

Results from the Second International Module Intercomparison

S. Rummel, A. Anderberg, and K. Emery

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

Conference Paper
NREL/CP-520-38938
November 2005

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



NOTICE

The submitted manuscript has been offered by an employee of the Midwest Research Institute (MRI), a contractor of the US Government under Contract No. DE-AC36-99GO10337. Accordingly, the US Government and MRI retain a nonexclusive royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for US Government purposes.

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

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>



Results from the Second International Module Intercomparison

S. Rummel, A. Anderberg, and K. Emery
National Renewable Energy Laboratory, Golden, Colorado, steve_rummel@nrel.gov

ABSTRACT

The peak-watt rating is a primary indicator of PV performance. The peak power rating is the maximum electrical power that is produced when the PV device is continuously illuminated at 1000 Wm⁻² total irradiance under International Electrotechnical Commission Standard 60904-2 reference spectrum, and 25°C cell temperature. Most manufacturers trace their peak-watt rating through calibrations performed at recognized terrestrial calibration facilities. Manufacturers typically perform intercomparisons among a set of their modules internally with other plants and among. Sometimes they have the same module measured at different calibration facilities to determine the differences in calibration. This intercomparison was to mimic this procedure and supply new thin film samples along with samples that could pose other problems. These intercomparisons sample the laboratories' everyday procedures better than a formal intercomparison where the laboratories' best procedures and data scrutiny are used.

1. Objectives

The objective of this intercomparison is to assess the capability of ISO 17025-accredited and national calibration facilities to evaluate the performance of modules of interest to the DOE program. Previous formal intercomparisons included reference cells made at the same time as the module. Modules submitted to NREL for calibration rarely have an accompanying reference cell. Previous intercomparisons also did not include multi-junction amorphous Si, CdTe, or Cu(In,Ga)(S,Se) modules. Laboratories accredited to international standards are required by ISO standard 17025 to demonstrate their proficiency in performing calibrations through periodic intercomparisons.¹ The PV testing group at NREL was recently accredited to perform secondary module calibrations. Typically these intercomparisons are limited in the number of participants. The most comprehensive formal intercomparison of module calibrations was carried out by PTB from 1985 to 1989.^{2,3} This intercomparison among national module calibration facilities was known as PEP '87 (Photovoltaic Energy Project) with participants representing the United States, Japan, Italy and the European Union.^{2,3}

2. Technical Approach

A wide range of samples was selected to show just how difficult some of the new PV devices were to measure. The 14 intercomparison modules were two each of mono-Si (Shell Solar), multi-Si

(AstroPower), CdTe (BP Solar), CIGS (Shell Solar), two multi-junction a-Si (United Solar, BP Solarex), and GaAs concentrator modules. Prior to circulation the nonconcentrator modules were mounted outdoors with load resistors and exposed to over 720 kWhm⁻² of sunlight. The concentrator module participated in the PEP'87 intercomparison.^{2,3} NREL hosted the intercomparison and covered all shipping and customs issues. Because of location and personnel changes, the Japanese national PV calibration facility, AIST, was unable to participate. If participants asked for spectral responsivity NREL provided what it typically receives, a curve claimed to be representative. The participants were NREL, Sandia, Florida Solar Energy Center, and Arizona State University in the United States, Fraunhofer ISE (Germany), TUV Rheinland (Germany), Energy Systems Testing Unit (European Union), JET (Japan), and LEEE-TISO (Switzerland). The Chinese (TIPS), and French (LCIE) declined to participate.

3. Results and Accomplishments

From the previous PEP module intercomparison the dispersion in the short-circuit current (I_{sc}) for the six modules tested was around 4% for the mono-Si and multi-Si and 6% for the a-Si module.^{2,3} The dispersion in Voc was 1.5% for the amorphous silicon modules and 2 to 5% for the mono-Si and multi-Si.^{2,3} These differences were larger than can be explained by temperature, since supposedly all data was corrected to 25°C. The dispersion in the fill factor was around 2%.^{2,3} The differences in fill factor and Voc were surprising to the participants and could not be satisfactorily explained. This indicates that among various calibration labs around the world, differences of 2% to 5% in I_{sc} and 3% to 8% in peak power rating can typically be expected.

