Third Party Validation of First Solar PAN Files

This document provides information demonstrating that First Solar PVSyst PAN files accurately predict module behavior according to IEC 61853 standards. First Solar demonstrates this by having CFV Solar Test Laboratories conduct measurements on First Solar modules (Series 3 Black Plus, Series 4, Series 4V2, and Series 4V3) according to the IEC 61853 standard and then compares those results to First Solar provided PAN files. This comparison shows that characteristics incorporated into PAN files are in strong agreement with independent third party IEC 61853 testing of the same characteristics.

Background

The IEC 61853 is an International Standard that establishes module performance testing and energy rating. This standard contains multiple parts which consist of guidelines to recording performance measurements at a variety of irradiance levels and temperatures, spectral response, incidence angle, and module operating temperature measurements. Also included is a description of calculations for energy rating and standard performance climate profiles. The data generated from IEC 61853-1 and 61853-2 provides the information necessary to generate PAN files.

Test Procedure

First Solar sent three of each module series (Series 3 Black Plus, Series 4, Series 4V2 and Series 4V3) to CFV Test Laboratories in Albuquerque, New Mexico. Each of the modules was then placed outside for a minimum of three weeks to ensure full recovery of dark storage conditions. Modules were then subjected to IEC 61853-1 testing of power, current and voltage at multiple irradiances (100, 200, 400, 600, 800, 1000, 1100 W/m^2) and temperatures (15, 25, 50, 65 degrees C).

After 61853-1 testing was complete, modules were subjected to the tests outlined in IEC 61853-2 which include angle-of-incidence (AOI), Quantum Efficiency (QE) and Nominal Module Operating Temperature (NMOT). Angle of Incidence testing was performed outdoors on a two-axis tracker. The tracker was moved from a position normal to the sun to a position 90° off angle at variations of 10° to 5°. Meanwhile, short-circuit current (I_{sc}) and key atmospheric variables were monitored. NMOT measurements were conducted on a fixed tilt south facing rack with the angle of the rack adjusted so that the modules were within ±5° of normal to the sun at solar noon. NMOT values were collected on ten days where the environmental conditions specified in the IEC standard were met. The modules were held at their maximum power point throughout the duration of the test with no correction factor for environmental conditions applied. Spectral response measurements were done by Fraunhofer ISE in Germany. One of each full sized module (Series 3 Black Plus, 4, Series 4V2, and Series 4V3) was measured. A Pasan flash simulator with a filtering system was used to measure the spectral response from 350 to 920 nm.

A full copy of the CFV Test Reports can be found in Appendix C. Power, voltage and current at a variety of temperatures and irradiances were extracted from First Solar PAN files using the PVsyst extraction tool for comparison to the CFV measured values. These values are available in Appendix D.

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Discussion

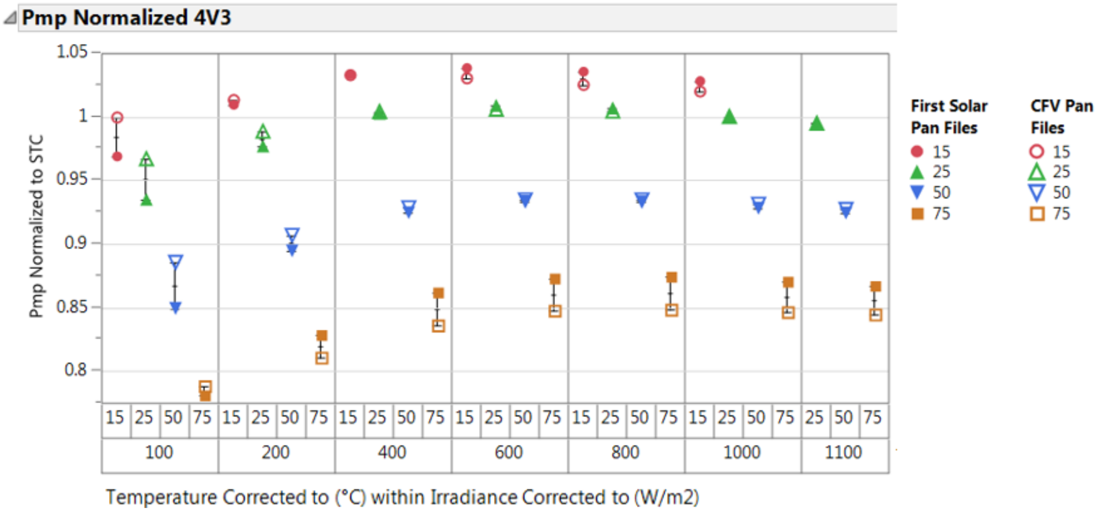
A comparison of the power at standard test conditions (STC) is shown in Table 1. All modules measured higher than nameplate at CFV, with the Series 4V2 module measured the highest at more than 8% above nameplate. The appearance of this discrepancy could be due to the fact that the S4V2 modules were an early release of this module type with a higher engineered performance margin (EPM) than the standard. Please look to First Solar's Guidance on Product Bins and Distribution (PD-5-800) for more information. The EPM change combined with the 3% measurement uncertainty may account for the difference in measured module power.

Table 1. Power at STC compared to nameplate power

First Solar	Nameplate Power (W)	CFV Measured Power (W)	Difference (CFV-FS)
Series 3 Black Plus	95	97	2.10%
Series 4	100	100.2	0.20%
Series 4v2	102.5	111.1	8.40%
Series 4V3	112.5	118.2	5.10%

Since First Solar PAN files are developed such that the power at 25°C and 1000W/m^2 is equal to nameplate power, subsequent comparisons will normalize out the difference between the measured power at STC and the nameplate value. Power normalized to power at STC ($P_{mp,norm}$) was compared between the CFV data and First Solar PAN file data (Figure 1). Figures for Series 3 Black Plus, Series 4, and Series 4V2 are shown in Appendix A.

Figure 1. Comparing Power Normalized to STC for Series 4V3



The largest deviation in $P_{mp,norm}$ between First Solar's data and CFV's data for the Series 4V3 module is 4.09% and occurs at 50°C and 100 W/m^2. The average discrepancy across all irradiances and temperature for Series 4V3 is -0.18%. Table 2 shows the average percent difference of the Power maximum point P_{mp} with consideration to temperature and irradiance.

Table 2. Average $P_{mp,norm}$ Percent Difference

First Solar and CFV Results Comparison for Series 4v3				Average Percent Difference (CFV-FS)			
				0.13%	0.57%	0.97%	-2.27%
				Temperature			
				15°C	25°C	50°C	65°C
Average Percent Difference (CFV-FS)	2.84%	Irradiance	100 (W/m^2)	3.07%	3.31%	4.09%	0.90%
	0.17%		200 (W/m^2)	0.37%	1.18%	1.35%	-2.20%
	-0.65%		400 (W/m^2)	-0.05%	0.14%	0.42%	-3.10%
	-0.98%		600 (W/m^2)	-0.78%	-0.30%	0.14%	-2.97%
	-1.04%		800 (W/m^2)	-1.01%	-0.26%	0.15%	-3.06%
	-0.82%		1000 (W/m^2)	-0.80%	0.00%	0.33%	-2.82%
	-0.80%		1100 (W/m^2)	**	-0.06%	0.32%	-2.66%

As part of IEC 61853-2 testing, CFV measured the angle of incidence response (IAM) of each of the modules tested. First Solar PAN files include IAM response curves which were measured by PVEL for Series 3 Black Plus, Series 4, Series 4v2 and Series 4V3 (see Appendix B for PVEL report). A comparison of the two data sets shows that the maximum difference is +/-1.53% and occurs at 55 degrees. The performance of each series of module is muddled with the natural variation that occures during AOI testing and should not be cause for concern.

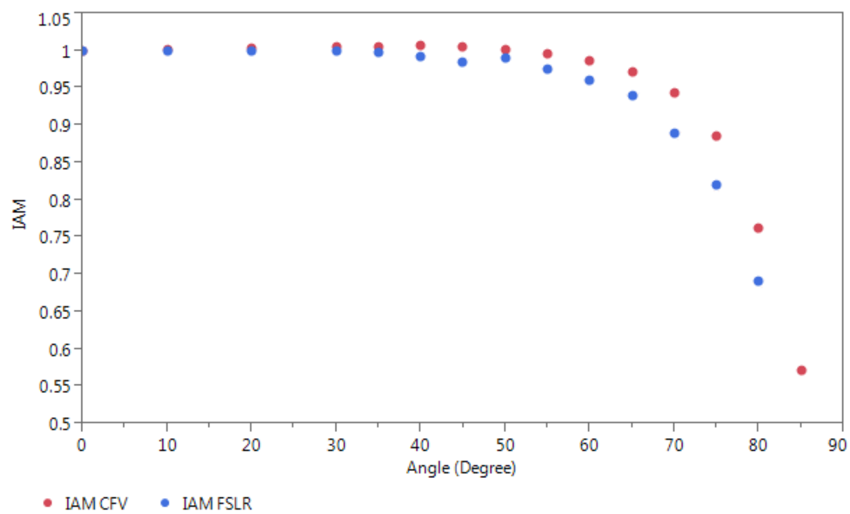


Figure 2. Comparing First Solar and CFV Angle of Incidence

Table 3. Comparing First Solar and CFV Angle of Incidence

AOI (deg)	CFV Results					First Solar Results					Average Percent Difference (CFV-FS)
	395-Plus (ARC)	395-Plus	4V1 (ARC)	4V2	4V3	395-Plus (ARC)	395-Plus	4V1 (ARC)	4V2	4V3	
0	1	1	1	1	1	1	1	1	1	1	0.00%
30	0.99	0.99	0.99	1	1	1	1	1	1	1	-0.60%
55	0.97	0.95	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.975	-1.53%
60	0.95	0.94	0.97	0.97	0.97	0.98	0.96	0.98	0.96	0.96	-0.83%
65	0.94	0.91	0.95	0.95	0.94	0.96	0.94	0.96	0.94	0.94	-1.06%
70	0.90	0.87	0.92	0.91	0.90	0.92	0.89	0.92	0.89	0.89	-0.22%
75	0.83	0.79	0.86	0.84	0.82	0.85	0.82	0.85	0.82	0.82	-0.48%
80	0.70	0.68	0.74	0.72	0.65	0.72	0.69	0.72	0.69	0.69	-0.57%

Module Energy Ratings

In order to estimate the expected difference in an energy prediction using First Solar's PAN files as compared to PAN files generated from CFV's 61853 data, the data presented in the previous section was used to generate a module energy rating for seven different climates. The procedure for doing this follows the requirements in the draft standards IEC 61853-3 and 61853-4 for the different locations.

Table 4. Comparing First Solar and CFV Climate Specific Energy Ratings

Location	**FS S3 Black Plus**		**FS S4**		**FS S4V2**		**FS S4V3**	
	CSER CFV	CSER FSLR	CSER CFV	CSER FSLR	CSER CFV	CSER FSLR	CSER CFV	CSER FSLR
Desert location	79.3%	78.6%	79.1%	78.7%	80.5%	79.0%	79.1%	79.1%
High Elevation	78.3%	80.8%	78.4%	80.9%	79.6%	82.7%	81.9%	81.1%
Mediterranean	78.7%	78.5%	78.8%	78.9%	80.4%	79.4%	79.5%	79.2%
Temperate Continental	79.4%	80.0%	79.3%	80.0%	80.9%	81.0%	81.3%	80.4%
Temperate Coastal	79.0%	80.9%	78.8%	80.5%	80.5%	82.0%	82.5%	81.0%
Tropical Humid	82.7%	81.6%	82.7%	82.2%	84.7%	82.5%	83.1%	82.5%
Tropical Semi-Arid	81.2%	80.2%	81.3%	80.6%	82.9%	80.8%	81.4%	81.0%

First Solar.

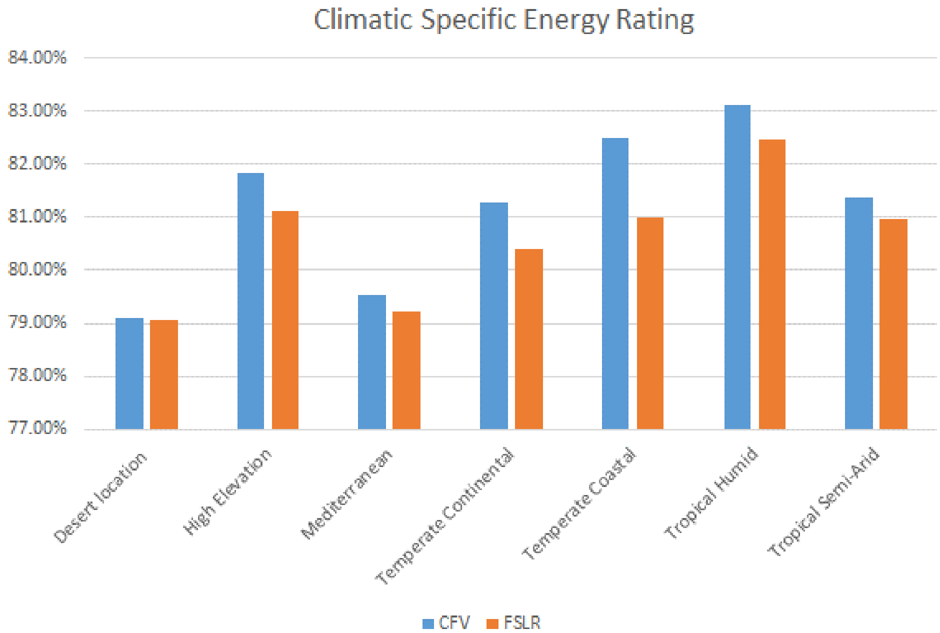


Figure 3. Comparing First Solar and CFV Climate Specific Energy Ratings for Series 4V3

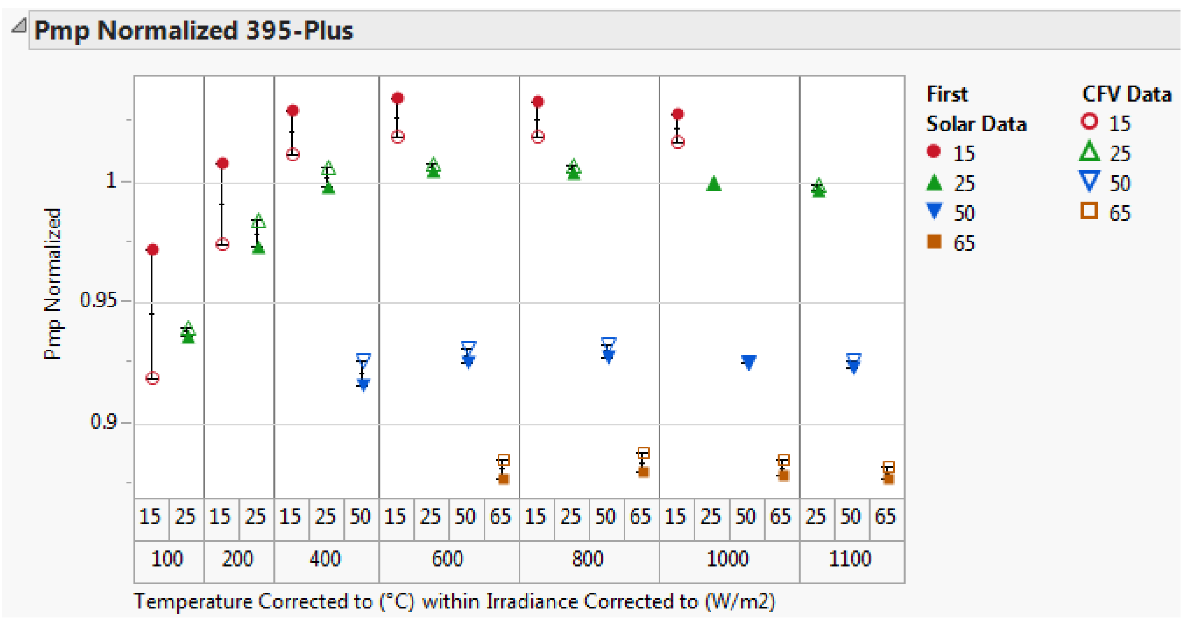
The Climate Specific Energy Rating (CSER) was used used to evaluate the PAN files as outlined in the IEC 61853-3. This quantity is interchangeable with the a Perfromance Ratio for a plant. CSER is the normalized energy collection for the reference climatic profile, this equation is outlined below.

$$CSER = \frac{E_{mod,year}}{P_{max,STC} * H_p}$$

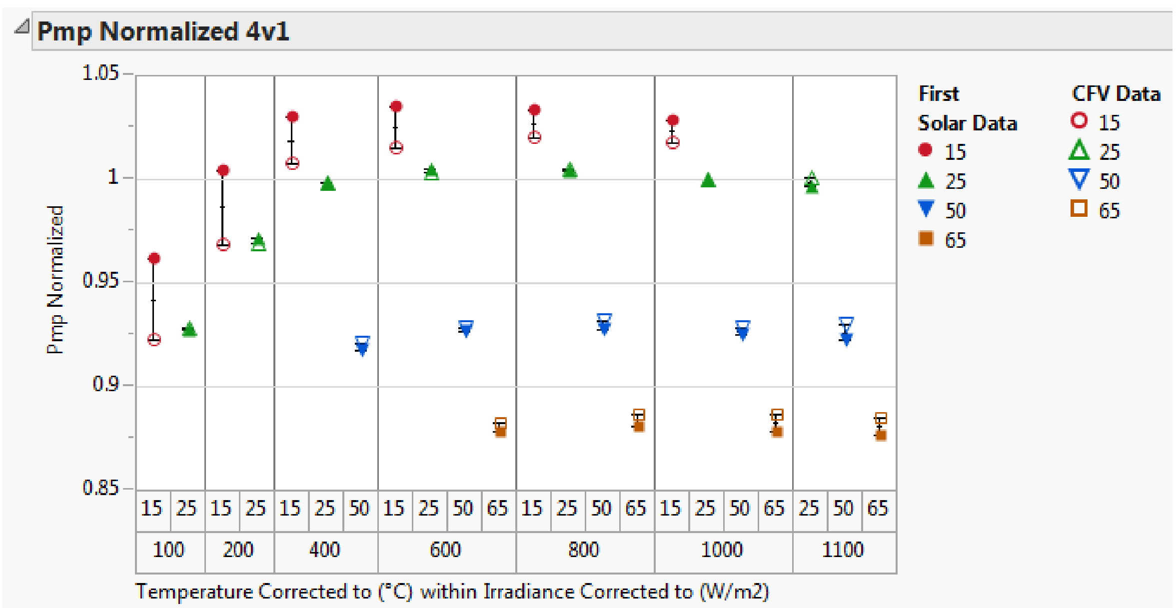
$E_{mod,year}$ is the sum performed overal time periods of the selected reference profile, $P_{max,STC}$ is the performance of the module at standard test condition, and H_p is the total of the hourly global in-plane irradiance values for the reference climatic period.

