well as in-house participation on PV standards committees. Cooperation and joint projects with PV manufacturers, systems integrators, and utilities are used to aid identification of potential problems prior to widespread commercial deployment.

## 3. Results and Accomplishments

### *3.1 PV Standards*

PV standards development was supported through a number of subcontracts, including the U.S. PV certification program, PowerMark Corp., and the Secretariat position of the International Electrotechnical Commission (IEC) Technical Committee for PV (TC-82). These subcontracts are reported elsewhere at this review meeting.[1] Support for ASTM PV standards activities continued through chairing subcommittee E44.09 on Photovoltaic Electric Power Conversion. Task staff members also participate on the IEEE SCC21 PV Battery and Stand-Alone Systems working group.

### *3.2 Outdoor Test Facility (OTF) Systems*

This project emphasizes testing small PV systems for two reasons. First, testing an array of modules provides greater statistics compared with testing single modules. Second, by using grid-tied arrays, the test modules are operated in an electrical environment that is identical or very similar to that of actual use. These PV systems are fully instrumented with data acquisition systems on both the DC and AC sides, and are carefully maintained and calibrated. A multiple regression against total irradiance, ambient temperature, and wind speed is applied to array DC output power to obtain the system rated power at Performance Test Conditions (PTC), namely 1,000 W/m$^2$ total irradiance, 20°C ambient temperature, and 1 m/s wind speed, for a month of data. The monthly PTC regressions are plotted versus time to examine trends in the system performance, especially degradation rates.[2] Results of the PTC regressions are communicated directly to the respective manufacturers quarterly.

PV systems currently monitored at the OTF and Solar Energy Research Facility (SERF) are:

- BP Solar a-Si Millennia, 1.8 kW, 40 modules, 1998 (dismantled July 2005; final report to be published as journal article and is also reported at this meeting[3])
- Siemens (now Shell) Solar CIGSS, 1.1 kW, 28 modules, 1998 (not grid-tied)
- ASE Americans (now RWE Schott) EFG ribbon Si, 1.4 kW, 5 modules, 1995
- First Solar CdTe, 1.2 kW, 24 modules, 2003
- USSC (now Uni-Solar) a-Si, 2.2 kW, 102 modules, 1992
- USSC a-Si roofing shingles, 1.2 kW, 72 modules, 1998
- Solar Cells Inc. (now First Solar) CdTe, 1.0 kW, 24 modules, 1995
- APS a-Si on single-axis Delta tracker, 1.7 kW, 30 modules, 1996 (dismantled January 2005 after complete failure of tracker)
- Siemens (now Shell) Solar crystalline-Si on SERF east roof, 6.3 kW, 140 modules, 1994[3]
- Siemens (now Shell) Solar crystalline-Si on SERF west roof, 6.3 kW, 140 modules, 1994[3]
- SunPower crystalline-Si, 1.0 kW, 5 modules, 2005 (see Fig. 1).

Two new grid-tied systems that are planned or under construction at the time of this writing include a 1 kW Shell Eclipse 80-C array and a second 1 kW SunPower crystalline-Si array. These should be operational early in FY 2006.

### *3.3 PVWATTS*

Improvements to the PVWATTS software, an Internet-accessible simulation tool originally developed in 1999 for providing quick estimates of the electrical energy produced by a grid-connected PV system, were completed.[4] PVWATTS can be accessed at: http://rredc.nrel.gov/solar/calculators/PVWATTS/.

Major improvements include:

- The PV system specification input for system size was changed from an AC power rating to a nameplate DC power rating. The nameplate DC power rating information is more readily available, and is less open to interpretation as to how it is determined, than is an AC power rating. A nameplate DC power rating is also more consistent with how energy performance is reported for fielded systems and how most PV systems are currently marketed.
- An input for an overall DC-to-AC derate factor was added for calculating a reference AC power rating by PVWATTS. The user may also have PVWATTS calculate a new overall DC-to-AC derate factor by specifying individual PV system component derate factors (11 possible). This offers more transparency for the loss factors used by PVWATTS and permits loss factors to be changed, if desired, to better match system-specific components or loss mechanisms. A default DC-to-AC derate factor allows novice users to obtain realistic results without a detailed knowledge of system components.