Another limited intercomparison among U.S. manufacturers and module calibration labs was hosted by NREL and was conducted from 1992 to 1994 to evaluate ASTM standard E1036.⁴ A packaged cell representative of the module spectral responsivity was included to facilitate spectral responsivity measurements. The dispersion among the four laboratories participating in the ASTM intercomparison was around 5%. The module technologies were mono-Si and multi-Si with four wires attached to the module along with a thermocouple bonded to the back of the module to minimize contacting related differences. The reported maximum power points (P_{max}) for three of the four labs were within 2% of each other for the six modules that were circulated.⁴

The results from this current intercomparison are summarized in Table 1 and Table 2. Many participating labs did not or chose not to measure the concentrator module or thin-film modules.

4. Conclusions

The uncertainty in P_{max} with respect to standard reference conditions of a commercial module measured at a competent PV calibration facility cannot be expected to be less than +/-3% based upon this intercomparison. Most of the difference can be attributed to differences in the short-circuit current. Many groups did not measure the thin-film or concentrator modules because they were outside their scope of capabilities. The range in P_{max} among the limited number of calibration labs for thin-film technologies is much larger approaching +/-6%.

ACKNOWLEDGEMENTS

The work was performed under DOE contract DE-AC36-99-GO10337

REFERENCES

- ¹“General requirements for the competence of testing and calibration laboratories,” ANSI/ISO standard 17025 (2005).
- ²J. Metzdorf, T. Wittchen, K. Heidler, K. Dehne, R. Shimokawa, F. Nagamine, H. Ossenbrink, L. Fornarini, C. Goodbody, M. Davies, K. Emery, and R. Deblasio, “Objectives and Results of the PEP '87 Round-Robin Calibration of Reference Cells and Modules,” *Proc. 21st IEEE PVSC*, 952 (1990)
- ³J. Metzdorf, et. al., “The Results of the PEP '87 Round-Robin Calibration of Reference Cells and Modules,- Final Report” PTB technical report PTB-Opt-31, Braunschweig, Germany, ISBN 3-89429-067-6 (1990).
- ⁴C. Osterwald, “Results of 1992 ASTM Cell and Module Measurement Intercomparison,” *Proc. 23rd IEEE PVSC*, 1102 (1993).

Table 1. Comparison of I_{sc} measurements in percent deviation from average. The participants are listed in the order they received the modules.

Type	Module #	$\langle I_{sc} \rangle, A$	NREL	Sandia	ASU	FSEC	ESTI	LEEE	TUV	ISE	JET	NREL
mono-Si	SIE0577	4.273	-2.8	2.0	0.6	0.9	0.1	-1.5	-0.5	-0.4	1.0	-2.2
	SIE0586	4.336	-2.6	2.6	0.3	-0.1	0.2	-1.3	-0.4	-0.2	0.8	-1.9
multi-Si	AsP0123	3.537	-2.7	1.6	0.1	-	1.8	-1.9	-1.0	0.9	-0.1	-1.5
	AsP0247	3.504	-2.1	2.1	-0.4	-	1.5	-2.4	0.5	0.4	-0.2	-1.5
a-Si/a-Si:Ge	BPS4213	2.913	-1.3	6.4	2.6	-	-12.4	-	4.7	-	-	2.0
	BPS4223	2.891	0.7	4.4	4.8	-	-7.4	-	-2.5	-	-	4.2
a-Si/a-Si/ a-Si:Ge	USSC234	1.449	1.7	0.7	2.8	-	-3.5	-	1.4	-	-	-1.4
	USSC382	1.458	1.2	1.1	2.2	-	-2.1	-	0.1	-	-	-1.2
CdTe	BP4405	3.081	-2.8	0.8	1.3	-	0.6	-	-2.6	-	-	0.1
	BP4505	3.079	-3.5	0.9	1.0	-	0.6	-	-1.9	-	-	-0.7
Cu(GaIn)(S,Se)	Sie9257	2.653	-1.8	2.5	1.0	-	0.5	-	-2.4	-	-	-1.7
	Sie9260	2.541	-2.7	4.1	0.7	-	0.9	-	-3.6	-	-	-2.2
GaAs Concentrator	PTEL#1	3.049	0.3	1.9	-	-	-4.5	-	-	-	-	2.6
	PTEL#2	2.916	-0.4	2.9	-	-	-6.2	-	-	-	-	3.2