Appendix A

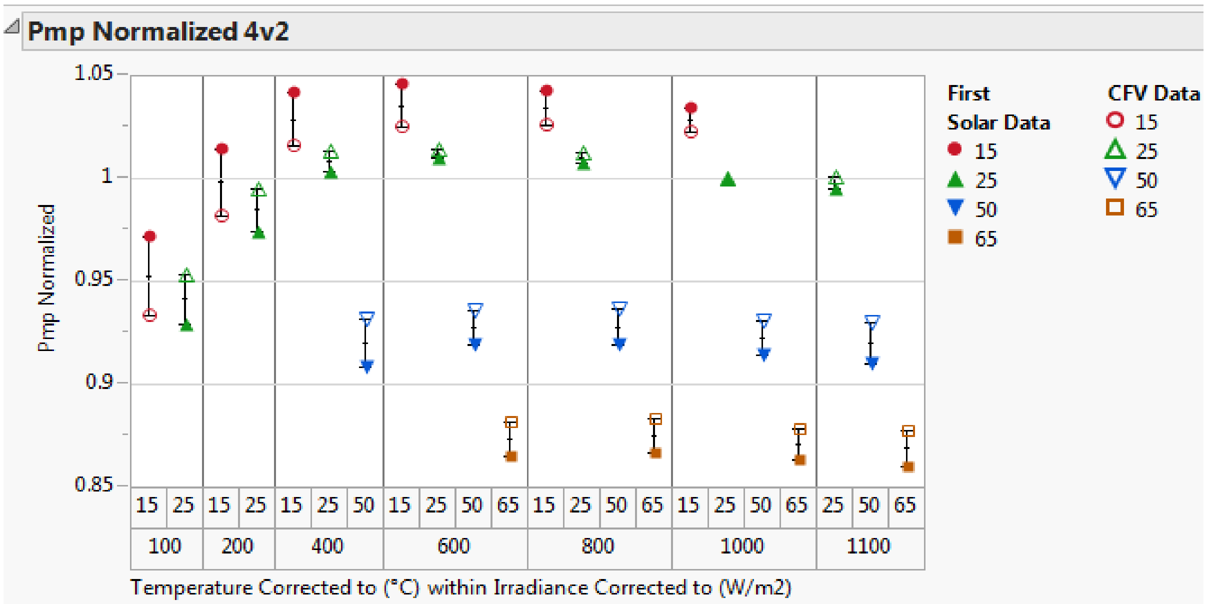
First Solar and CFV Results Comparison for Series 3		Average Percent Difference			
		-2.49%	0.43%	0.53%	0.78%
		Temperature			
Average Percent Difference	Irradiance	15°C	25°C	50°C	65°C
-2.82%	100 (W/m²)	-5.64%	0.34%	**	**
-1.60%	200 (W/m²)	-3.41%	1.09%	**	**
0.04%	400 (W/m²)	-1.77%	0.79%	1.11%	**
0.07%	600 (W/m²)	-1.59%	0.30%	0.60%	0.98%
0.08%	800 (W/m²)	-1.39%	0.29%	0.55%	0.88%
-0.11%	1000 (W/m²)	-1.15%	0.00%	0.04%	0.68%
0.37%	1100 (W/m²)	**	0.20%	0.32%	0.58%



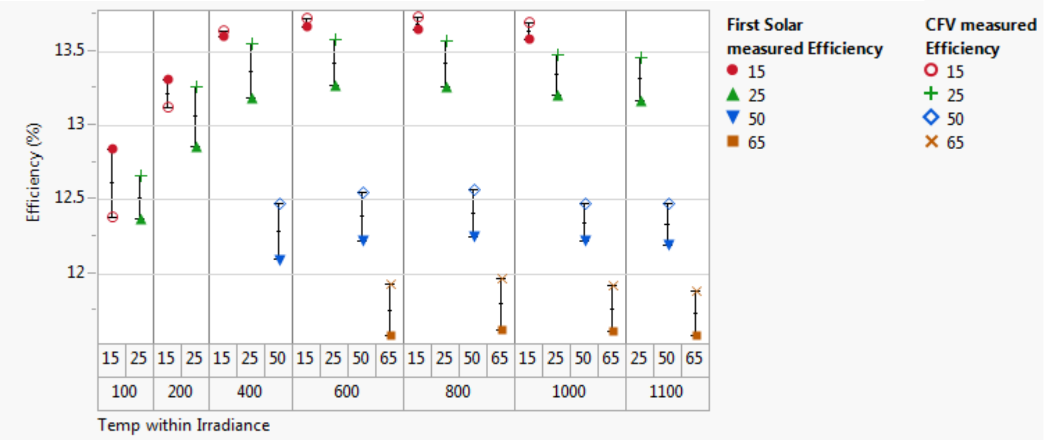
First Solar and CFV Results Comparison for Series 4				Average Percent Difference			
				-2.39%	0.04%	0.43%	0.89%
				Temperature			
				15°C	25°C	50°C	65°C
Average Percent Difference	-2.03%	Irradiance	100 (W/m^2)	-4.18%	0.13%	**	**
	-1.94%		200 (W/m^2)	-3.69%	-0.18%	**	**
	-0.60%		400 (W/m^2)	-2.21%	0.03%	0.38%	**
	-0.36%		600 (W/m^2)	-1.93%	-0.14%	0.19%	0.44%
	-0.02%		800 (W/m^2)	-1.29%	0.05%	0.45%	0.70%
	0.16%		1000 (W/m^2)	-1.03%	0.00%	0.36%	0.91%
	0.71%		1100 (W/m^2)	**	0.39%	0.78%	0.96%



First Solar and CFV Results Comparison for Series 4v2				Average Percent Difference			
				2.43%	-1.02%	-2.02%	-1.92%
				Temperature			
				15°C	25°C	50°C	65°C
Average Percent Difference	0.75%	Irradiance	100 (W/m²)	4.03%	-2.53%	**	**
	0.54%		200 (W/m²)	3.25%	-2.**16**%	**	**
	-0.34%		400 (W/m²)	2.51%	-0.99%	-2.53%	**
	-0.50%		600 (W/m²)	2.07%	-0.41%	-1.81%	-1.86%
	-0.72%		800 (W/m²)	1.57%	-0.52%	-1.88%	-2.04%
	-0.58%		1000 (W/m²)	1.17%	0.00%	-1.77%	-1.72%
	-1.56%		1100 (W/m²)	**	-0.52%	-2.13%	-2.04%



Comparing Efficiency for Series 3



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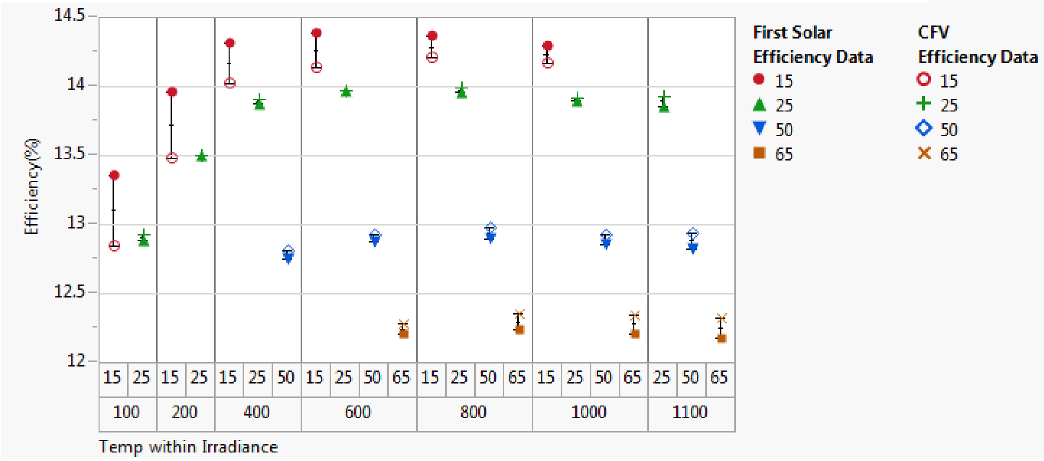
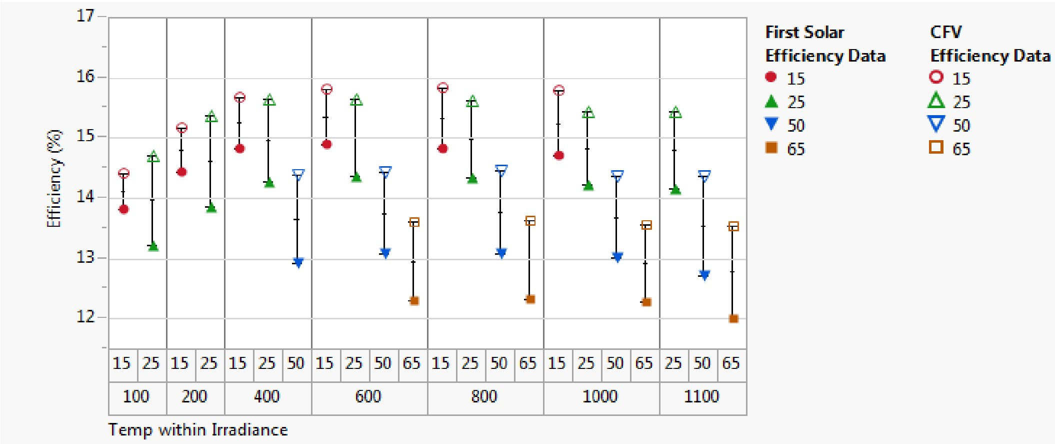


Comparing Efficiency for Series 4v2



Appendix B

Module Characterization

Angle of Incidence Response of First Solar Modules

This document provides supplemental information about the response of the First Solar FS Series Modules to incident light at different angles. The data is intended to support the proper design of systems using modules with and without anti-reflective coatings (ARC) as well as the development of more accurate models for energy prediction. All data reported in this document is the result of consolidation of multiple characterization studies made on individual modules within the First Solar product family. These studies were performed by First Solar and PV Evolution Labs ("PVEL").

First Solar modules with ARC are indicated in the product name by an "A" descriptor. For example, a module labeled FS-497A would include ARC while an FS-497 would not. The benefits of ARC are twofold. First, the efficiency at normal incidence increases. Part of the increase in efficiency seen in STC flash tests can be attributed to this, which translates directly to an increase in the nameplate rating of the module. Because the bin class of the module reflects the normal incidence benefit of ARC, this benefit does not need to be accounted for in an energy prediction, except through the choice of module bin class.

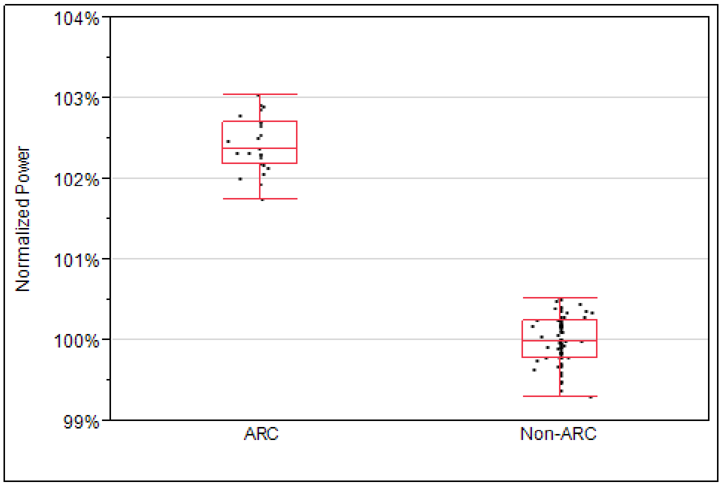


Figure 1. Distribution of P_{mp} at normal incidence for modules with and without ARC. An average P_{mp} increase of 2.4% is measured.

The second benefit of ARC is the increase in light transmissivity at non-normal incidence angles. This benefit needs to be explicitly accounted for in energy predictions in order to accurately reflect the module energy output. The short circuit current (I_{sc}) of multiple First Solar modules with and without ARC is characterized at varying angles of incidence. When these results are normalized to the Isc at Standard Test Conditions (1000 W/m^2 total irradiance with AM1.5 global spectrum and 25°C module temperature) and for cosine irradiance losses, the relative short circuit current as a function of angle-of-incidence can be determined as shown in Figure 1. For brevity, the relative short circuit current will be termed the "IAM" (Incident Angle Modifier).

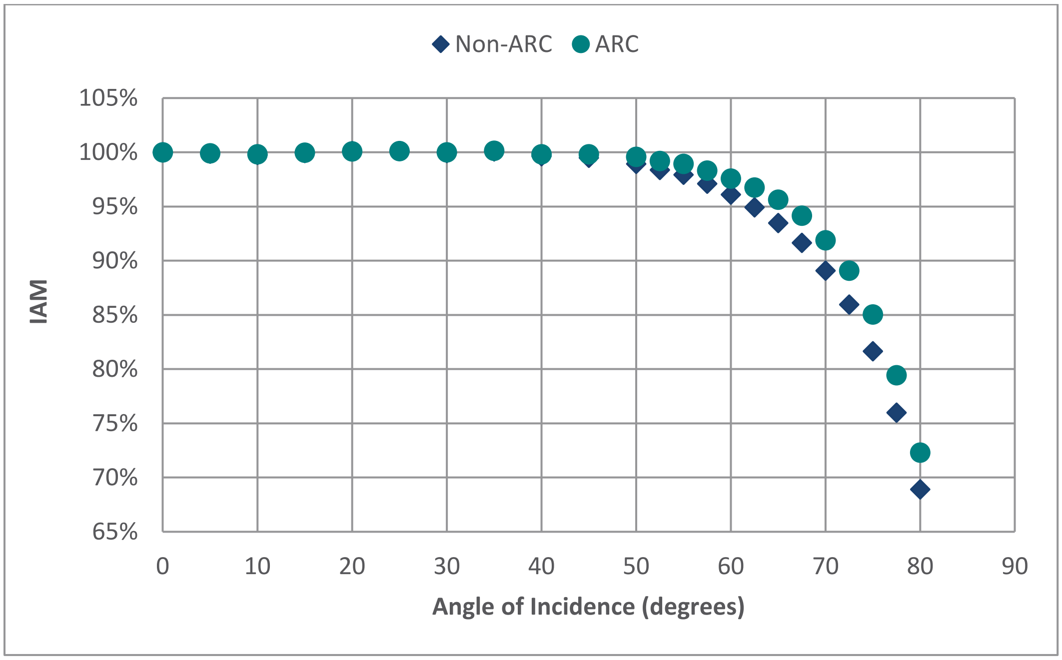


Figure 1. Measured I_{sc} relative to Isc at normal incidence for First Solar modules with and without ARC.

Historically, the ASHRAE model has been used in prediction models to estimate the IAM response of PV modules. This model is the default in PVsyst and First Solar has previously recommended a b_o value of 0.05 to match standard (non-ARC) glass response.

$$IAM = 1 - \frac{b_o}{\cos(AOI) - 1}$$

With the release of ARC, it was recognized that the ASHRAE model does not provide the necessary precision to fully capture the difference in the IAM responses of standard glass modules and modules with ARC. We found that the Sandia IAM response model is a more accurate functional representation of IAM losses:

$$\text{IAM} = C_0 + C_1 AOI + C_2 AOI^2 + C_3 AOI^3 + C_4 AOI^4 + C_5 AOI^5$$

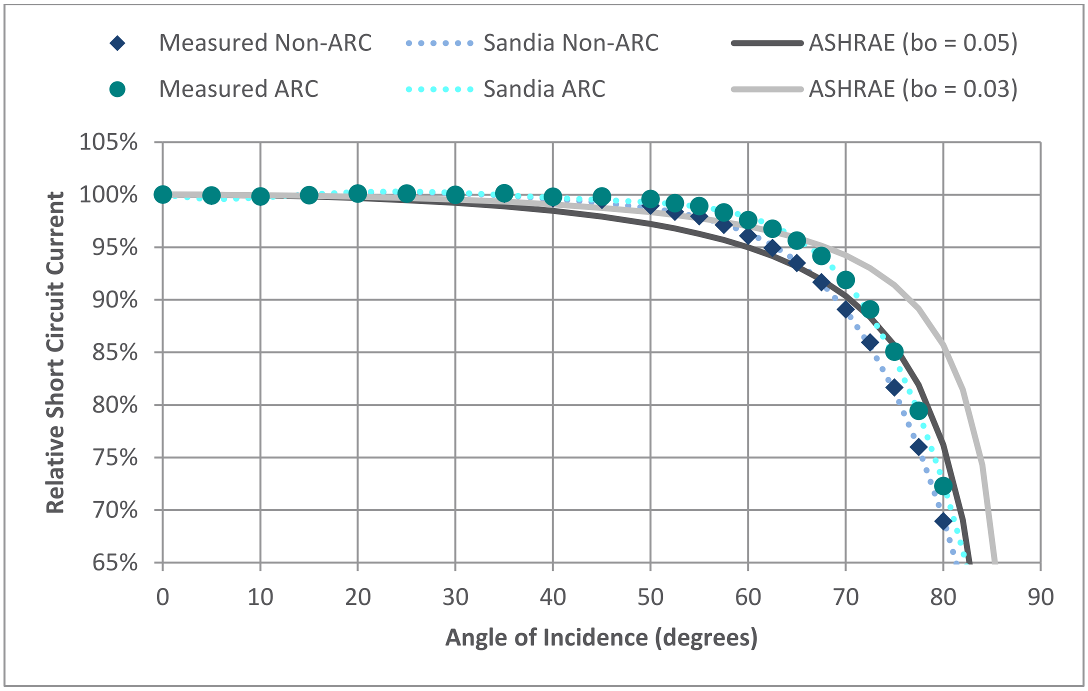


Figure 2. Measured Isc relative to Isc at normal incidence for First Solar modules without ARC shown with the ASHRAE and Sandia IAM response models.

With the release of ARC, First Solar's prediction guidance changed to ensure that users fully capture the response of modules both with ARC and standard glass. For software tools which allow a custom IAM function or include the Sandia IAM model, we recommend use of the Sandia model for both ARC and standard glass modules. For PVsyst, we recommend use of tabulated values for both ARC and standard glass modules. PAN files provided by First Solar after May 2014 which are used in PVsyst V6.0 and later include these tabulated values and the user therefore does not need to enter them into PVsyst. In PVsyst V5 and earlier, we recommend inputting tabulated values into the Detailed Losses dialogue box. These recommendations are summarized in Table 1.

Table 1. Recommended prediction inputs for PVsyst and other user defined toolsets for modules with and without ARC.

<table>
<tr><th>Module Type</th><th>User Defined Toolset (i.e., Isis)</th><th>PVsyst V6</th><th>PVsyst V5 and earlier</th></tr>
<tr>
<td>with ARC
(i.e. FS-4XXXA, FS-4XXXA-2, FS-4XXXA-3)</td>
<td>Sandia Model
(5th-order polynomial)

$C_0 = 1.0000E+00$
$C_1 = -1.9386E-03$
$C_2 = 2.5854E-04$
$C_3 = -1.1229E-05$
$C_4 = 1.9962E-07$
$C_5 = -1.2818E-09$</td>
<td>Included in May 2014 and later manufacturer PAN file
<table><tr><th>AOI</th><th>IAM</th></tr><tr><td>0</td><td>1.00</td></tr><tr><td>30</td><td>1.00</td></tr><tr><td>55</td><td>0.99</td></tr><tr><td>60</td><td>0.98</td></tr><tr><td>65</td><td>0.96</td></tr><tr><td>70</td><td>0.92</td></tr><tr><td>75</td><td>0.85</td></tr><tr><td>80</td><td>0.72</td></tr><tr><td>90</td><td>0.00</td></tr></table></td>
<td>User input into Detailed Losses dialogue box
<table><tr><th>AOI</th><th>IAM</th></tr><tr><td>0</td><td>1.00</td></tr><tr><td>30</td><td>1.00</td></tr><tr><td>55</td><td>0.99</td></tr><tr><td>60</td><td>0.98</td></tr><tr><td>65</td><td>0.96</td></tr><tr><td>70</td><td>0.92</td></tr><tr><td>75</td><td>0.85</td></tr><tr><td>80</td><td>0.72</td></tr><tr><td>90</td><td>0.00</td></tr></table></td>
</tr>
<tr>
<td>without ARC
(i.e. FS-4XXX, FS-4XXX-2, FS-4XXX-3)</td>
<td>Sandia Model
(5th-order polynomial)

$C_0 = 1.0000E+00$
$C_1 = -1.6754E-03$
$C_2 = 2.1896E-04$
$C_3 = -9.3467E-06$
$C_4 = 1.6452E-07$
$C_5 = -1.0767E-09$</td>
<td>Included in May 2014 and later manufacturer PAN file
<table><tr><th>AOI</th><th>IAM</th></tr><tr><td>0</td><td>1.00</td></tr><tr><td>30</td><td>1.00</td></tr><tr><td>50</td><td>0.99</td></tr><tr><td>60</td><td>0.96</td></tr><tr><td>65</td><td>0.94</td></tr><tr><td>70</td><td>0.89</td></tr><tr><td>75</td><td>0.82</td></tr><tr><td>80</td><td>0.69</td></tr><tr><td>90</td><td>0.00</td></tr></table></td>
<td>User input into Detailed Losses dialogue box
<table><tr><th>AOI</th><th>IAM</th></tr><tr><td>0</td><td>1.00</td></tr><tr><td>30</td><td>1.00</td></tr><tr><td>50</td><td>0.99</td></tr><tr><td>60</td><td>0.96</td></tr><tr><td>65</td><td>0.94</td></tr><tr><td>70</td><td>0.89</td></tr><tr><td>75</td><td>0.82</td></tr><tr><td>80</td><td>0.69</td></tr><tr><td>90</td><td>0.00</td></tr></table></td>
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Evaluation of FS Series PV modules across all rated power bins has shown strong performance consistency for the entire series with minor variation from module to module. Limited variation from module to module is normal and is to be expected when comparing measured results to actual field performance.

Appendix C

CFV solar test laboratory

Testing Cert #: 3301.01

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www.cfvsolar.com

Report Date: October 31, 2014

CFV Project ID: 14038

Customer Project No: 14038 – First Solar Series 3 IEC 61853-1

Customer Contact: Lauren Ngan
First Solar, Inc.
28101 Cedar Park Blvd.
Perrysburg, OH 43551-4871

1 **Project Summary:** CFV Solar Test Laboratory conducted performance testing per IEC 61853-1 on three First Solar FS-395-Plus modules. The modules were measured inside a class AAA flash solar simulator at the irradiance and temperature levels specified in the IEC 61853-1 performance matrix. CFV Solar Test Laboratory has an ISO 17025 accreditation for the IEC 61853-1 standard. Temperature coefficients were also measured inside the flash solar simulator using three different methods: 1) heated up immediately after outdoor exposure from 41 to 65 °C, 2) cooled down from 65 to 25 °C and 3) heated up from 25 to 65 °C. Methods 2) and 3) met the requirements of the IEC 61646 § 10.4 standard, for which CFV Solar Test Laboratory has an ISO 17025 accreditation.