*3.4 External PV Systems Assistance*

Staff members working on this task also provide assistance with PV systems to external organizations on an informal basis. Examples include:

- Assisted the Warsaw University of Technology Centre for PV with the establishment of an outdoor test facility
- Designed and installed a new data acquisition system and program for the Rocky Mountain Oil Test Center PV pumping station in Wyoming
- Discussed with Raytheon Polar Services a PV system to power their Black Island Telecommunications Facility in January 2006 in Antarctica
- Responded to a question from the University of Michigan, Center for Sustainable Systems regarding the monitoring of a 30-kW PV system installed on the roof of their building
- Helped a person involved with the 2005 Solar Decathlon who needed information about how bypass and blocking diodes affect PV array performance.

## 4. Conclusions

Progress has been made in the study of PV system performance, and efforts are underway to expand this work in the future. All milestones for this subtask listed in the FY 2005 AOP have been met.


## ACKNOWLEDGEMENTS

The bulk of the work on this subtask was performed by members of the Engineering and Technology Validation Team: Jill Adelstein, Joe del Cueto, Bob Hansen, Bill Marion, Peter McNutt, Jim Pruett, Bill Sekulic, and Dave Trudell. Members of the PV Measurements and Characterization Group generate many I-V curves that are an integral part of this work: Steve Rummel, Allan Anderberg, and Larry Ottoson. This work was supported by the U.S. Department of Energy under contract DE-AC36-99GO10337.


## REFERENCES


[1]T.S. Basso, H.O. Barikmo, and S. Chalmers, "Photovoltaic System and Component Certification and Test Facility Accreditation, and Photovoltaic Energy Systems International Standards," *Proc. of the DOE Solar Energy Tech. Prog. Review Meeting*, Denver, CO, Nov. 7-10, 2005.

[2]J. Adelstein, "Small Systems PV Degradation," *Proc. of the DOE Solar Energy Tech. Prog. Review Meeting*, Denver, CO, Nov. 7-10, 2005.

[3]P. McNutt, J. Adelstein, and B. Sekulic, "Solarex 1.2-kWac a-Si System Performance Evaluation — Final Report." *Proc. of the DOE Solar Energy Tech. Prog. Review Meeting*, Denver, CO, Nov. 7-10, 2005.

[4]B. Marion, "Recent Revisions to PVWATTS," *Proc. of the DOE Solar Energy Tech. Prog. Review Meeting*, Denver, CO, Nov. 7-10, 2005.


## MAJOR FY 2005 PUBLICATIONS


B. Marion, J. Adelstein, K. Boyle, H. Hayden, B. Hammond, T. Fletcher, S. Canada, D. Narang, A. Kimber, L. Mitchell, G. Rich, and T. Townsend, "Performance Parameters for Grid-Connected PV Systems," *Proc. 31st IEEE PV Spec. Conf.*, Jan. 3-7, 2005, 1601-1606.

J. Adelstein and B. Sekulic, "Performance and Reliability of a 1 kW Amorphous Silicon Photovoltaic Roofing System," *Proc. 31st IEEE PV Spec. Conf.*, Jan. 3-7, 2005, 1627-1630.


Fig. 1. The first of two new SunPower crystalline Si grid-tied systems recently installed in the OTF array field.

| **REPORT DOCUMENTATION PAGE** | *Form Approved OMB No. 0704-0188* |
|---|---|



| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| November 2005 | Conference Paper | |

**4. TITLE AND SUBTITLE**
PV System Performance & Standards

**5a. CONTRACT NUMBER**
DE-AC36-99-GO10337

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
C.R. Osterwald

**5d. PROJECT NUMBER**
NREL/CP-520-38932

**5e. TASK NUMBER**
PVC6.7101

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

**8. PERFORMING ORGANIZATION REPORT NUMBER**
NREL/CP-520-38932

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSOR/MONITOR'S ACRONYM(S)**
NREL

**11. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**12. DISTRIBUTION AVAILABILITY STATEMENT**
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT** *(Maximum 200 Words)*
This paper presents a brief overview of the status and accomplishments during fiscal year (FY) 2005 of the Photovoltaic (PV) System Performance & Standards Subtask, which is part of the PV Systems Engineering Project (a joint NREL-Sandia project).

**15. SUBJECT TERMS**
Photovoltaics; solar; system performance; standards; PV; NREL

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | |
| Unclassified | Unclassified | Unclassified | UL | | 19b. TELEPONE NUMBER *(Include area code)* |