Table 2. Comparison of Peak Power (P_{max}) measurements in percent deviation from average.

Type	Module #	$\langle P_{max} \rangle, W$	NREL	Sandia	ASU	FSEC	ESTI	LEEE	TUV	ISE	JET	NREL
mono-Si	SIE0577	66.84	-2.9	3.2	1.6	-4.2	0.4	-0.2	-0.2	0.8	1.3	-2.6
	SIE0586	67.22	-3.2	2.9	1.3	-4.2	0.4	0.6	-0.6	0.7	1.7	-2.8
multi-Si	AsP0123	51.54	-3.5	1.7	0.7	-	0.9	-1.4	0.3	0.8	-0.6	-2.4
	AsP0247	52.87	-3.1	1.8	0.6	-	1.4	-1.5	0.1	0.6	-0.9	-2.1
a-Si/a-Si:Ge	BPS4213	41.04	4.8	-0.3	2.3	-	-7.2	-	3.3	-	-	1.8
	BPS4223	36.82	3.7	1.8	3.7	-	-3.3	-	-3.9	-	-	1.6
a-Si/a-Si/ a-Si:Ge	USSC234	19.24	3.2	-0.6	-0.2	-	-7.8	-	9.1	-	-	-0.5
	USSC382	19.41	2.7	-0.5	-0.6	-	-7.2	-	8.7	-	-	-0.5
CdTe	BP4405	84.13	0.1	-0.7	4.7	-	-2.9	-	-1.0	-	-	-0.1
	BP4505	87.96	-1.3	-0.5	4.1	-	-3.4	-	-1.0	-	-	0.7
Cu(GaIn)(S,Se)	Sie9257	40.54	-3.3	5.0	3.1	-	-3.1	-	-1.3	-	-	-3.7
	Sie9260	40.10	-3.5	7.6	4.2	-	-4.7	-	-3.0	-	-	-4.1
GaAs Concentrator	PTEL#1	3.015	3.3	0.8	-	-	-3.8	-	-	-	-	3.0
	PTEL#2	2.913	-0.3	3.0	-	-	-7.3	-	-	-	-	4.3

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE (DD-MM-YYYY) November 2005		2. REPORT TYPE Conference Paper		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Results from the Second International Module Intercomparison				5a. CONTRACT NUMBER DE-AC36-99-GO10337	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) S. Rummel, A. Anderberg, and K. Emery				5d. PROJECT NUMBER NREL/CP-520-38938	
				5e. TASK NUMBER PVA6.3401	
				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-520-38938	
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) The peak-watt rating is a primary indicator of PV performance. The peak power rating is the maximum electrical power that is produced when the PV device is continuously illuminated at 1000 Wm ⁻² total irradiance under International Electrotechnical Commission Standard 60904-2 reference spectrum, and 25°C cell temperature. Most manufacturers trace their peak-watt rating through calibrations performed at recognized terrestrial calibration facilities. Manufacturers typically perform intercomparisons among a set of their modules internally with other plants and among. Sometimes they have the same module measured at different calibration facilities to determine the differences in calibration. This intercomparison was to mimic this procedure and supply new thin film samples along with samples that could pose other problems. These intercomparisons sample the laboratories' everyday procedures better than a formal intercomparison where the laboratories' best procedures and data scrutiny are used.					
15. SUBJECT TERMS Photovoltaics; solar; module intercomparison; PV; NREL					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code)