2 **Executive Summary of Results:** At standard test conditions CFV Solar measured the three modules 1.9 to 3.0% high to nameplate Pmp. The Isc was linear (± 0.8%) with respect to light intensity when spectral corrections were applied. The multi-irradiance and temperature data showed profiles that are typical of PV module behavior: the power changed proportionally to irradiance and temperature. The temperature coefficients measured per methods 2) and 3) showed the best agreement to the FS-395-Plus datasheet. The detailed test data is documented in an Excel workbook titled "14038 CFV Project Workbook.xls". Any opinions and interpretation of data in this report are those of CFV Solar Test Laboratory.

Report authorized by:
Larry Pratt
Laboratory Manager

Digitally signed by Larry Pratt
Date: 2014.10.31 14:53:06 -06'00'

3 Procedures:

3.1 Incoming Inspection and Labelling: The modules were unpacked and labeled according to CFV Solar convention. The module IDs and the manufacturer's serial numbers were recorded in the Excel documents.

3.2 Electroluminescence (EL) Imaging: EL images were taken with a Sensovation HR-830 camera that has a resolution of 8.3 MPixels. A long pass filter was affixed to the lens, which blocked incoming light below wavelengths of 850 nm. A constant DC bias of 1.94 amps (Imp*1.25) was applied to the modules for two minutes while the imaging was performed in a dark room. The EL images were taken without preconditioning.

3.3 Preconditioning: The three tested modules were placed on a fixed racked at latitude tilt (35°) and grid connected prior to indoor performance testing. The modules were exposed outdoors for a minimum of three weeks before receiving multi-irradiance measurements at 25, 50 and 65 °C. Because the entire IEC 61853-1 performance matrix could not be completed in a single day the modules were placed outside (this time in open circuit) for an additional week before they were brought back inside for multi-irradiance testing at 15 °C.

3.4 Indoor Performance Measurements: The indoor flash tests were done in a class AAA h.a.l.m. flash solar simulator. The h.a.l.m. flasher generates a 45 millisecond pulse from a Xenon arc lamp and a sweep time of 40 milliseconds was used. The modules were measured from Isc to Voc then from Voc to Isc and averaged. The process was repeated three times and the results averaged for each irradiance and temperature level. The testing was performed according to IEC 61853-1. Specifically, the environmental conditions stated in Table 2 within Section 8 of the standard were directly measured; measurements were done at 65 °C instead of 75 °C per the standard due to the current heating limitations of the flasher's integrated thermal chamber. Measurements at 15 °C were done by first placing the module in an external climate chamber at 5 °C and then transporting it to the flasher for measurement. The average temperature gradient was 0.1 °C between forward and reverse IV traces at 15 °C.

Back sheet temperatures were directly measured within ± 1 °C of target and irradiances were directly measured within ± 3 W/m^2 of target. Voltage and current corrections were applied as needed per correction procedure 1 within IEC 60891; no corrections were made to series or shunt resistance. The raw data is also made available in the Excel documents. Proximity to air mass (AM) 1.5 is verified by the h.a.l.m. flasher's class A spectral match to the IEC 60904-3 reference spectrum.

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The h.a.l.m. Xenon arc lamp was calibrated for irradiance with a high optical quality (HOQ) mono-silicon small area monitor cell with an absolute uncertainty of ± 0.55%. The HOQ monitor cell has a different spectral response than the CdTe device under test (DUT) (Figure 3.4.1). Spectral mismatch factors were calculated for each intensity level to minimize the measurement errors associated with multi-irradiance measurements. The mismatch factors take into account the spectral differences between the reference cell, the device under test, the Xenon lamp spectrum at multiple irradiances, and the IEC 60904-3 reference spectrum.

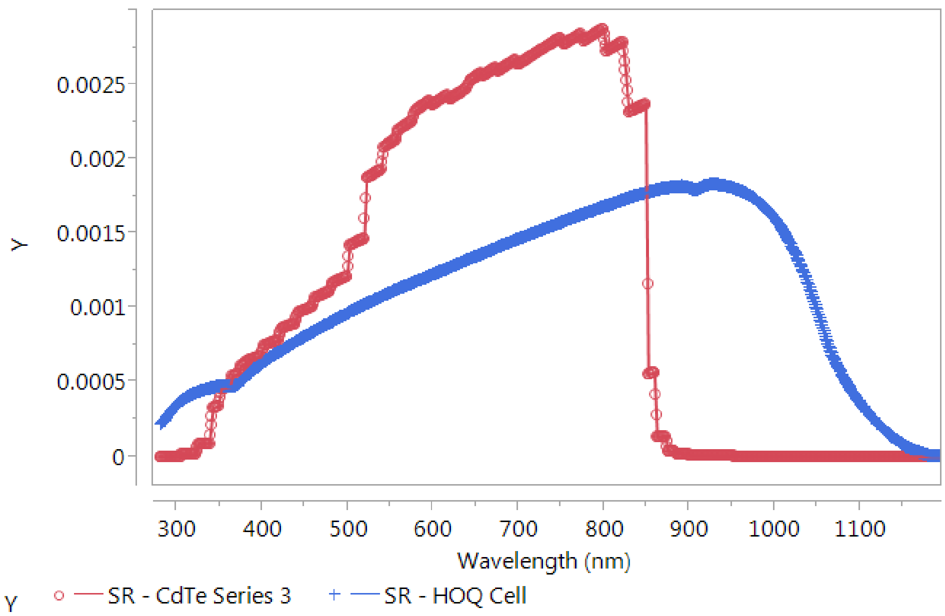

Figure 3.4.1: Overlay of the normalized spectral response of the Series 3 module and the HOQ mono-Si reference cell used in testing. When measured at 1000 W/m^2 on the h.a.lm. the spectral mismatch factor is 0.922, which means the measured result will be 7.8% higher than if no spectral correction were applied. The spectral responses are normalized to the column sum.

The spectral mismatch factors were calculated at one sun (1000 W/m^2) using quantum efficiency data provided by First Solar (Figure 3.4.1) and with equation 3 in IEC 60904-7. Spectral mismatch factors were calculated for the remaining intensity levels (i.e. 100 W/m^2, 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2 and 1100 W/m^2) by first directly measuring a Series 3 and QED module at each of these intensities, but without accounting for spectral mismatch. Then, the Isc of these measurements was normalized to their corresponding values at 1000 W/m^2 (Figure 3.4.2). Finally, the average normalized Isc value at each intensity level in Figure 3.4.2 was multiplied by the spectral mismatch factor calculated at one-sun. The spectral correction factors calculated in this procedure gave the DUTs a nearly linear response across the irradiances specified in IEC 61853-1.

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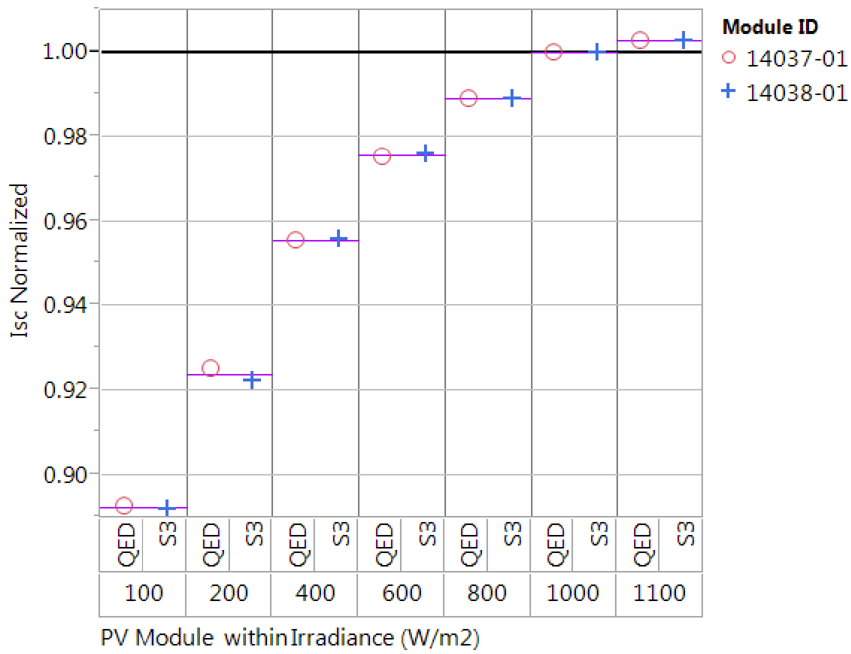

Figure 3.4.2: Variability plot that shows the deviation from a linear response when spectral mismatch is not accounted for. The modules measured are a Series 3 (Blue) and QED (Red). The purple lines indicate the average.

Figure 3.4.3: Class AAA h.a.l.m. flash solar simulator with a standard silicon module.

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Table 3.4.1 shows the absolute and relative uncertainty of the h.a.l.m. flasher measurements. These uncertainties take in to account all the major sources of uncertainty, including the calibration, spectrum of the flasher, non-uniformity of the irradiance in the test plane, etc. The relative uncertainty for power measurements is ± 0.4%, which means the test system can detect smaller relative shifts in performance that may result from environmental and mechanical stresses called for by a particular test sequence.

Table 3.4.1 Absolute and relative uncertainties of the flash data for crystalline silicon modules.

Parameter	Absolute [%]	Relative [%]
Pmp	+/- 2.8	+/- 0.40
Isc	+/- 2.3	+/- 0.20
Imp	+/- 2.3	+/- 0.25
Voc	+/- 0.6	+/- 0.20
Vmp	+/- 0.7	+/- 0.25

3.5 Temperature Coefficients: The temperature coefficient tests were done in the Class AAA h.a.l.m. flash solar simulator. Four PT100s were placed on the back sheet of the modules and IV measurements were not taken until temperature uniformity was less than 1.5° C. A single IV measurement was taken at each temperature interval with sweeps from Isc to Voc and from Voc to Isc; the two sweeps were averaged for a final IV curve. Three procedures were used to derive temperature coefficients. In the first procedure, the module was placed in the test bed within 15 minutes of being removed from outdoors. IV measurements were taken in intervals of 2° C starting at the temperature the module stabilized at (41° C) and increased to 65° C. The second procedure was performed immediately after the first and the module was measured from 65° to 25° C in intervals of roughly 1° C. Finally, the module was measured from 25° to 65° C in intervals of 2° C. Regression analyses were then used to derive temperature coefficients for the IV characteristics of interest.

4 Discussion of Results:

4.1 Indoor Performance Measurements: Figure 4.1.1 shows the performance measurements of the three FS-395-Plus modules corrected to STC. The y-axis shows the delta between CFV Solar's measurements and the FS-395-Plus nameplate (NP) values. On average, CFV Solar measured maximum power (Pmp) 2.1% higher than the First Solar NP. The Imp values measured 2.2% low relative to NP and Isc values were 2.1% low to NP, on average. Vmp averaged 4.1% high relative to NP; Voc averaged 4.5% high relative to NP.

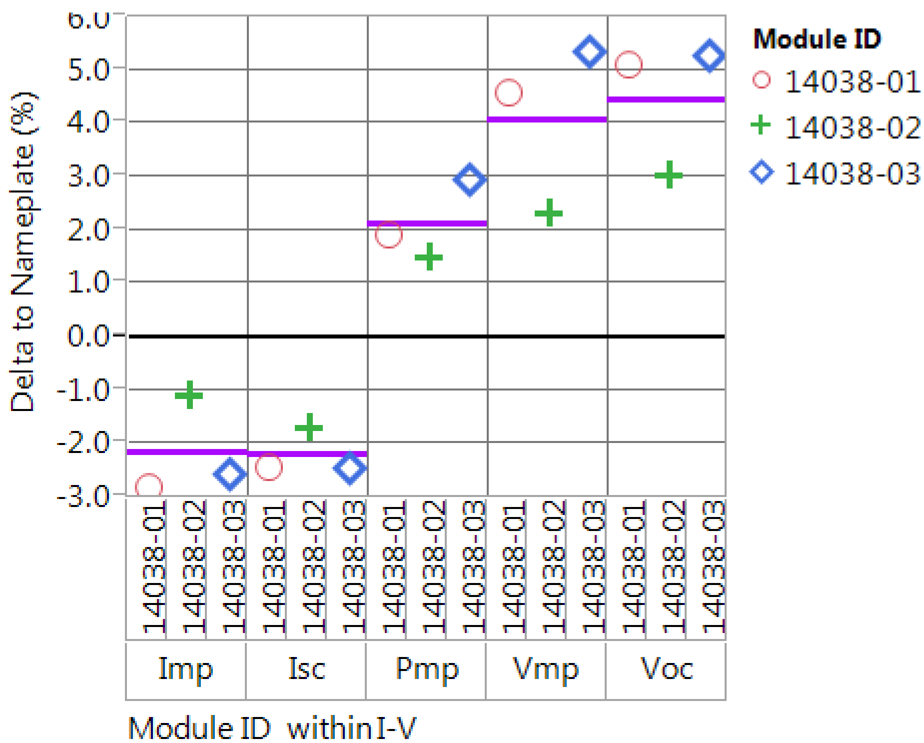

Figure 4.1.1: Variability plot showing the delta between CFV Solar's measurements and the FS-395-Plus nameplate for all I-V characteristics at standard test conditions (STC). The group means are shown by the horizontal purple lines.

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Figure 4.1.2 shows the Isc values of all three FS-395-Plus modules normalized with respect to their corresponding Isc values at 1000 W/m^2. This figure shows a strong improvement to the non-linear response observed in Figure 3.4.2. When the spectral mismatch factor has been applied the Isc response of the FS-395-Plus modules is linear (within ± 0.8%) with respect to irradiance when measured in the h.a.l.m. indoor solar simulator.

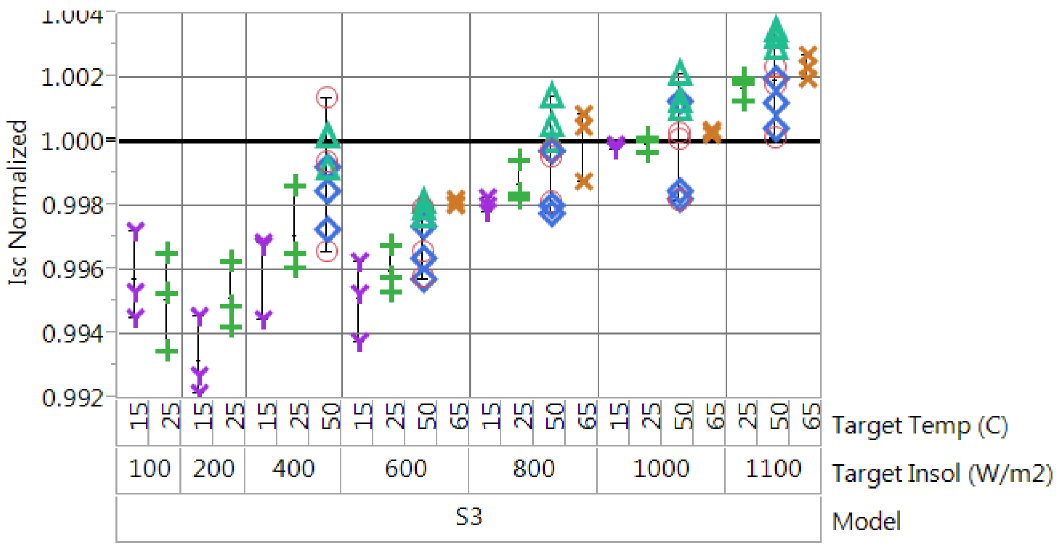

Figure 4.1.2: Variability plot showing the normalized Isc of the series four modules. The Isc response is within +/- 1% of being linear with respect to light intensity.

Figures 4.1.3 to Figure 4.1.5 show the corrected module efficiency at all irradiances and temperatures. When temperature is at 25° C the peak varies between 400 W/m^2 and 800 W/m^2 depending on the sample. The “Temperature Group” legend indicates the order in which the measurements were performed. The third round of testing at 50° C show a slight improvement in efficiency compared to the first and second rounds of testing at 50° C. The third round of testing at 50° C was performed immediately after testing at 65° C; the exposure to the elevated temperature may have increased efficiency.

At low irradiance (i.e. 100 W/m^2, 200 W/m^2 and 400 W/m^2) and 15° C the FS-395-Plus modules show a peculiar behavior. Specifically, some of the efficiencies appear lower than expected at low irradiance and 15° C. The reasons for these anomalies are still unknown. Most of the deviations from the expected Pmp values at low irradiance are due to shifts in Imp values. Since the delta is mostly in current, the instability of the Xenon arc lamp at low irradiances is one possible explanation for the trends in efficiency at low irradiance.

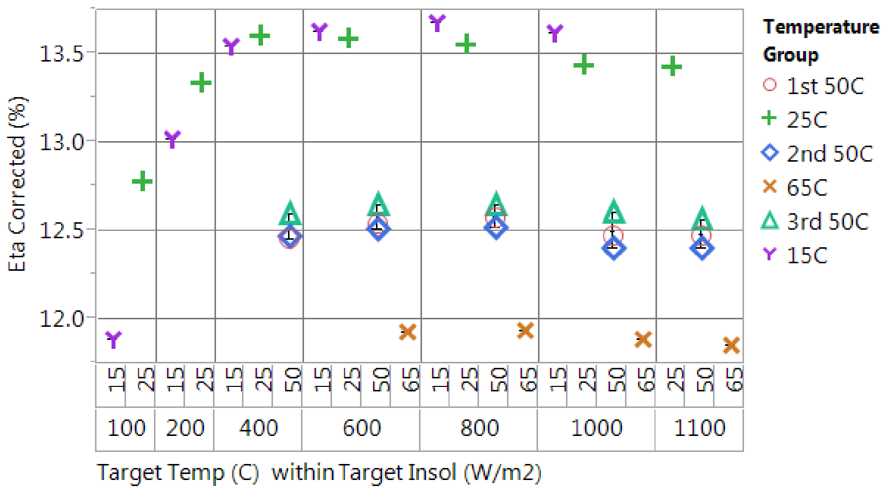

Figure 4.1.3: Efficiency of module 14038-01 for the light intensities and temperatures specified in IEC 61853-1.

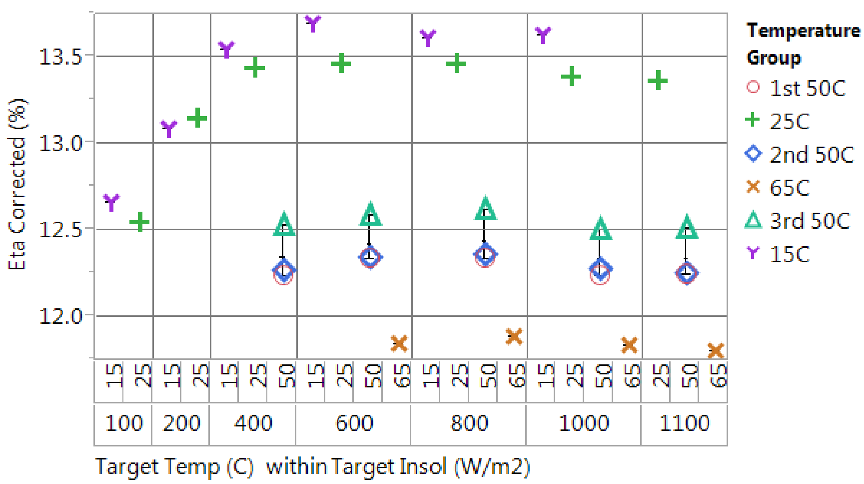

Figure 4.1.4: Efficiency of module 14038-02 for the light intensities and temperatures specified in IEC 61853-1.

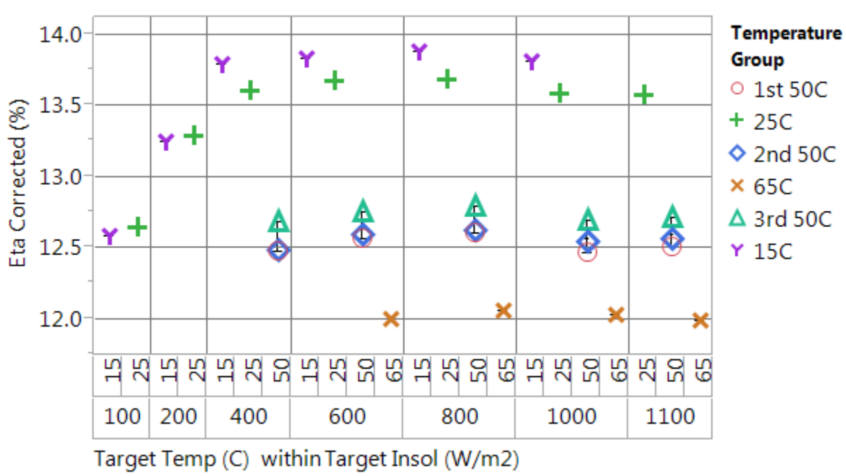

Figure 4.1.5: Efficiency of module 14038-03 for the light intensities and temperatures specified in IEC 61853-1.

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4.2 Temperature Coefficients: The delta between CFV Solar's measured temperature coefficients and the FS-395-Plus datasheet are shown below in Figure 4.2.1. The initial measurement method, wherein the module was measured immediately after outdoor exposure, yielded a Pmp temperature coefficient with a lower slope than the other two methods (Figure 4.2.2). The initial method showed the greatest delta to the data sheet. The second and third methods yielded identical results that were matched to the datasheet with 0.02 %/C°. The temperature coefficients of all I-V characteristics are provided in the Excel documents.

