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Results from the Second International Module Intercomparison

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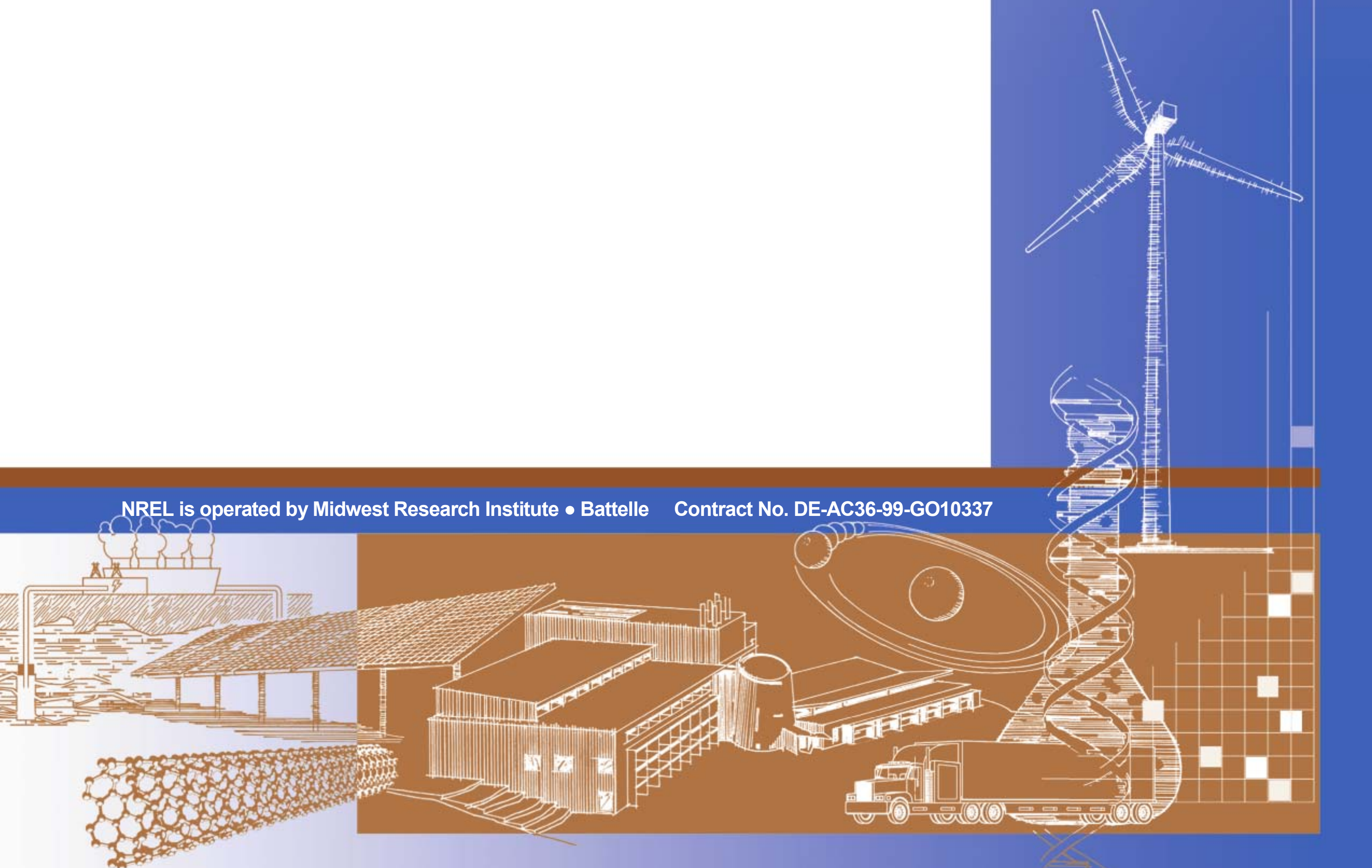

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Results from the Second International Module Intercomparison

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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 know 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 $kWhrm^{-2}$ 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

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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/	USSC234	1.449	1.7	0.7	2.8	-	-3.5	-	1.4	-	-	-1.4
a-Si:Ge	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	PTEL#1	3.049	0.3	1.9	-	-	-4.5	-		-	-	2.6
Concentrator	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/	USSC234	19.24	3.2	-0.6	-0.2	-	-7.8	-	9.1	-	-	-0.5
a-Si:Ge	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	PTEL#1	3.015	3.3	0.8	-	-	-3.8	-	-	-	-	3.0
Concentrator	PTEL#2	2.913	-0.3	3.0	-	-	-7.3	-	-	-	-	4.3

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