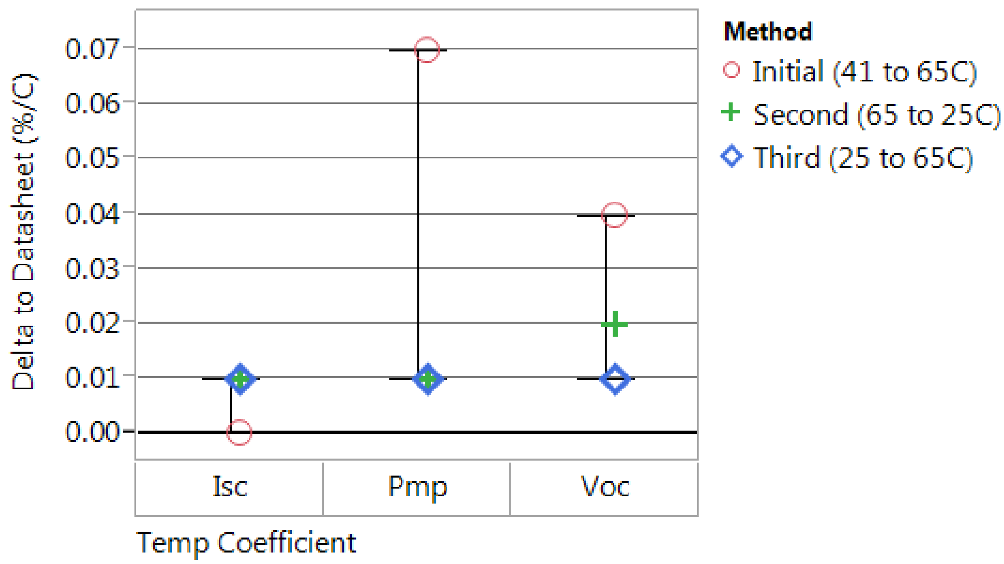

Figure 4.2.1: Variability plot showing the delta between CFV Solar's temperature coefficient measurements and the FS-4100 datasheet. All deltas are in absolute form.

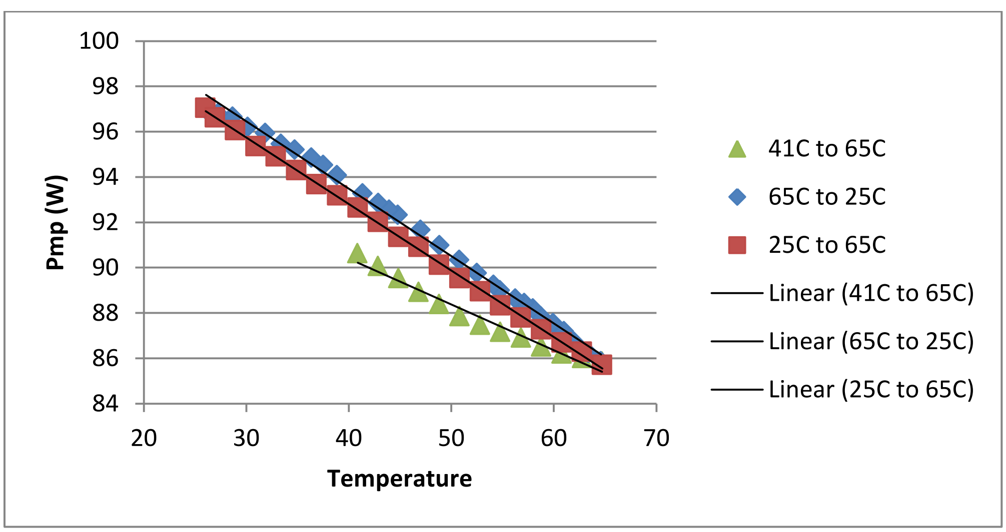

Figure 4.2.2: Regression of Pmp by temperature for the three different temperature coefficient measurement methods used.

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Report Date: October 31, 2014

CFV Project ID: 14035

Customer Project No: 14035 – First Solar Series 4 IEC 61853-1

Customer Contact: Lauren Ngan
First Solar, Inc.
28101 Cedar Park Blvd.
Perrysburg, OH 43551-4871

1 **Project Summary:** CFV Solar Test Laboratory conducted performance testing per IEC 61853-1 on three First Solar FS-4100 (series 4) modules. The modules were measured inside a class AAA flash solar simulator at the irradiance and temperature levels specified in the IEC 61853-1 performance matrix. CFV Solar Test Laboratory has an ISO 17025 accreditation for the IEC 61853-1 standard. Temperature coefficients were also measured inside the flash solar simulator using three different methods: 1) heated up from immediately after outdoor exposure 33 to 65 °C, 2) cooled down from 65 to 25 °C and 3) heated up from 25 to 65 °C. Methods 2) and 3) met the requirements of the IEC 61646 § 10.4 standard, for which CFV Solar Test Laboratory has an ISO 17025 accreditation.

2 **Executive Summary of Results:** At standard test conditions CFV Solar measured the three modules 0.3% low to 0.9% high to nameplate Pmp. The Isc was linear (± 1.0%) with respect to light intensity when spectral corrections were applied. The multi-irradiance and temperature data showed profiles that are typical of PV module behavior: the power changed proportionally to irradiance and temperature. The temperature coefficients measured per methods 2) and 3) showed the best agreement to the FS-4100 datasheet. The detailed test data is documented in an Excel workbook titled “14035 CFV Project Workbook.xls”. Any opinions and interpretation of data in this report are those of CFV Solar Test Laboratory.

Report authorized by:
Larry Pratt
Laboratory Manager

Digitally signed by Larry Pratt
Date: 2014.10.31 14:49:18 -06'00'

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3 Procedures:

3.1 Incoming Inspection and Labelling: The modules were unpacked and labeled according to CFV Solar convention. The module IDs and the manufacturer's serial numbers were recorded in the Excel documents.

3.2 Electroluminescence (EL) Imaging: EL images were taken with a Sensovation HR-830 camera that has a resolution of 8.3 MPixels. A long pass filter was affixed to the lens, which blocked incoming light below wavelengths of 850 nm. A constant DC bias of 1.5 amps (Imp*1.25) was applied to the modules for two minutes while the imaging was performed in a dark room. The EL images were taken without preconditioning.

3.3 Preconditioning: The three tested modules were placed on a fixed racked at latitude tilt (35°) and grid connected prior to indoor performance testing. The modules were exposed outdoors for a minimum of three weeks before receiving multi-irradiance measurements at 25, 50 and 65 °C. Because the entire IEC 61853-1 performance matrix could not be completed in a single day the modules were placed outside (this time in open circuit) for another12 days before they were brought back inside for multi-irradiance testing at 15 °C.

3.4 Indoor Performance Measurements: The indoor flash tests were done in a class AAA h.a.l.m. flash solar simulator. The h.a.l.m. flasher generates a 45 millisecond pulse from a Xenon arc lamp and a sweep time of 40 milliseconds was used. The modules were measured from Isc to Voc then from Voc to Isc and averaged. The process was repeated three times and the results averaged for each irradiance and temperature level. The testing was performed according to IEC 61853-1. Specifically, the environmental conditions stated in Table 2 within Section 8 of the standard were directly measured; measurements were done at 65 °C instead of 75 °C per the standard due to the current heating limitations of the flasher's integrated thermal chamber. Measurements at 15 °C were done by first placing the module in an external climate chamber at 5 °C and then transporting it to the flasher for measurement. The average temperature gradient was 0.1 °C between forward and reverse IV traces at 15 °C.

Back sheet temperatures were directly measured within ± 1 °C of target and irradiances were directly measured within ± 3 W/m^2 of target. Voltage and current corrections were applied as needed per correction procedure 1 within IEC 60891; no corrections were made to series or shunt resistance. The raw data is also made available in the Excel documents. Proximity to air mass (AM) 1.5 is verified by the h.a.l.m. flasher's class A spectral match to the IEC 60904-3 reference spectrum.

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The h.a.l.m. Xenon arc lamp was calibrated for irradiance with a high optical quality (HOQ) mono-silicon small area monitor cell with an absolute uncertainty of ± 0.55%. The HOQ monitor cell has a different spectral response than the CdTe device under test (DUT) (Figure 3.4.1). Spectral mismatch factors were calculated for each intensity level to minimize the measurement errors associated with multi-irradiance measurements. The mismatch factors take into account the spectral differences between the reference cell, the device under test, the Xenon lamp spectrum at multiple irradiances, and the IEC 60904-3 reference spectrum.

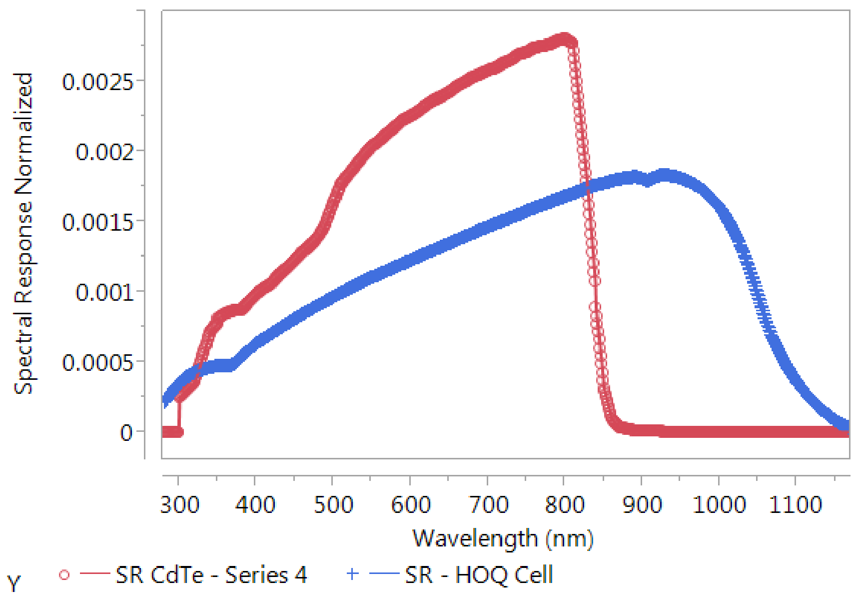

Figure 3.4.1: Overlay of the normalized spectral response of the series 4 module and the HOQ mono-Si reference cell used in testing. When measured at 1000 W/m^2 on the h.a.lm. the spectral mismatch factor is 0.925, which means the measured result will be 7.5% higher than if no spectral correction were applied. The spectral responses are normalized to the column sum.

The spectral mismatch factors were calculated at one sun (1000 W/m^2) using quantum efficiency data provided by First Solar and with equation 3 in IEC 60904-7. Spectral mismatch factors were calculated for the remaining intensity levels (i.e. 100 W/m^2, 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2 and 1100 W/m^2) by first directly measuring a Series 3 and QED module at each of these intensities, but without accounting for spectral mismatch. Then, the Isc of these measurements was normalized to their corresponding values at 1000 W/m^2 (Figure 3.4.2). Finally, the average normalized Isc value at each intensity level in Figure 3.4.2 was multiplied by the spectral mismatch factor calculated at one-sun. The spectral correction factors calculated in this procedure gave the DUTs a nearly linear response across the irradiances specified in IEC 61853-1.

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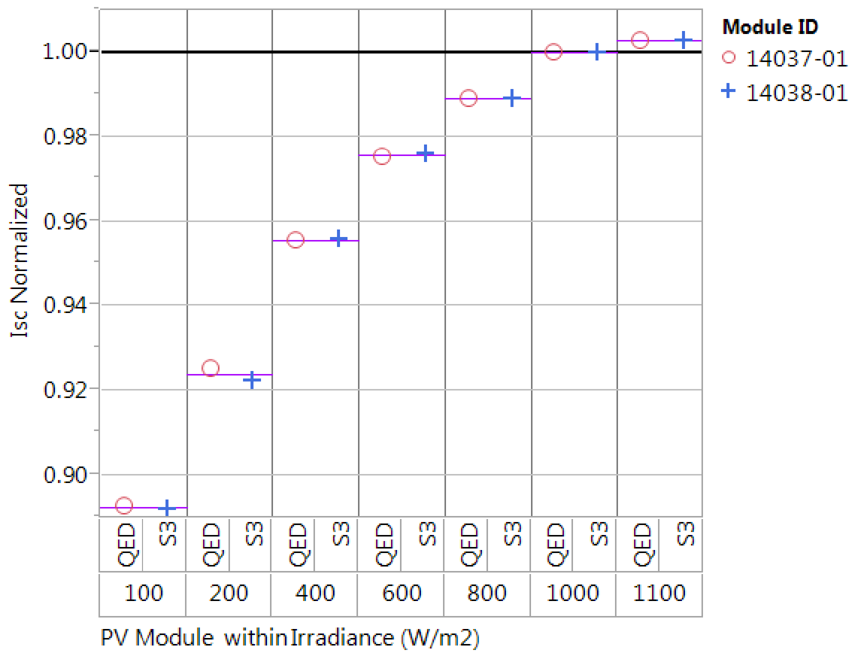

Figure 3.4.2: Variability plot that shows the deviation from a linear response when spectral mismatch is not accounted for. The modules measured are a Series 3 (Blue) and QED (Red). The purple lines indicate the average.

Figure 3.4.3: Class AAA h.a.l.m. flash solar simulator with a standard silicon module.

Table 3.4.1 shows the absolute and relative uncertainty of the h.a.l.m. flasher measurements. These uncertainties take in to account all the major sources of uncertainty, including the calibration, spectrum of the flasher, non-uniformity of the irradiance in the test plane, etc. The relative uncertainty for power measurements is ± 0.4%, which means the test system can detect smaller relative shifts in performance that may result from environmental and mechanical stresses called for by a particular test sequence.

Table 3.4.1 Absolute and relative uncertainties of the flash data for crystalline silicon modules.

Parameter	Absolute [%]	Relative [%]
Pmp	+/- 2.8	+/- 0.40
Isc	+/- 2.3	+/- 0.20
Imp	+/- 2.3	+/- 0.25
Voc	+/- 0.6	+/- 0.20
Vmp	+/- 0.7	+/- 0.25

3.5 Temperature Coefficients: The temperature coefficient tests were done in the Class AAA h.a.l.m. flash solar simulator. Four PT100s were placed on the back sheet of the modules and IV measurements were not taken until temperature uniformity was less than 1.5° C. A single IV measurement was taken at each temperature interval with sweeps from Isc to Voc and from Voc to Isc; the two sweeps were averaged for a final IV curve. Three procedures were used to derive temperature coefficients. In the first procedure, the module was placed in the test bed within 15 minutes of being removed from outdoors. IV measurements were taken in intervals of 2° C starting at the temperature the module stabilized at (33° C) and increased to 65° C. The second procedure was performed immediately after the first and the module was measured from 65° to 25° C in intervals of roughly 1° C. Finally, the module was measured from 25° to 65° C in intervals of 2° C. Regression analyses were then used to derive temperature coefficients for the IV characteristics of interest.

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4 Discussion of Results:

4.1 Indoor Performance Measurements:

Figure 4.1.1 shows the performance measurements of the three FS-4100 modules corrected to STC. The y-axis shows the delta between CFV Solar's measurements and the FS-4100 nameplate (NP) values. On average, CFV Solar measured maximum power (Pmp) 0.2% higher than the First Solar NP. The Imp values measured 1.8% low relative to NP and Isc values were 0.6% low to NP, on average. Vmp averaged 1.9% high relative to NP; Voc averaged 2.2% high relative to NP.

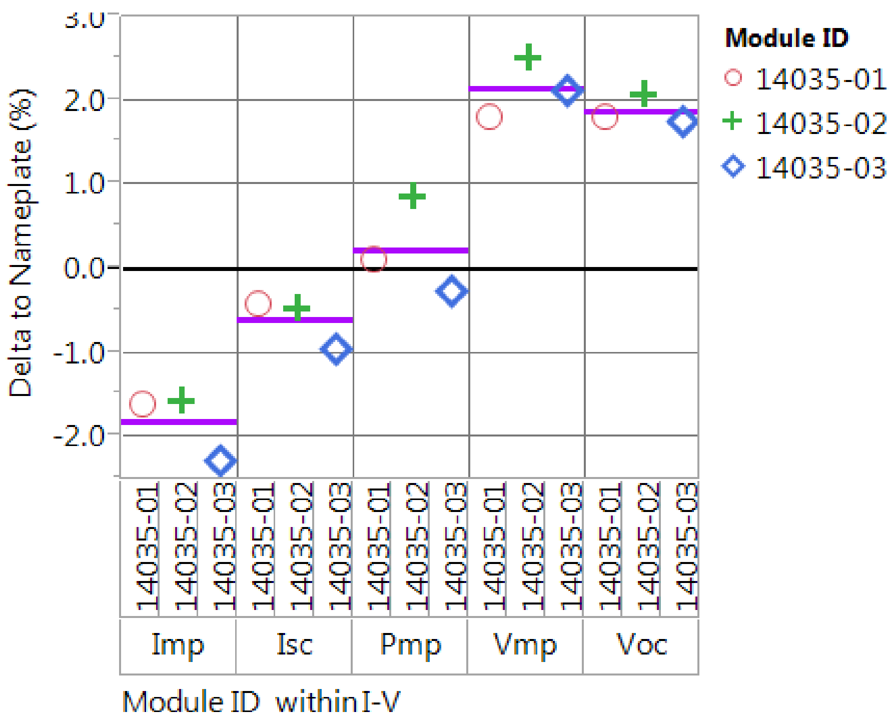

Figure 4.1.1: Variability plot showing the delta between CFV Solar's measurements and the FS-4100 nameplate for all I-V characteristics at standard test conditions (STC). The group means are shown by the horizontal purple lines.

Figure 4.1.2 shows the Isc values of all three FS-4100 modules normalized with respect to their corresponding Isc values at 1000 W/m^2. This figure shows a strong improvement to the non-linear response observed in Figure 3.4.2. When the spectral mismatch factor has been applied the Isc response of the FS-4100 modules is linear (within ± 1%) with respect to irradiance when measured in the h.a.l.m. indoor solar simulator.

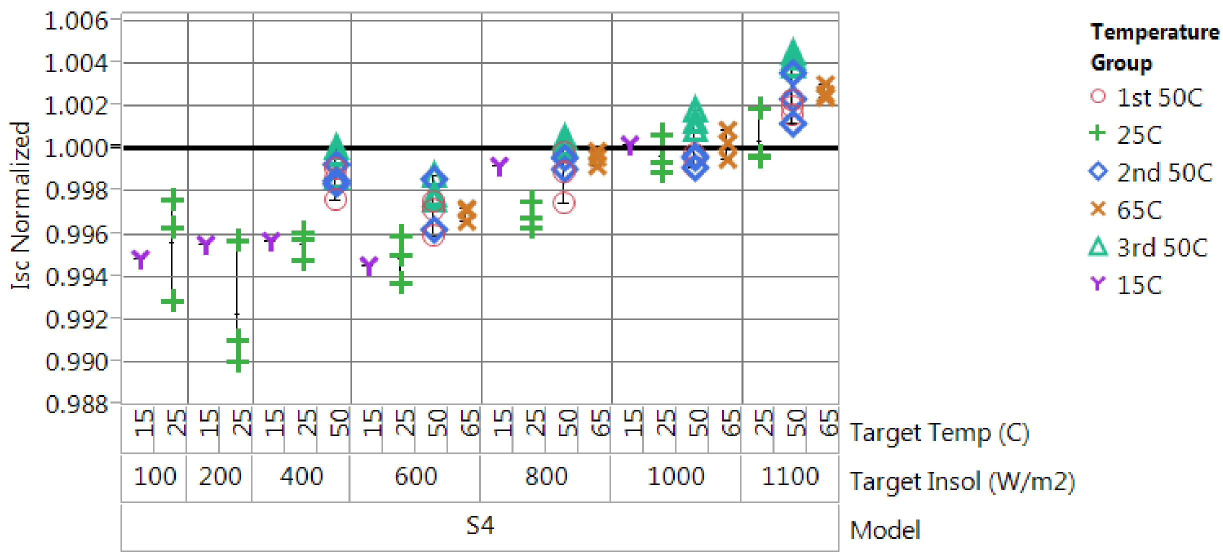

Figure 4.1.2: Variability plot showing the normalized Isc of the series four modules. The Isc response is within +/- 1% of being linear with respect to light intensity.

Figures 4.1.3 to Figure 4.1.5 show the corrected module efficiency at all irradiances and temperatures. When temperature is at 25° C the peak efficiency is at 800 W/m^2. The "Temperature Group" legend indicates the order in which the measurements were performed. The third round of testing at 50° C show a slight improvement in efficiency compared to the first and second rounds of testing at 50° C. The third round of testing at 50° C was performed immediately after testing at 65° C; the exposure to the elevated temperature may have increased efficiency.

At low irradiance (i.e. 100 W/m^2 and 200 W/m^2) and 15° C modules 14035-01 and 14035-02 show peculiar behavior (Figures 4.1.3 and 4.1.4). Specifically, the efficiency of 14035-01 at 200 W/m^2 and 15° C appears about 0.5% lower than expected, and the efficiency of module 14035-02 at 100 W/m^2 and 15° C appears about 0.5% lower than expected. The reasons for these anomalies are still unknown. Most of the deviations from the expected Pmp values at low irradiance are due to shifts in Imp values. Since the delta is mostly in current, the instability of the Xenon arc lamp at low irradiances is one possible explanation for the trends in efficiency at low irradiance.

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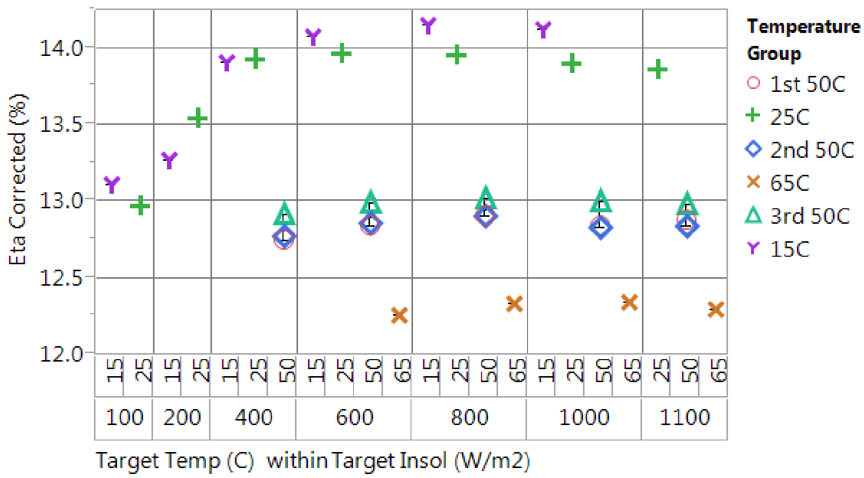

Figure 4.1.3: Efficiency of module 14035-01 for the light intensities and temperatures specified in IEC 61853-1.

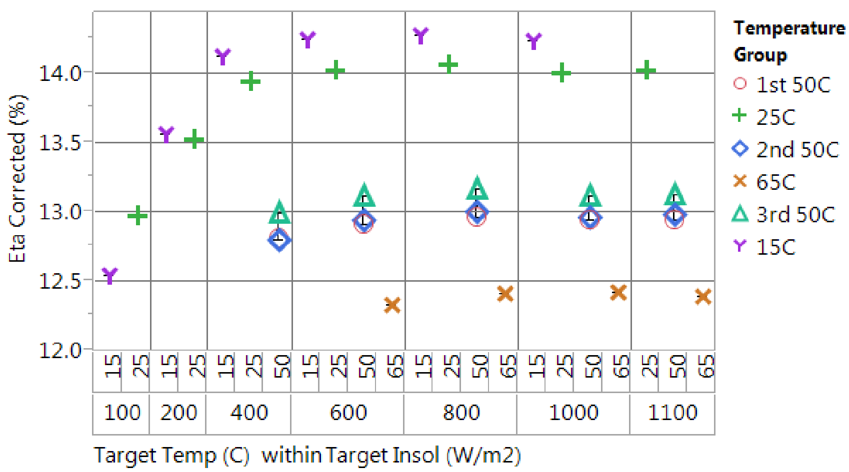

Figure 4.1.4: Efficiency of module 14035-02 for the light intensities and temperatures specified in IEC 61853-1.

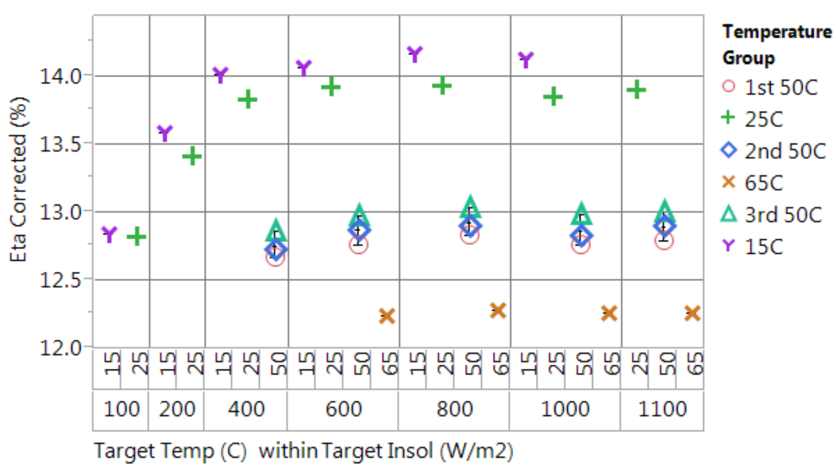

Figure 4.1.5: Efficiency of module 14035-03 for the light intensities and temperatures specified in IEC 61853-1.

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4.2 Temperature Coefficients: The delta between CFV Solar's measured temperature coefficients and the FS-4100 datasheet are shown below in Figure 4.2.1. The initial measurement method, wherein the module was measured immediately after outdoor exposure, yielded a Pmp temperature coefficient with a lower slope than the other two methods (Figure 4.2.2). The initial method showed the greatest delta to the data sheet. The second and third methods yielded identical results that were matched to the datasheet with 0.01 %/C°. The temperature coefficients of all I-V characteristics are provided in the Excel documents.

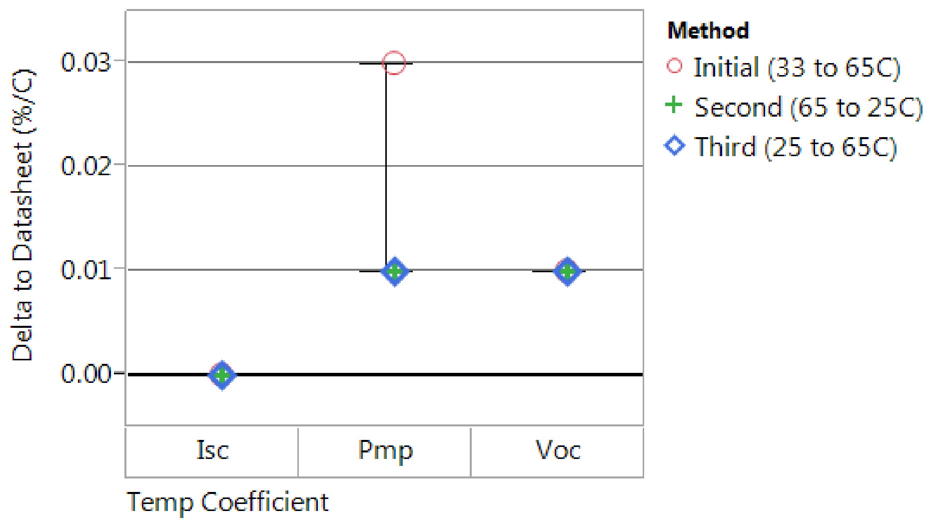

Figure 4.2.1: Variability plot showing the delta between CFV Solar's temperature coefficient measurements and the FS-4100 datasheet. All deltas are in absolute form.

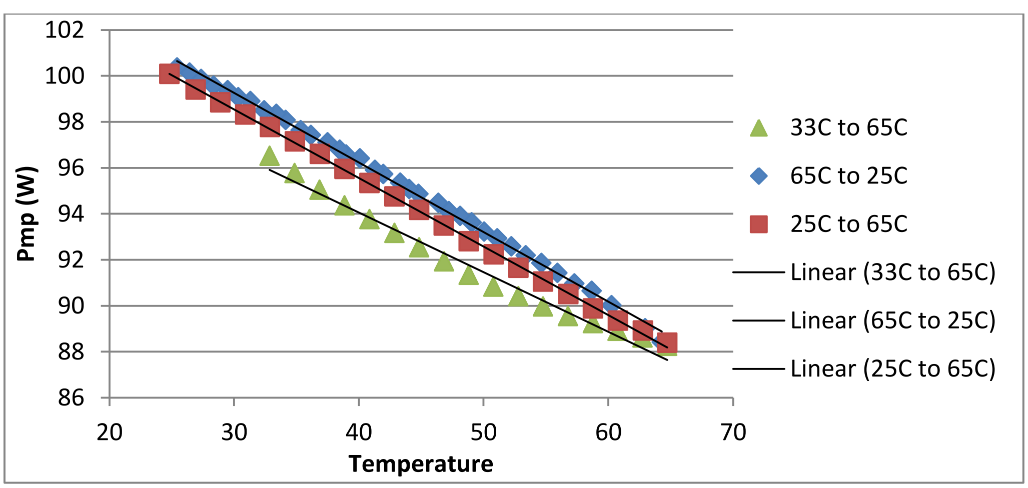

Figure 4.2.2: Regression of Pmp by temperature for the three different temperature coefficient measurement methods used.

Report Prepared By: Nicholas Riedel PV Test Engineer

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Report Date: **October 31, 2014**

CFV Project ID: **14037**

Customer Project No: **14037 – First Solar QED IEC 61853-1**

Customer Contact: **Lauren Ngan**
First Solar, Inc.
28101 Cedar Park Blvd.
Perrysburg, OH 43551-4871

1 **Project Summary:** CFV Solar Test Laboratory conducted performance testing per IEC 61853-1 on three First Solar FS-4102 (QED) modules. The modules were measured inside a class AAA flash solar simulator at the irradiance and temperature levels specified in the IEC 61853-1 performance matrix. CFV Solar Test Laboratory has an ISO 17025 accreditation for the IEC 61853-1 standard. Temperature coefficients were also measured inside the flash solar simulator using three different methods: 1) heated up immediately after outdoor exposure from 37 to 65 °C, 2) cooled down from 65 to 25 °C and 3) heated up from 25 to 65 °C. Methods 2) and 3) met the requirements of the IEC 61646 § 10.4 standard, for which CFV Solar Test Laboratory has an ISO 17025 accreditation.

2 **Executive Summary of Results:** At standard test conditions CFV Solar measured the three modules 8.1 to 8.6% high to nameplate Pmp. The Isc was linear (± 0.7%) with respect to light intensity when spectral corrections were applied. The multi-irradiance and temperature data showed profiles that are typical of PV module behavior: the power changed proportionally to irradiance and temperature. The temperature coefficients measured per methods 2) and 3) showed the best agreement to the FS-4102 datasheet. The detailed test data is documented in an Excel workbook titled "14037 CFV Project Workbook.xls". Any opinions and interpretation of data in this report are those of CFV Solar Test Laboratory.

Report authorized by:
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Laboratory Manager

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3 Procedures:

3.1 Incoming Inspection and Labelling: The modules were unpacked and labeled according to CFV Solar convention. The module IDs and the manufacturer's serial numbers were recorded in the Excel documents.

3.2 Electroluminescence (EL) Imaging: EL images were taken with a Sensovation HR-830 camera that has a resolution of 8.3 MPixels. A long pass filter was affixed to the lens, which blocked incoming light below wavelengths of 850 nm. A constant DC bias of 1.5 amps (Imp*1.25) was applied to the modules for two minutes while the imaging was performed in a dark room. The EL images were taken without preconditioning.

3.3 Preconditioning: The three tested modules were placed on a fixed racked at latitude tilt (35°) and grid connected prior to indoor performance testing. The modules were exposed outdoors for a minimum of three weeks before receiving multi-irradiance measurements at 25, 50 and 65 °C. Because the entire IEC 61853-1 performance matrix could not be completed in a single day the modules were placed outside (this time in open circuit) for another10 days before they were brought back inside for multi-irradiance testing at 15 °C.

3.4 Indoor Performance Measurements: The indoor flash tests were done in a class AAA h.a.l.m. flash solar simulator. The h.a.l.m. flasher generates a 45 millisecond pulse from a Xenon arc lamp and a sweep time of 40 milliseconds was used. The modules were measured from Isc to Voc then from Voc to Isc and averaged. The process was repeated three times and the results averaged for each irradiance and temperature level. The testing was performed according to IEC 61853-1. Specifically, the environmental conditions stated in Table 2 within Section 8 of the standard were directly measured; measurements were done at 65 °C instead of 75 °C per the standard due to the current heating limitations of the flasher's integrated thermal chamber. Measurements at 15 °C were done by first placing the module in an external climate chamber at 5 °C and then transporting it to the flasher for measurement. The average temperature gradient was 0.1 °C between forward and reverse IV traces at 15 °C.

Back sheet temperatures were directly measured within ± 1 °C of target and irradiances were directly measured within ± 3 W/m^2 of target. Voltage and current corrections were applied as needed per correction procedure 1 within IEC 60891; no corrections were made to series or shunt resistance. The raw data is also made available in the Excel documents. Proximity to air mass (AM) 1.5 is verified by the h.a.l.m. flasher's class A spectral match to the IEC 60904-3 reference spectrum.

The h.a.l.m. Xenon arc lamp was calibrated for irradiance with a high optical quality (HOQ) mono-silicon small area monitor cell with an absolute uncertainty of ± 0.55%. The HOQ monitor cell has a different spectral response than the CdTe device under test (DUT) (Figure 3.4.1). Spectral mismatch factors were calculated for each intensity level to minimize the measurement errors associated with multi-irradiance measurements. The mismatch factors take into account the spectral differences between the reference cell, the device under test, the Xenon lamp spectrum at multiple irradiances, and the IEC 60904-3 reference spectrum.

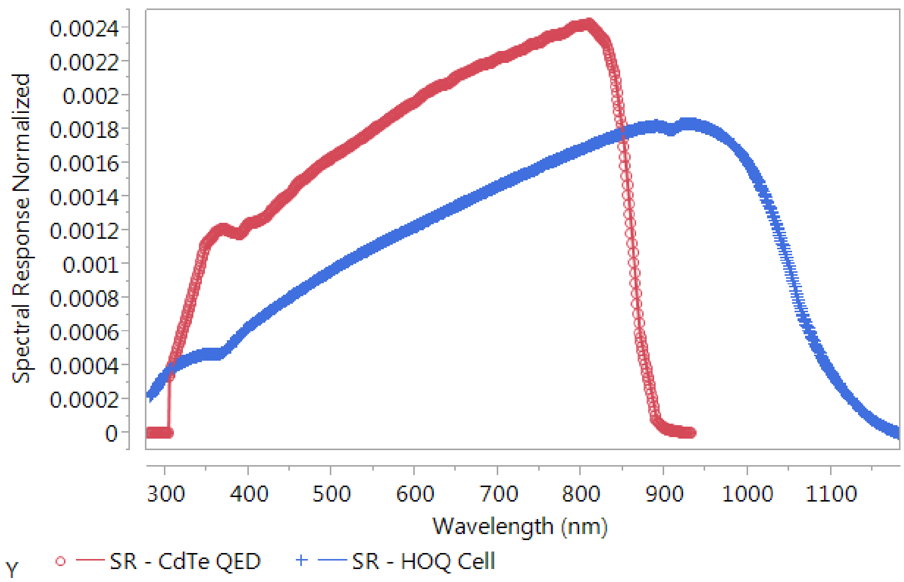

Figure 3.4.1: Overlay of the normalized spectral response of the QED module and the HOQ mono-Si reference cell used in testing. When measured at 1000 W/m^2 on the h.a.lm. the spectral mismatch factor is 0.927, which means the measured result will be 7.3% higher than if no spectral correction were applied. The spectral responses are normalized to the column sum.

The spectral mismatch factors were calculated at one sun (1000 W/m^2) using quantum efficiency data provided by First Solar and with equation 3 in IEC 60904-7. Spectral mismatch factors were calculated for the remaining intensity levels (i.e. 100 W/m^2, 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2 and 1100 W/m^2) by first directly measuring a Series 3 and QED module at each of these intensities, but without accounting for spectral mismatch. Then, the Isc of these measurements was normalized to their corresponding values at 1000 W/m^2 (Figure 3.4.2). Finally, the average normalized Isc value at each intensity level in Figure 3.4.2 was multiplied by the spectral mismatch factor calculated at one-sun. The spectral correction factors calculated in this procedure gave the DUTs a nearly linear response across the irradiances specified in IEC 61853-1.

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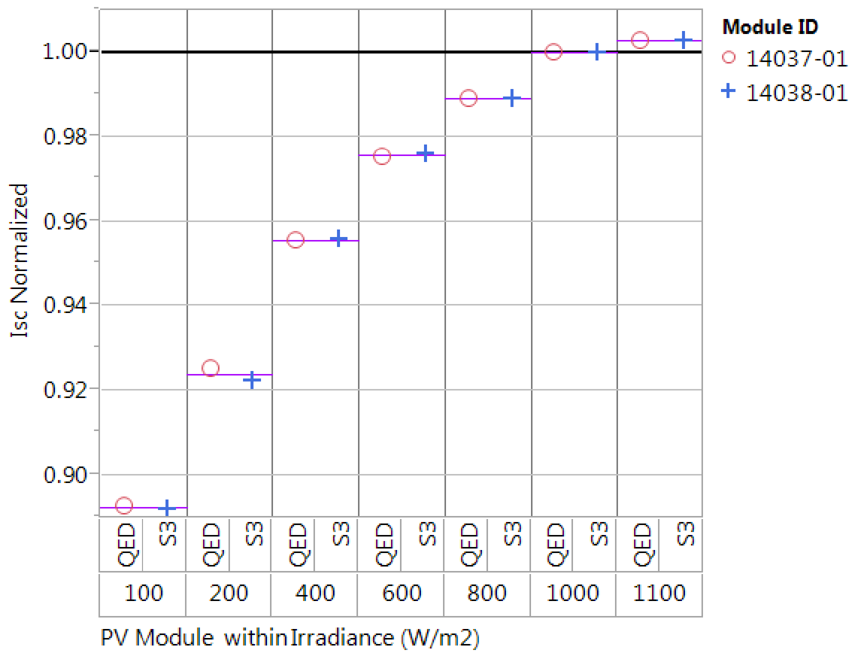

Figure 3.4.2: Variability plot that shows the deviation from a linear response when spectral mismatch is not accounted for. The modules measured are a Series 3 (Blue) and QED (Red). The purple lines indicate the average.

Figure 3.4.3: Class AAA h.a.l.m. flash solar simulator with a standard silicon module.

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Table 3.4.1 shows the absolute and relative uncertainty of the h.a.l.m. flasher measurements. These uncertainties take in to account all the major sources of uncertainty, including the calibration, spectrum of the flasher, non-uniformity of the irradiance in the test plane, etc. The relative uncertainty for power measurements is ± 0.4%, which means the test system can detect smaller relative shifts in performance that may result from environmental and mechanical stresses called for by a particular test sequence.

Table 3.4.1 Absolute and relative uncertainties of the flash data for crystalline silicon modules.

Parameter	Absolute [%]	Relative [%]
Pmp	+/- 2.8	+/- 0.40
Isc	+/- 2.3	+/- 0.20
Imp	+/- 2.3	+/- 0.25
Voc	+/- 0.6	+/- 0.20
Vmp	+/- 0.7	+/- 0.25

3.5 Temperature Coefficients: The temperature coefficient tests were done in the Class AAA h.a.l.m. flash solar simulator. Four PT100s were placed on the back sheet of the modules and IV measurements were not taken until temperature uniformity was less than 1.5° C. A single IV measurement was taken at each temperature interval with sweeps from Isc to Voc and from Voc to Isc; the two sweeps were averaged for a final IV curve. Three procedures were used to derive temperature coefficients. In the first procedure, the module was placed in the test bed within 15 minutes of being removed from outdoors. IV measurements were taken in intervals of 2° C starting at the temperature the module stabilized at (37° C) and increased to 65° C. The second procedure was performed immediately after the first and the module was measured from 65° to 25° C in intervals of roughly 1° C. Finally, the module was measured from 25° to 65° C in intervals of 2° C. Regression analyses were then used to derive temperature coefficients for the IV characteristics of interest.

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4 Discussion of Results:

4.1 Indoor Performance Measurements:

Figure 4.1.1 shows the performance measurements of the three FS-4102 QED modules corrected to STC. The y-axis shows the delta between CFV Solar's measurements and the FS-4102 QED nameplate (NP) values. On average, CFV Solar measured maximum power (Pmp) 8.4% higher than the First Solar NP. The Imp values measured 5.3% high relative to NP and Isc values were 2.8% low to NP, on average. Vmp averaged 2.8% high relative to NP; Voc averaged 2.3% high relative to NP.

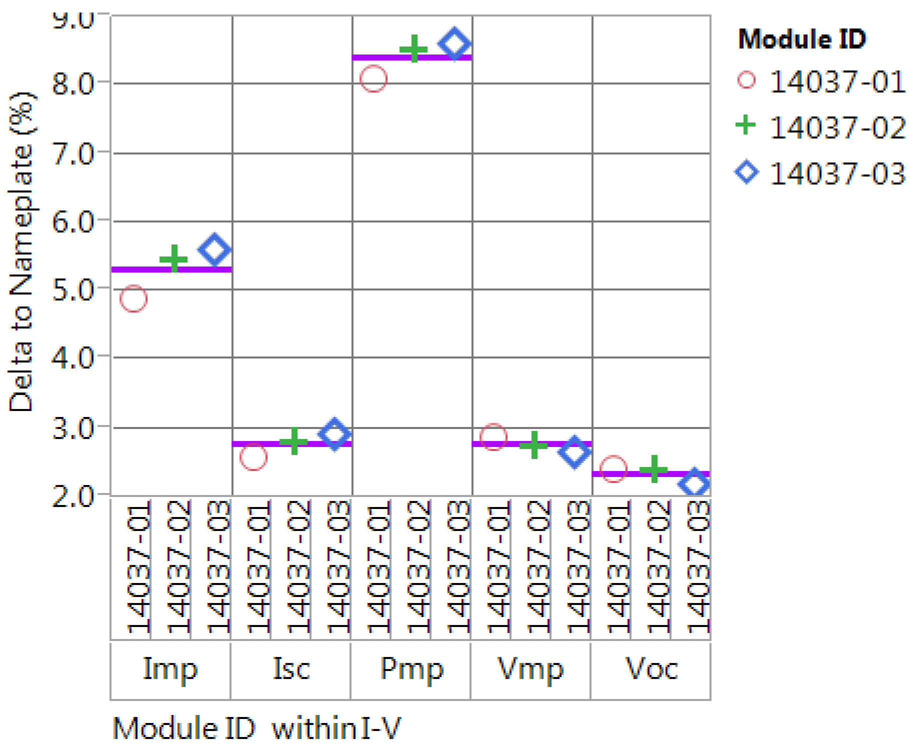

Figure 4.1.1: Variability plot showing the delta between CFV Solar's measurements and the FS-4102 nameplate for all I-V characteristics at standard test conditions (STC). The group means are shown by the horizontal purple lines.

Figure 4.1.2 shows the Isc values of all three FS-4102 QED modules normalized with respect to their corresponding Isc values at 1000 W/m^2. This figure shows a strong improvement to the non-linear response observed in Figure 3.4.2. When the spectral mismatch factor has been applied the Isc response of the FS-4102 QED modules is linear (within ± 0.7%) with respect to irradiance when measured in the h.a.l.m. indoor solar simulator.

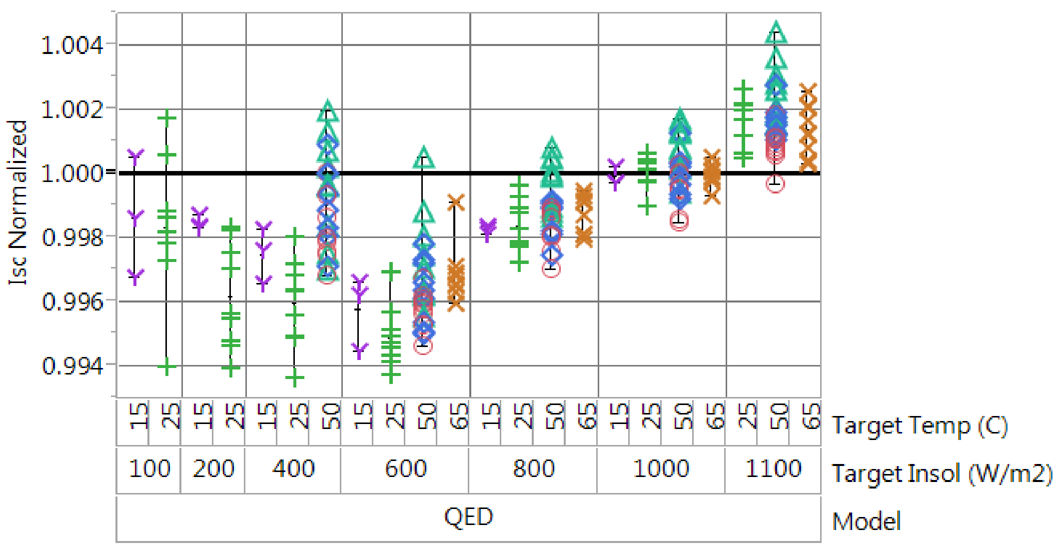

Figure 4.1.2: Variability plot showing the normalized Isc of the series four modules. The Isc response is within +/- 1% of being linear with respect to light intensity.

Figures 4.1.3 to Figure 4.1.5 show the corrected module efficiency at all irradiances and temperatures. When temperature is at 25° C the peak efficiency of modules 14037-01 and 14037-02 is at 600 W/m^2. The peak efficiency at 25° C of module 14037-03 is at 400 W/m^2. The “Temperature Group” legend indicates the order in which the measurements were performed.

At low irradiance (i.e. 100 W/m^2, 200 W/m^2 and 400 W/m^2) and 15° C modules 14037-02 and 14037-03 show peculiar behavior (Figures 4.1.4 and 4.1.5). Specifically, the efficiencies of 14037-02 and 14037-03 appear lower than expected at low irradiance and 15° C. The reasons for these anomalies are still unknown. Most of the deviations from the expected Pmp values at low irradiance are due to shifts in Imp values. Since the delta is mostly in current, the instability of the Xenon arc lamp at low irradiances is one possible explanation for the trends in efficiency at low irradiance.

Figure 4.1.3: Efficiency of module 14037-01 for the light intensities and temperatures specified in IEC 61853-1.

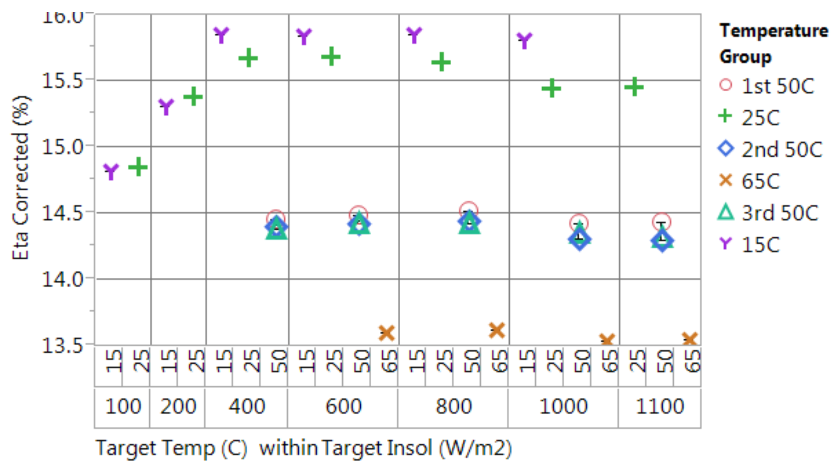

Figure 4.1.4: Efficiency of module 14037-02 for the light intensities and temperatures specified in IEC 61853-1.

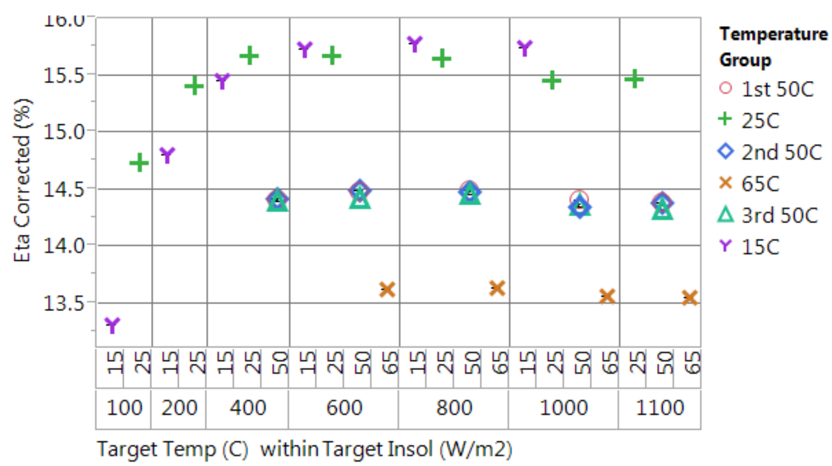

Figure 4.1.5: Efficiency of module 14037-03 for the light intensities and temperatures specified in IEC 61853-1.

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4.2 Temperature Coefficients: The delta between CFV Solar's measured temperature coefficients and the FS-4102 datasheet are shown below in Figure 4.2.1. The initial measurement method, wherein the module was measured immediately after outdoor exposure, yielded a Pmp temperature coefficient with a higher slope than the other two methods (Figure 4.2.2). The initial method showed the greatest delta to the data sheet. The second and third methods yielded identical results that were matched to the datasheet with 0.03 %/C°. The temperature coefficients of all I-V characteristics are provided in the Excel documents.

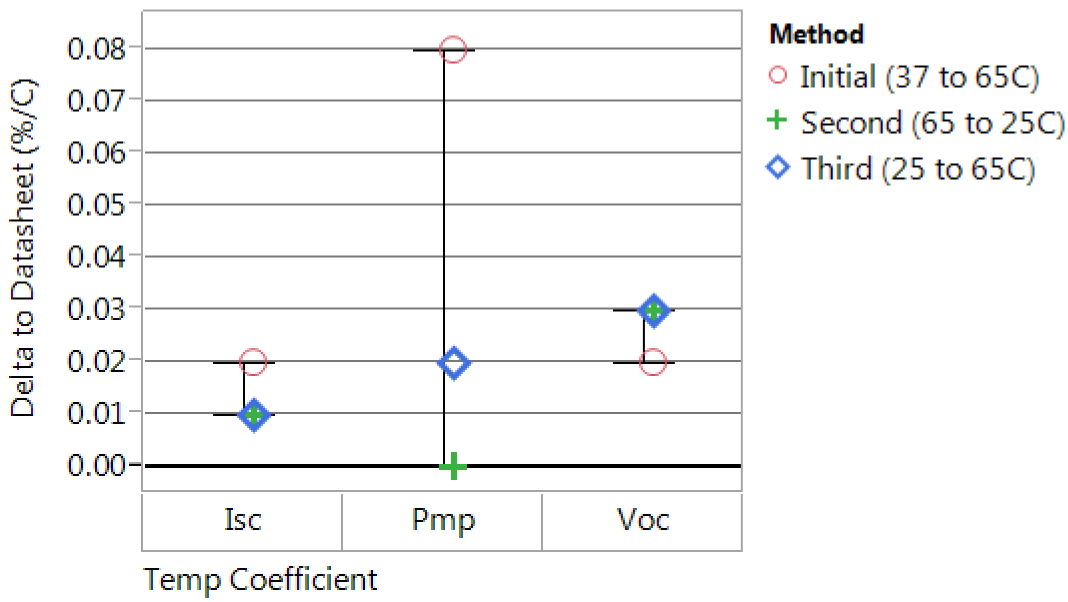

Figure 4.2.1: Variability plot showing the delta between CFV Solar's temperature coefficient measurements and the FS-4102 datasheet. All deltas are in absolute form.

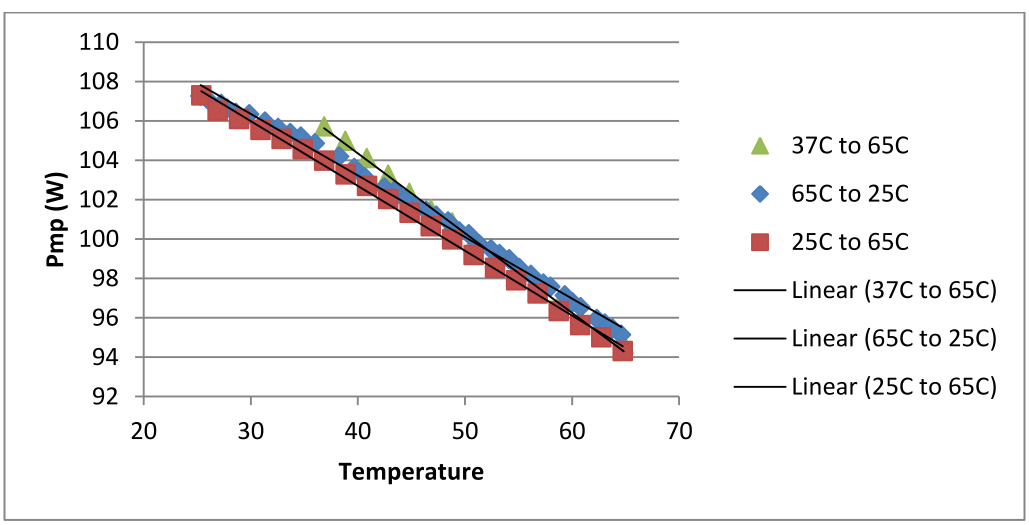

Figure 4.2.2: Regression of Pmp by temperature for the three different temperature coefficient measurement methods used.

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Report Date: March 19, 2015

CFV Project ID: 14056

Customer Project No: First Solar – IEC 61853-2 Tests

Customer Contact: Lauren Ngan
First Solar, Inc.
28101 Cedar Park Blvd.
Perrysburg, OH 43551-4871

1 Project Summary: CFV Solar Test Laboratory tested three First Solar module types per the IEC 61853-2 draft standard. The test modules consisted of FS-395-plus, FS-4100 and FS-4102-2 models. The IEC 61853-2 standard contains three performance tests, which include angle of incidence (AOI), nominal module operating temperature (NMOT) and spectral response (SR) measurements. Six modules received AOI measurements including three FS-4102-2 modules without anti-reflective coating (ARC), one FS-395-plus with ARC, one FS-395-plus without ARC, and one FS-4100 with ARC. One FS-395-plus, one FS-4100 and one FS-4102-2 received NMOT and SR measurements, none of which had ARC. The AOI and NMOT measurements were conducted at CFV Solar in Albuquerque, New Mexico. Upon completion of the AOI and NMOT tests, the modules were sent to Fraunhofer ISE in Freiburg, Germany for SR measurements.

2 Executive Summary of Results: The FS-4100 and FS-4102-2 both had measured NMOT values of 37.9 °C. The FS-395-plus had a higher NMOT value of 41.5 °C. The SR of the FS-4100 and FS-395-plus were well matched at all measured wavelengths (350 – 900 nm). However, the FS-4102-2 generates more current than the FS-395-plus and FS-4100 modules at wavelengths from 350 to 550 nm and from 850 to 900 nm. The AOI test results were confounded with day to day variability, so conclusions based on the relative performance of different module types were not conclusive. The detailed test data is documented in an Excel workbook titled "14056 CFV Project Workbook – First Solar IEC 61853-2 Test.xls". Any opinions and interpretation of data in this report are those of CFV Solar Test Laboratory.

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3 Procedures:

3.1 Incoming Inspection and Labeling:

Incoming Inspection and Labeling: The modules were tested previously under various CFV Solar Projects. The modules measured for AOI came from CFV Solar projects 14029 and 14037. Modules tested for NMOT and SR were tested previously under CFV Solar projects 14035, 14037 and 14038. All previous testing was performance related. The module IDs and the manufacturer's serial numbers are recorded in the 14056 Excel document that accompanies this report. Table 3.1.1 shows the module types tested and whether the module tested was ARC or not. Most modules were non-ARC.

Table 3.1.1: Summary of First Solar module types tested. Whether the module was anti-reflective coated or not is specified.

Test	FS-395-plus	FS-4100	FS-4102-2
AOI	ARC and Non-ARC	ARC	Non-ARC
NMOT	Non-ARC	Non-ARC	Non-ARC
SR	Non-ARC	Non-ARC	Non-ARC

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3.2 Previous Testing at CFV Solar: The 61853-2 standard requires that preconditioning, visual inspection and max power determination tests be performed on three modules of a given model type. These tests were performed under projects 14035, 14037 and 14038. Please refer to these reports for test results.

3.3 Angle of Incidence (AOI) Test per Sandia National Labs: The AOI measurements were done in accordance with procedures currently under final review in preparation for publication by Sandia National Labs (SNL). The module is mounted on a precision two-axis tracker outdoors and moved from a position normal to the sun to a position 90 degrees off angle. The short circuit current of the module and the AOI adjusted irradiance from a pyranometer are recorded, along with sun position and module position at fixed points along the way. A ratio of two estimates for direct beam irradiance is then calculated to generate the AOI response of the module.

3.4 Nominal Module Operating Temperature (NMOT): The NMOT measurements were conducted on a fixed tilt south facing rack. The angle of the rack was adjusted such that the modules were within ±5° of normal to the sun at solar noon. The rack angle was set to 55° for the test. Four thermal couples (TCs) were placed on the back of the test modules in locations specified by IEC 61853-2. Thermal imaging was used to avoid placement of TCs on abnormally hot cells. Module backsheet temperature was recorded over a range of wind speed, irradiance and ambient temperature conditions. No corrections were made for cell temperature.

The NMOT values were determined with data collected on ten days where the environmental conditions specified in the standard were met. The NMOT value is calculated through linear regression of $G/(T_m\text{-}T_{amb})$ by the five minute average wind speed. Wherein G is the plane of array irradiance, T_m is module temperature (i.e. backsheet temperature), and T_{amb} is ambient temperature. The delta between T_m and T_{amb} is determined at an irradiance of 800W/m^2 and a wind speed of 1 m/s. The NMOT is then determined as $(T_m - T_{amb}) + 20°$. The NMOT value has no correction factor for environmental conditions. The modules were actively held at their maximum power point throughout the duration of the test in the configuration shown below.

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Figure 3.4.1: Fixed-tilt, open air array of FS-395-Plus, FS-4100, and FS-4102-2 modules measured for NMOT.

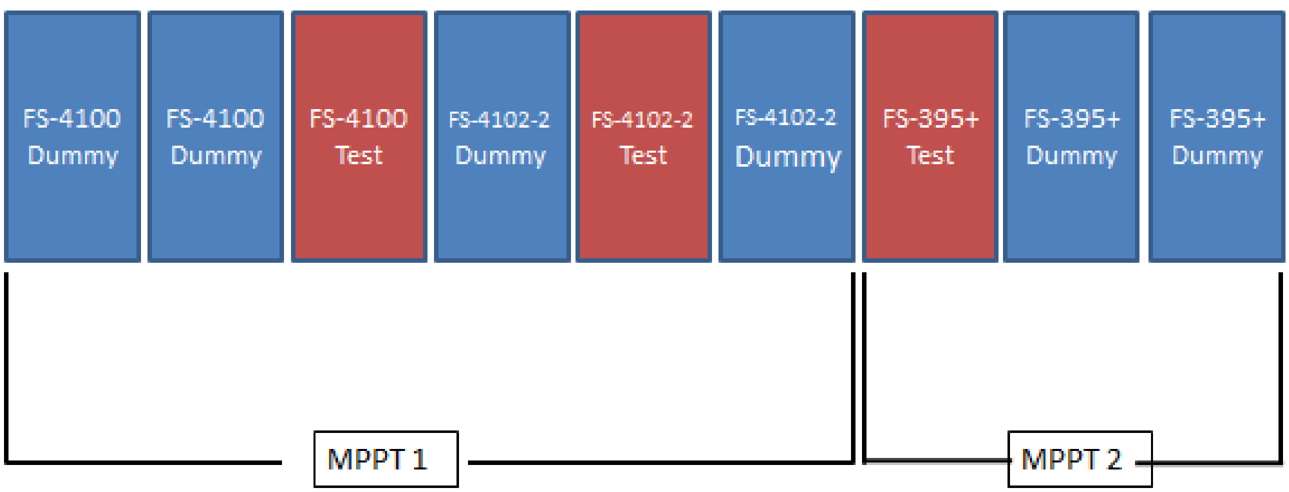

Figure 3.4.2: Configuration of First Solar modules measured for NMOT. The modules in red modules labeled as "test" indicate which modules were instrumented with TCs. Modules labeled as "dummy" had no TCs, but were used as thermal barriers. The figure is shown as facing the sunny side of the modules (North). The series 4 modules were placed on a separate string than the series 3 modules to minimize current mismatch.

3.5 Spectral Response Measurements: The spectral response measurements were done by Fraunhofer ISE in Germany. One FS-395-plus, one FS-4100 and one FS-4102-2 module were sent for measurement. The measurements were done on the full sized modules and were non-destructive. A Pasan flasher with a filtering system was used to measure spectral response from 350 to 920 nm.

4 Discussion of Results:

4.1 Angle of Incidence (AOI): Table 4.1.1 shows the average AOI response from each model type tested. There were three FS-4102-2 modules that were all tested on the same day. The results show larger deviations between modules at higher AOIs. There were two FS-395-plus modules, one with anti-reflective coating (ARC) and one without ARC. Finally, there was one FS-4100 module with ARC. All modules were tested on separate days except for the FS-4102-2 modules, which were all tested on the same day.

Table 4.1.1: Summary table of incidence angle modifiers (IAM) as measured by CFV Solar Test Laboratory.

AOI (deg)	FS-4102-2 (No ARC) Avg. IAM	FS-4102-2 Std. Dev.	FS-395-Plus (ARC) IAM	FS-395-Plus (No ARC) IAM	FS-4100 (ARC) IAM
0	1.00	0.000	1.00	1.00	1.00
10	1.00	0.001	1.00	1.00	1.00
20	1.00	0.002	0.99	0.99	1.00
30	1.00	0.003	0.99	0.99	0.99
35	1.00	0.003	0.98	0.99	0.99
40	0.99	0.003	0.98	0.98	0.99
45	0.99	0.004	0.98	0.98	0.98
50	0.99	0.004	0.97	0.97	0.99
55	0.98	0.005	0.97	0.95	0.98
60	0.97	0.005	0.95	0.94	0.97
65	0.95	0.006	0.94	0.91	0.95
70	0.91	0.008	0.90	0.87	0.92
75	0.84	0.011	0.83	0.79	0.86
80	0.72	0.017	0.70	0.68	0.74
85	0.56	0.026	0.53	0.56	0.62
no. samples	3		1	1	1

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The measured AOI data are shown in Figure 4.1.1. The Fresnel model is shown for reference using two index of refraction terms 1 and 1.52. The FS-4100 with ARC performed the best having the highest IAM on average. The FS-4102 with no ARC performed better than the FS-395-Plus with ARC. The FS-395-plus with ARC performed better than the FS-395-plus without ARC. The relative performance of each module type is confounded with the day to day variation associated with the AOI test. CFV recommends testing different module types during the same day for higher quality comparisons.

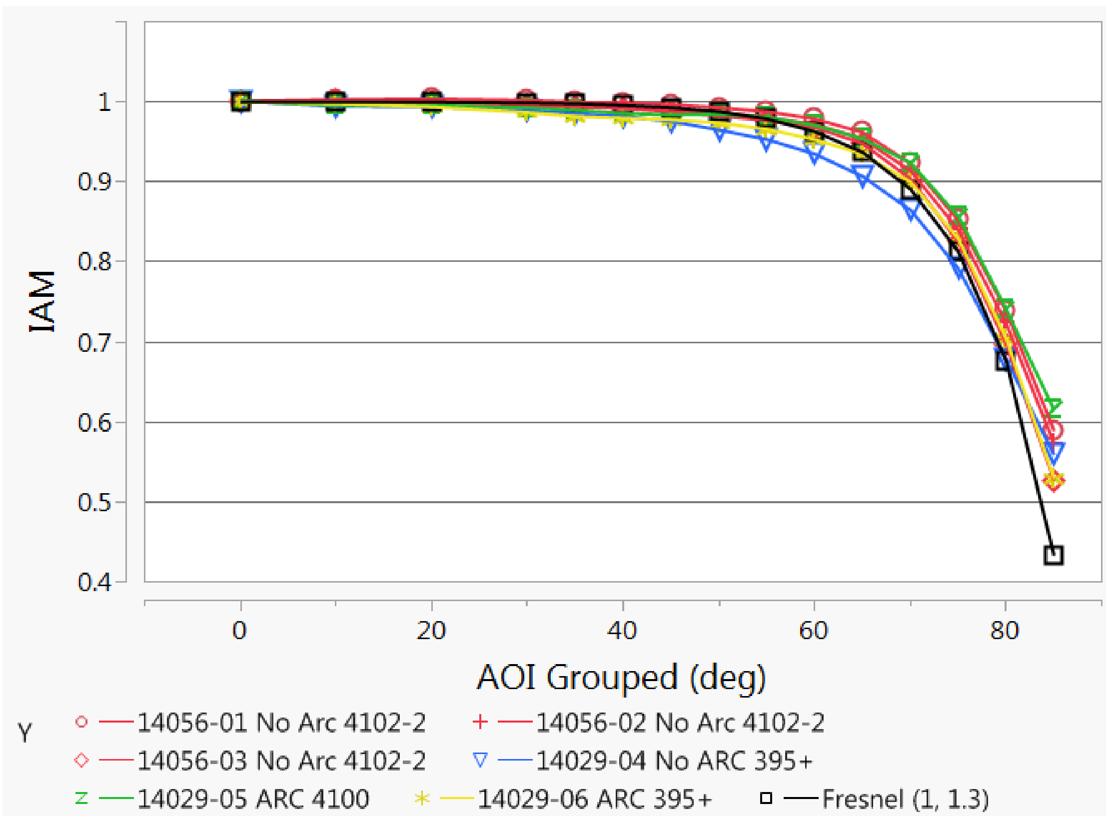

Figure 4.1.1: Incidence Angle Modifiers (IAM) for the four module types. The black line shows the Fresnel equation.

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4.2 Nominal Operating Module Temperature (NMOT): The ten good days of data used in the regression were collected over a 40 day period. The strict environmental data filtering requirements in IEC 61853-2 resulted in 75% of test days being rejected during the winter season in Albuquerque, NM. Table 4.2.1 shows a summary of the coefficients and NMOTs derived for the FS-395-plus, FS-4100 and FS-4102-2. None of these modules had ARC.

The intercepts and slopes in Table 4.2.1 are determined through plotting *G/(Tm-Tamb)* by the five minute average wind speed. The linear regression plots used to derive the coefficients in Table 4.2.1 are provided in the data workbook that accompanies this document. The intercept U_0 is given in units of (W/m^2*C), which can be referred to as the 'overall heat transfer coefficient'. It follows that the intercept of the regression is essentially a measure of heat loss in the module at zero wind speed.

Table 4.2.1: Summary of coefficients and operating temperatures

Module ID	Intercept U_0 (W/m^2*C)	Slope U_1 ($W*s/m^3$*C)	NMOT (°C)
14035-03 (FS-4100)	42.0	2.71	37.9
14037-02 (FS-4102-2)	41.4	3.21	37.9
14038-01 (FS-395+)	32.5	4.63	41.5

The measured NMOT of FS-395-plus module is 3.6 °C higher than the FS-4100 and FS-4102-2 modules. The calculated NMOT values range from 37.9 °C to 41.5 °C, which is considerably lower than typical nominal operating cell temperature (NOCT) values. The lower NMOT values can be attributed in part to the state the modules are held at during the respective tests. The test modules are held in open-circuit during the NOCT test and are held at their maximum power point during the NMOT test.

As mentioned previously, the NMOT is calculated at an irradiance of 800 W/m^2 and a wind speed of 1 m/s. Although the NMOT values of the FS-4100 and FS-4102-2 modules are both 37.9 °C, the steeper coefficient of the FS-4102-2 indicates that at wind speeds above 1 m/s, the module temperature (T_m) of the FS-4102-2 would be lower than the T_m of the FS-4100.

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4.3 Spectral Response: The spectral response (SR) data from Fraunhofer ISE are shown in Figure 4.3.1. The SR of each module shown below is normalized to the maximum measurement in A/W. The FS-395-plus and FS-4100 show good agreement at all measured wavelengths. However, the FS-4102-2 generates more current than the FS-395-plus and FS-4100 modules at wavelengths from 350 to 550 nm and from 850 to 900 nm. None of these modules had ARC.

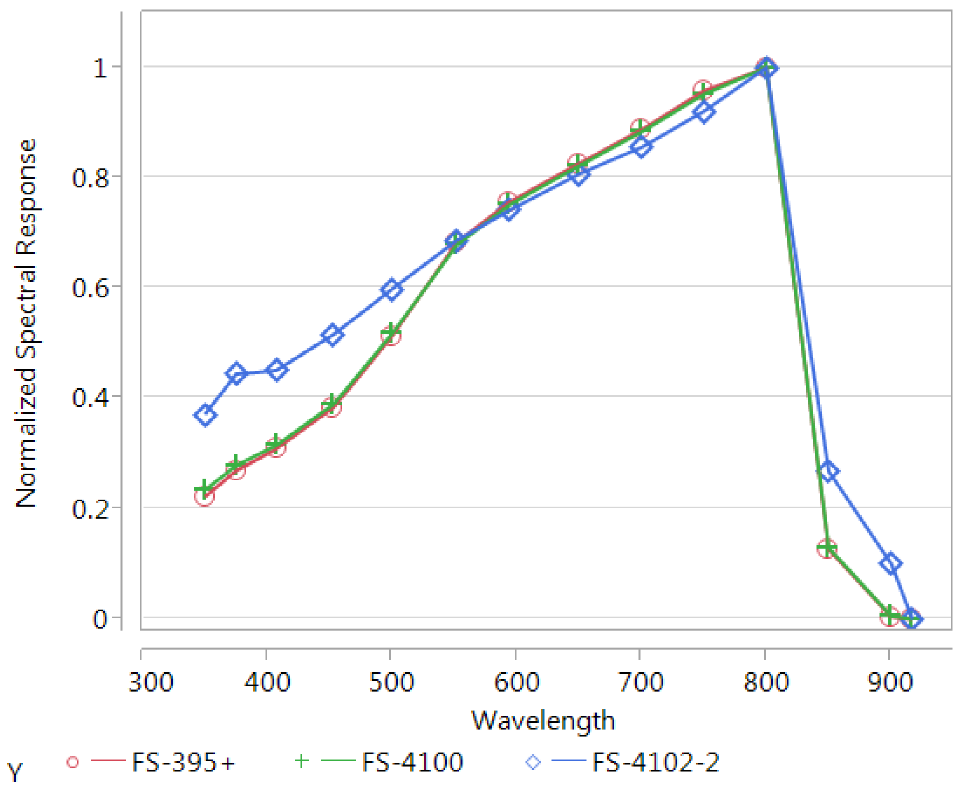

Figure 4.3.1: Normalized spectral response as measured by Fraunhofer ISE.

Quantum efficiency data were provided by First Solar for all three module types. These data were converted to SR, normalized and compared to the normalized SR from Fraunhofer ISE (Figure 4.3.1). The data shown are in absolute terms. A positive value indicates that First Solar measured higher than ISE at that wavelength. Note that the SR was measured on the same module types, but not on the same module. Figure 4.3.1 shows that the SR measurements from the two labs were within ± 0.1 at all wavelengths except for 850 nm. At 850 nm the First Solar measurements of the FS-395-plus and FS-4102-2 modules are considerably higher than the measurements from ISE.

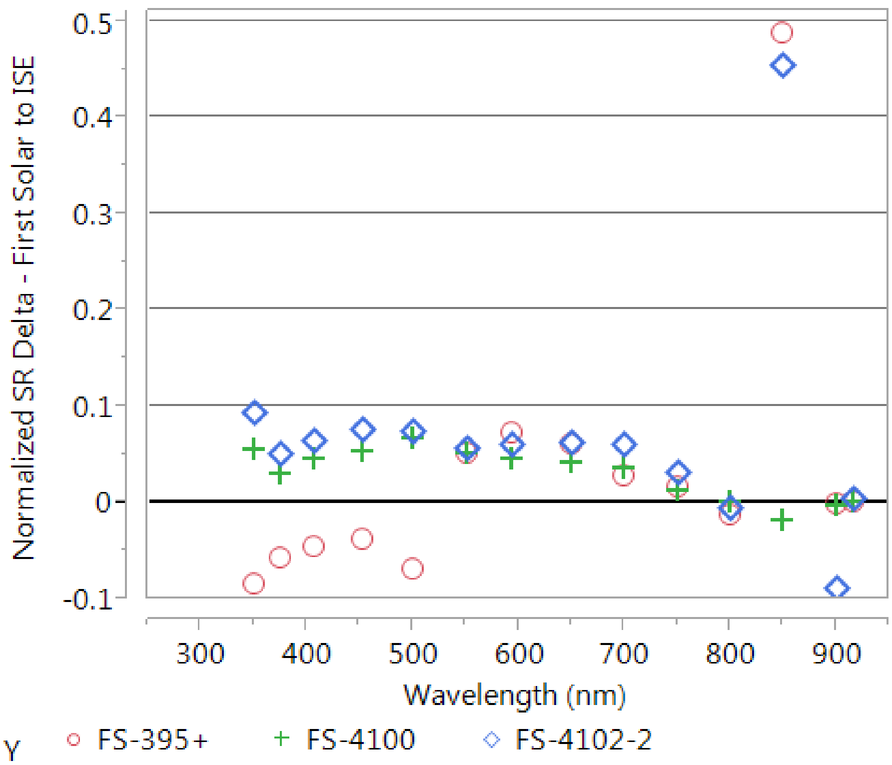

Figure 4.3.2: Delta between normalized spectral response measurements as measured by Fraunhofer ISE and First Solar. A positive value indicates that First Solar measured higher at a given wavelength.

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IEC 61853 Test Report

Report Date: **September 28, 2016**

CFV Project ID: **16035**

Customer Project No: **4600080335**

Customer Contact: **Lauren Ngan / First Solar, Inc.**
350 W Washington St, Tempe, AZ 85281
United States

1 Project Summary

CFV Solar conducted IEC 61853-1 and IEC 61853-2 tests on three **First Solar FS-4112-3** modules. Namely, the multi-irradiance and multi-temperature performance test (IEC 61853-1), the measurement of incidence angle effects (IEC 61853-2), the measurement of spectral responsivity (IEC 61853-2), and the nominal module operating temperature test (IEC 61853-2) were carried out. The modules were preconditioned according to First Solar's guidelines prior to the multi-irradiance and multi-temperature performance test.

2 Executive Summary of Results

The IEC 61853-1 and IEC 61853-2 test results were obtained separately on the three modules. Detailed test data are documented in an Excel workbook titled "16035 CFV Project Workbook - FS Series 4 V3 61853.xlsx". Any opinions and interpretation of the data presented in this report are those of CFV Solar Test Laboratory.

Report Authorized by:

Larry Pratt - Laboratory Manager

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Jim Crimmins – General Manager

James P. Crimmins

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3 Procedures

3.1 Incoming Inspection

The modules were unpacked, cleaned, and labeled according to CFV Solar convention. The serial numbers from the nameplates are listed in the Results section.

3.2 Preconditioning

To reverse the transient degradation caused by storage and shipping on the CdTe modules, the modules were at first preconditioned by biasing them in a temperature-controlled chamber, according to the procedure defined in First Solar Testing Specifications and Guidelines, Revision 7 (75 V, 65°C, and 24 hours). First attempts at the IEC 61853-1 multi-irradiance and multi-temperature, however, showed that the modules were degrading through CFV's standard IEC 61853-1 test, which involved measurements at 50°C and 75°C.

After discussions with the customer, CFV Solar preconditioned the modules with a light-soaking chamber, with the expectation that the light soaking would bring the modules to more stable states. Following tests revealed that this was not the case, and that reordering the multi-temperature measurements (original: 25°C-50°C-75°C-15°C; revised: 15°C-25°C-50°C-25°C-75°C) was more effective. The modules still degraded through the 75°C stage, but this problem could be remedied by excluding the 75°C points during the PAN file optimization step.

Although the light-soaking-based preconditioning step offered no advantage to the standard preconditioning step, the light soaking approach was still used for the preconditioning before the final performance measurements for this project.

3.3 Performance at STC

Indoor flash tests were carried out with a class $A^+A^+A^+$ solar simulator, located in a temperature-controlled room (25 ± 1°C). The module temperature was measured at four points, with calibrated RTDs having uncertainties of ± 0.13°C.

The irradiance of the Xenon arc lamp flash at the module plane was measured with a co-planar reference cell calibrated at PTB of Germany, having an uncertainty of ± 0.50 %. The irradiance is controlled within 1000 ± 3 W/m^2 for the measurements.

A performance measurement involved six I-V sweeps. The I-V curve was first swept from Isc to Voc, and then in reverse from Voc to Isc for the subsequent flash. The forward and reverse sweeps were repeated three times, and the Isc, Voc, Imp, Vmp, Pmp, and FF averages were recorded as the measured values.

Table 3.3.1 shows the accuracy and repeatability of CFV's STC performance data for CdTe modules. The values take in to account all the major sources of error, including the reference cell calibration, spectrum of the flasher, non-uniformity of the irradiance in the test plane, and etc.

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Table 3.3.1 Accuracy and repeatability of CFV's STC performance data for CdTe modules

Parameter	Accuracy [%]	Repeatability [%]
Isc	± 2.5	± 0.5
Voc	± 0.8	± 0.5
Imp	± 2.9	± 0.45
Vmp	± 1.6	± 0.9
Pmp	± 3.2	± 1.2

For this project, a PTB-calibrated Fraunhofer WPVS cell with KG3 filter glass was used as the reference cell. A spectral mismatch factor of 0.986, derived with the spectral response data of a First Solar Series 4 V2 control module at CFV, was employed for the measurements. The spectral responsivity measurements at Fraunhofer ISE CalLab that followed revealed the correct spectral mismatch factor for the Series V3 modules to be 0.988, and the I-V data was subsequently corrected for the mismatch factor difference.

The external quantum efficiency (EQE) profiles of the three 16035 modules are shown along with that of the CFV reference cell in Fig. 3.3.1. The spectrum of CFV's flasher and the reference AM1.5G spectrum are shown in Fig. 3.3.2.

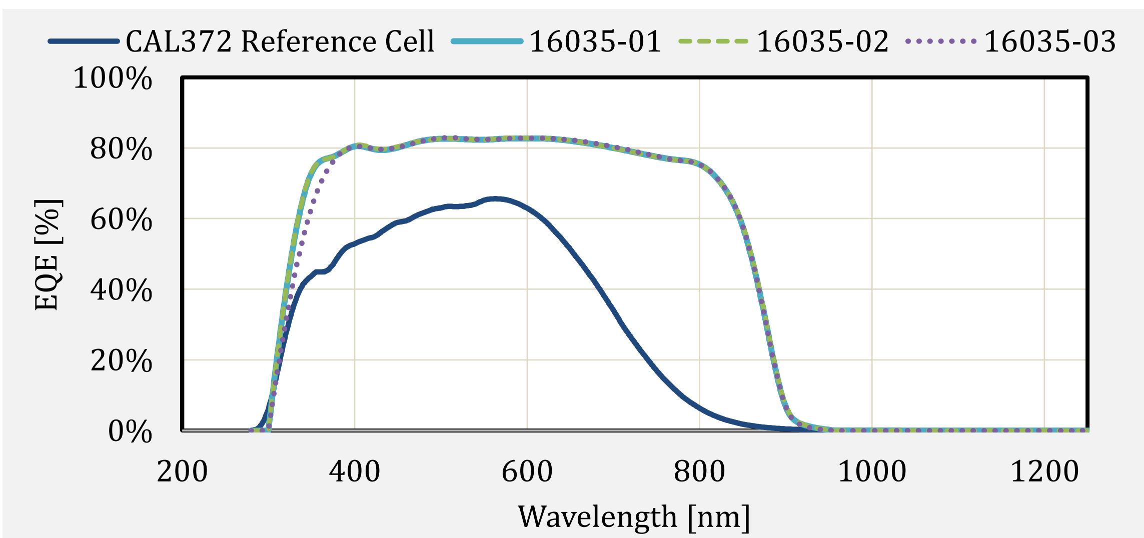

Fig. 3.3.1 EQE of CFV's reference cell and the project modules

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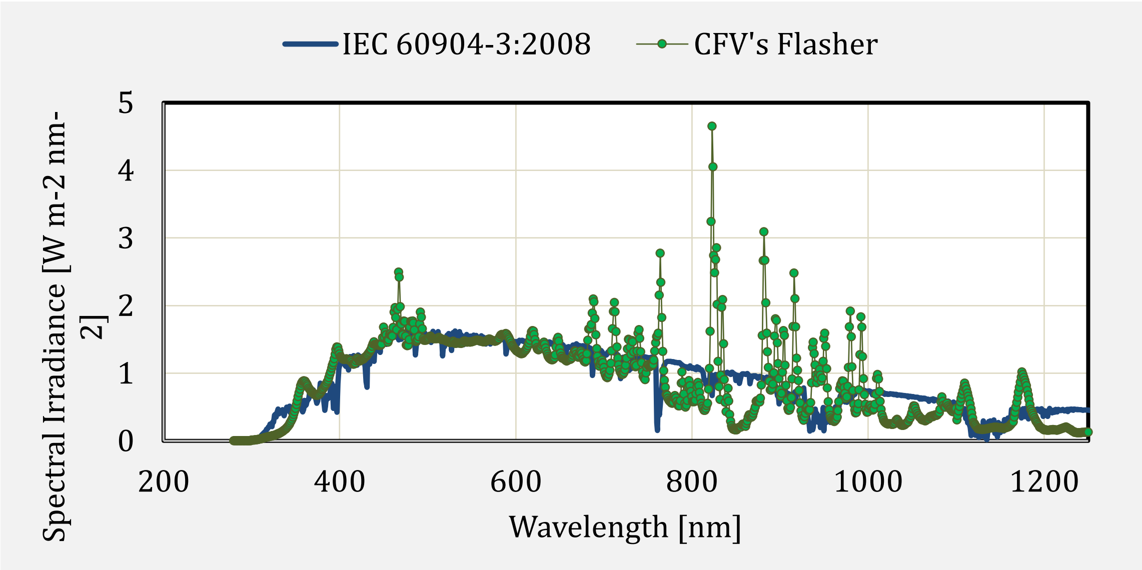

Fig. 3.3.2 Spectral irradiance of the AM1.5G reference spectrum and CFV's flasher spectrum

3.4 Angle-of-Incidence (AOI) Test

CFV Solar used an outdoor test procedure to determine the incident angle modifier (IAM) profile. The test procedure uses two 2-axis trackers, with the first tracker maneuvering the module to obtain a target angle of incidence (AOI) while the second tracker is constantly tracking the sun. The procedure is nearly identical to the one described in IEC 61853-2 (FDIS version, 2016), with two key differences: (1) the tests are conducted when the solar position allows the full 0-85° AOI range, as close to the solar noon as possible, but not strictly at the solar noon as specified the standard, and (2) the air mass modifier profile is determined a priori correct for the solar spectral variation during the tests. The IAM values were obtained at 15 points in the AOI range of 0 to 85 degrees.

3.5 IEC 61853-1 Performance Matrix

The multi-irradiance and multi-temperature I-V measurements were carried out with a class $A^+A^+A^+$ solar simulator, at the test points specified in IEC 61853-1 § 8.1 and at five additional points (Table 3.5.1). The test points cover irradiances from 100-1100 W/m^2, and temperatures from 15 to 75°C. The irradiance of the solar simulator was varied by adjusting the voltage applied to the Xe arc lamp. The spectral distribution remains class A or better for all irradiances. An integrated thermal chamber varied the module temperature with a laminar air flow, and the module temperature was monitored at 4 points with calibrated temperature sensors. Measurements were obtained only when the max-min temperature spread was less than 1.5°C.

The monitor cell was mounted at a location outside the test chamber and was not coplanar with the test module. The monitor cell sensitivity was adjusted to reproduce the Isc measured at STC on the test module. Other than the irradiance and temperature controls, the measurement procedure is identical to the Performance at STC test.

Table 3.5.1: Test points for the performance matrix. 5 additional test points are indicated.

Irradiance (W/m^2)	**Temperature**			
	15°C	**25°C**	**50°C**	**75°C**
1100		⊙	⊙	⊙
1000	⊙	⊙	⊙	⊙
800	⊙	⊙	⊙	⊙
600	⊙	⊙	⊙	⊙
400	⊙	⊙	⊙	⊗
200	⊙	⊙	⊗	⊗
100	⊙	⊙	⊗	⊗

⊙ Measured and required by the IEC 61853-1 standard
⊗ Additional test points; Measured but not required by the IEC 61853-1 standard

3.6 Spectral Response

The modules were sent to Fraunhofer ISE CalLab of Germany for spectral response (SR) measurements. Fraunhofer ISE CalLab used bandpass filters (FWHM ~20 nm) in the 350-950 wavelength range with its indoor flasher to obtain the SR profile. No bias light was used for the measurement.

3.7 Nominal Module Operating Temperature (NMOT)

The modules were mounted on a fixed rack for the nominal module operating temperature (NMOT) test described in the latest draft of IEC 61853-2 (FDIS version, 2016). The plane-of-array (POA) irradiance, the ambient temperature, the wind speed, and the backside temperatures at 4 different points on each module were measured with calibrated sensors until sufficient data were collected. The modules were individually connected to resistive loads over the course of the test, with the resistance values fixed at STC Vmp / STC Imp. The coefficients u0 and u1 were determined from the data regression, and finally the NMOT was calculated using these coefficients.

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4 Results

4.1 Incoming Inspection

The module IDs designated by CFV Solar, the module types, and the serial numbers are listed in Table 4.1.1. The nameplate showed the module type to be FS-4112-2, but the customer confirmed that these modules were in fact engineering samples of FS-4112-3.

Table 4.1.1 CFV's module IDs, serial numbers, and the module type

CFV Module ID	Serial Number	Module Type
16035-01	160301251386	FS-4112-3
16035-02	160301251400	FS-4112-3
16035-03	160301251396	FS-4112-3

4.2 Preconditioning

As described in the Procedures section, the modules underwent multiple preconditioning steps before finding the optimal IEC 61853-1 measurement recipe. Prior to the final IEC 61853-1 measurements, the modules were light-soaked to more than 30 kWh/m^2 of irradiation dose, with the average irradiation of 1100 W/m^2. The module temperatures were kept below 65°C during the preconditioning by controlling the air flow through the light-soaking chamber. The conditions per module are summarized in Table 4.2.1.

Table 4.2.1 Summary of the light-soaking-based preconditioning prior to the performance tests

Module ID	Total Irradiation Dose (kWh/m^2)	Average Module Temperature (°C)
16035-01	33.7	62.2
16035-02	95.7	60.9
16035-03	120.1	60.9

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4.3 Performance at STC

Table 4.3.1 summarizes the results of the STC I-V measurement, after preconditioning. Also shown in the table are the nameplate values, as specified in the First Solar Series 4 V3 datasheet (March 2016). Fig. 4.3.1 shows the difference of the measurement values to the corresponding nameplate values.

Table 4.3.1 Summary of the I-V performance at STC

Module ID	Isc (A)	Voc (V)	Imp (A)	Vmp (V)	Pmp (W)	FF (%)	Eff. (%)
16035-01	1.80	90.6	1.64	71.3	117.3	71.9	16.3
16035-02	1.81	90.3	1.65	71.6	118.4	72.5	16.4
16035-03	1.81	90.3	1.66	71.4	118.3	72.4	16.4
Nameplate	1.83	87.0	1.64	68.5	112.5	70.7	15.6

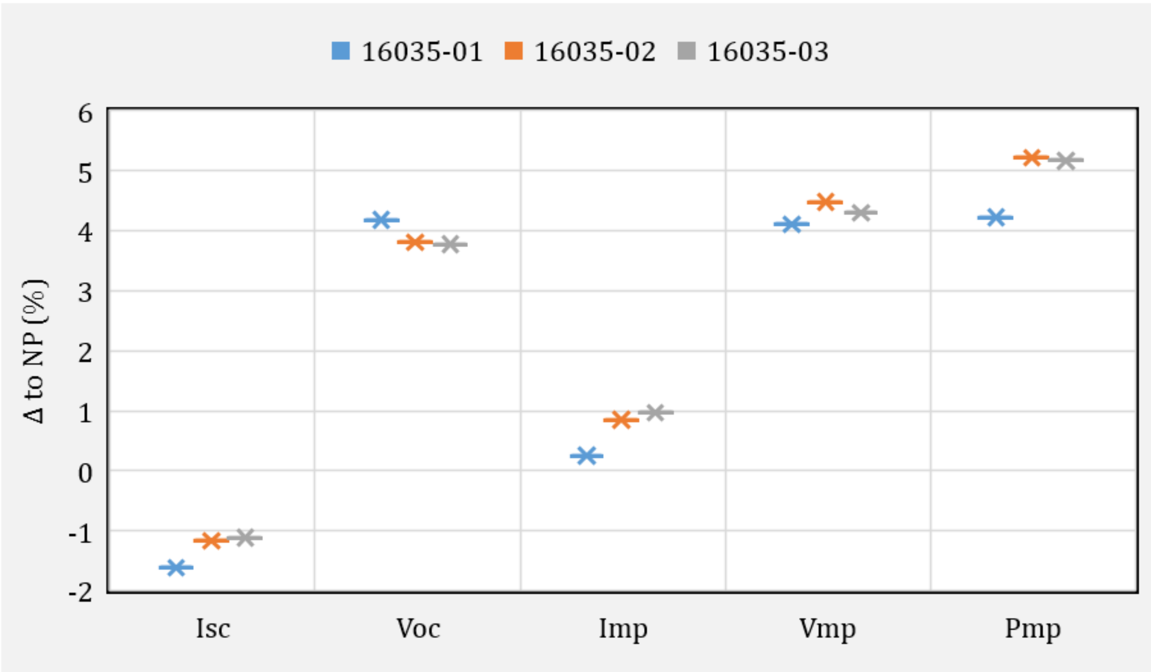

Fig. 4.3.1 The difference of I-V parameters to the nameplate values

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4.4 Angle-of-Incidence (AOI) Test

The measured IAM profiles are plotted in Fig. 4.4.1, along with the default IAM used in PVsyst (ASHRAE model with b_o=0.05). The Series 4 V3 modules outperformed the default ASHRAE model in the measured range. Table 4.4.1 shows the tabulated results.

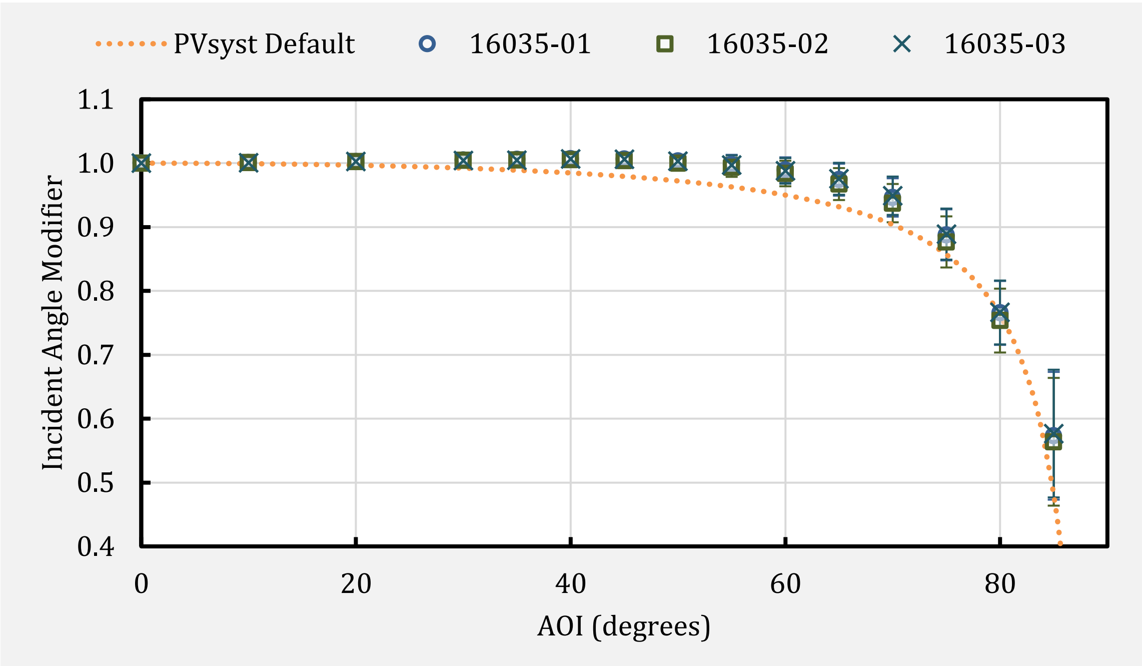

Fig. 4.4.1 Incident Angle Modifier (IAM) profiles of the measured modules; The vertical error bars indicate the accuracy of the measurements.

Table 4.4.1 Average values of the measured IAM profiles

Module ID	Angle of Incidence (AOI)							
	0°	**10°**	**20°**	**30°**	**35°**	**40°**	**45°**	**50°**
16035-01	1.000	1.001	1.002	1.005	1.006	1.007	1.006	1.003
16035-02	1.000	1.001	1.003	1.004	1.005	1.005	1.004	1.000
16035-03	1.000	1.001	1.003	1.004	1.005	1.007	1.006	1.003
Accuracy	±0.005	±0.005	±0.005	±0.005	±0.010	±0.010	±0.010	±0.010

Module ID	Angle of Incidence (AOI)							
	55°	**60°**	**65°**	**70°**	**75°**	**80°**	**85°**	
16035-01	0.998	0.989	0.974	0.946	0.888	0.766	0.573	
16035-02	0.994	0.984	0.967	0.937	0.877	0.754	0.564	
16035-03	0.997	0.988	0.976	0.949	0.889	0.766	0.577	
Accuracy	±0.015	±0.020	±0.025	±0.030	±0.040	±0.050	±0.100	

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4.5 IEC 61853-1 Performance Matrix

Table 4.5.1 through 4.5.3 show the measured 61853-1 test data. Figures 4.5.1 through 4.5.4 show the efficiency as a function of the irradiance, at the measured temperature points.

Table 4.5.1 Performance of the 16035-01 module at the IEC 61853-1 matrix conditions

T (°C)	G (W/m²)	Isc (A)	Voc (V)	Imp (A)	Vmp (A)	Pmp (W)	FF (%)	Eff. (%)
15	100	0.18	84.8	0.16	71.7	11.8	77.0	16.4
	200	0.36	87.2	0.33	73.3	23.9	77.3	16.6
	400	0.71	89.6	0.66	74.0	48.7	76.1	16.9
	600	1.08	91.0	0.99	73.9	72.9	74.2	16.9
	800	1.43	92.0	1.32	73.6	96.8	73.5	16.8
	1000	1.81	92.7	1.65	73.0	120.4	71.7	16.7
25	100	0.18	81.9	0.17	69.2	11.4	76.8	15.9
	200	0.36	84.5	0.33	70.9	23.3	76.9	16.2
	400	0.71	87.1	0.66	71.9	47.4	76.1	16.4
	600	1.09	88.5	0.99	71.8	71.3	74.2	16.5
	800	1.44	89.5	1.32	71.6	94.8	73.5	16.5
	1000	1.82	90.3	1.66	71.1	118.0	71.9	16.4
	1100	1.99	90.6	1.82	70.9	129.2	71.5	16.3
50	100	0.18	74.8	0.17	62.3	10.4	76.0	14.5
	200	0.36	77.4	0.33	64.2	21.3	76.1	14.8
	400	0.73	80.2	0.67	65.7	43.8	75.0	15.2
	600	1.09	81.9	1.00	66.0	66.1	74.0	15.3
	800	1.46	83.0	1.34	66.0	88.1	72.8	15.3
	1000	1.84	83.9	1.67	65.6	109.6	71.2	15.2
	1100	2.02	84.2	1.84	65.4	120.2	70.8	15.2
75	100	0.19	66.8	0.17	54.4	9.3	74.0	12.9
	200	0.37	69.8	0.33	56.7	19.0	73.8	13.2
	400	0.74	73.1	0.67	58.7	39.3	72.9	13.6
	600	1.11	75.0	1.01	59.4	60.1	71.9	13.9
	800	1.48	76.3	1.34	59.6	79.8	70.5	13.8
	1000	1.86	77.3	1.68	59.4	99.6	69.2	13.8
	1100	2.05	77.6	1.84	59.2	109.1	68.5	13.8

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Table 4.5.2 Performance of the 16035-02 module at the IEC 61853-1 matrix conditions

T (°C)	G (W/m²)	Isc (A)	Voc (V)	Imp (A)	Vmp (A)	Pmp (W)	FF (%)	Eff. (%)
15	100	0.18	84.9	0.16	72.0	11.9	77.7	16.5
	200	0.36	87.3	0.33	73.4	24.0	77.3	16.7
	400	0.72	89.7	0.66	74.2	48.9	76.1	17.0
	600	1.08	91.1	0.99	74.2	73.2	74.5	16.9
	800	1.43	92.0	1.31	73.8	97.0	73.6	16.8
	1000	1.80	92.8	1.65	73.3	120.6	72.1	16.7
25	100	0.18	82.0	0.17	69.4	11.5	77.3	16.0
	200	0.36	84.6	0.33	71.0	23.3	77.2	16.2
	400	0.72	87.1	0.66	72.1	47.7	76.3	16.6
	600	1.09	88.5	0.99	72.0	71.3	74.1	16.5
	800	1.44	89.6	1.32	71.8	95.0	73.5	16.5
	1000	1.81	90.3	1.66	71.4	118.3	72.3	16.4
	1100	1.99	90.7	1.82	71.1	129.5	71.6	16.3
50	100	0.18	74.9	0.17	62.5	10.6	76.3	14.7
	200	0.36	77.5	0.33	64.4	21.3	76.1	14.8
	400	0.73	80.3	0.67	65.9	43.9	75.2	15.2
	600	1.10	81.9	1.00	66.2	66.3	73.8	15.3
	800	1.46	83.1	1.34	66.2	88.5	73.0	15.4
	1000	1.84	84.0	1.68	65.9	110.4	71.4	15.3
	1100	2.02	84.3	1.84	65.6	120.8	70.9	15.2
75	100	0.19	67.0	0.17	54.7	9.3	74.1	13.0
	200	0.37	70.1	0.34	57.0	19.3	74.1	13.4
	400	0.74	73.3	0.67	59.0	39.6	73.1	13.7
	600	1.11	75.2	1.01	59.6	60.2	72.0	13.9
	800	1.49	76.4	1.35	59.7	80.4	70.5	14.0
	1000	1.87	77.4	1.68	59.6	100.3	69.4	13.9
	1100	2.05	77.8	1.85	59.6	110.0	69.0	13.9

Table 4.5.3 Performance of the 16035-03 module at the IEC 61853-1 matrix conditions

T (°C)	G (W/m²)	Isc (A)	Voc (V)	Imp (A)	Vmp (A)	Pmp (W)	FF (%)	Eff. (%)
15	100	0.18	84.9	0.16	72.0	11.8	77.0	16.4
	200	0.35	87.3	0.32	73.7	23.9	77.3	16.6
	400	0.72	89.7	0.66	74.4	48.9	76.2	17.0
	600	1.08	91.1	0.98	74.3	73.2	74.6	16.9
	800	1.43	92.1	1.31	73.9	97.1	73.7	16.9
	1000	1.80	92.8	1.65	73.3	120.8	72.2	16.8
25	100	0.18	82.0	0.16	69.4	11.3	76.8	15.8

	200	0.36	84.6	0.33	71.3	23.4	77.0	16.3
	400	0.71	87.2	0.66	72.2	47.4	76.2	16.5
	600	1.08	88.6	0.99	72.2	71.5	75.0	16.5
	800	1.44	89.6	1.32	71.9	95.2	73.7	16.5
	1000	1.81	90.4	1.66	71.4	118.4	72.4	16.4
	1100	2.00	90.7	1.82	71.1	129.5	71.6	16.4
50	100	0.18	75.2	0.17	62.9	10.4	75.8	14.5
	200	0.36	77.9	0.33	64.9	21.7	76.4	15.0
	400	0.73	80.5	0.67	66.1	44.1	75.3	15.3
	600	1.09	82.1	1.00	66.3	66.5	74.2	15.4
	800	1.46	83.2	1.34	66.3	88.6	73.0	15.4
	1000	1.84	84.0	1.67	65.9	110.3	71.2	15.3
	1100	2.02	84.4	1.84	65.6	120.8	71.0	15.3
75	100	0.19	67.2	0.17	55.0	9.4	74.0	13.0
	200	0.37	70.3	0.34	57.3	19.2	74.2	13.4
	400	0.74	73.4	0.67	59.1	39.7	73.3	13.8
	600	1.11	75.2	1.01	59.7	60.1	72.2	13.9
	800	1.49	76.5	1.35	59.8	80.6	71.0	14.0
	1000	1.86	77.5	1.68	59.7	100.4	69.7	13.9
	1100	2.04	78.1	1.85	59.7	110.4	69.2	13.9

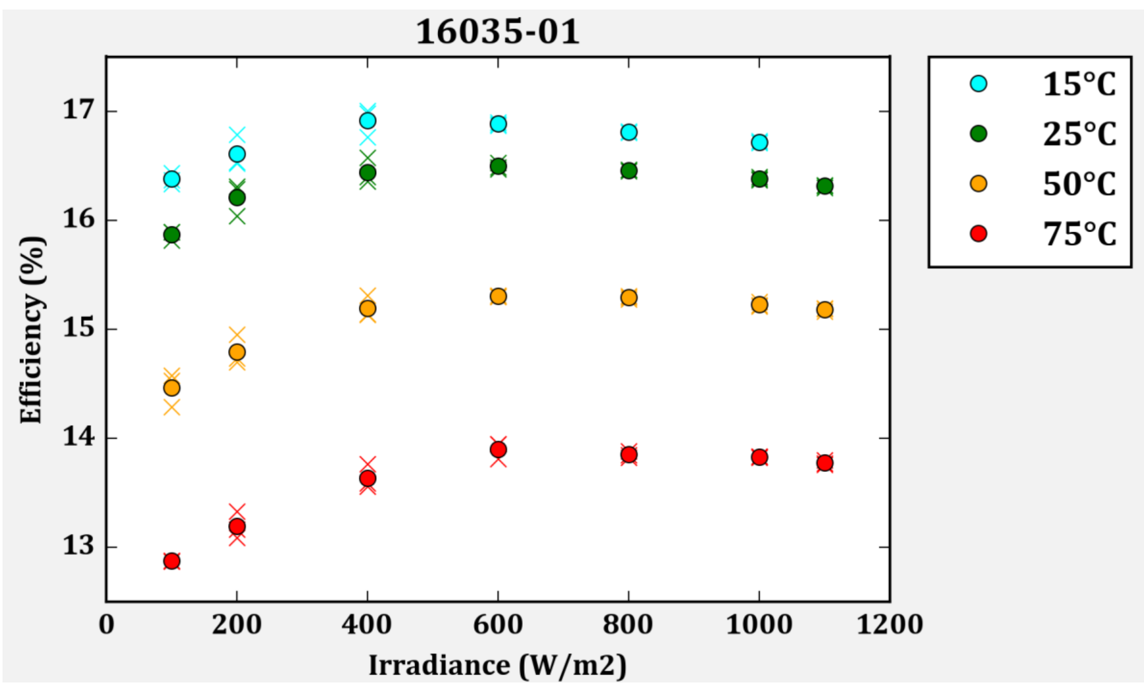

Fig. 4.5.1 Multi-irradiance and multi-temperature efficiency plot for the 16035-01 module; Circles show the average values, and the X markers show the individual values.

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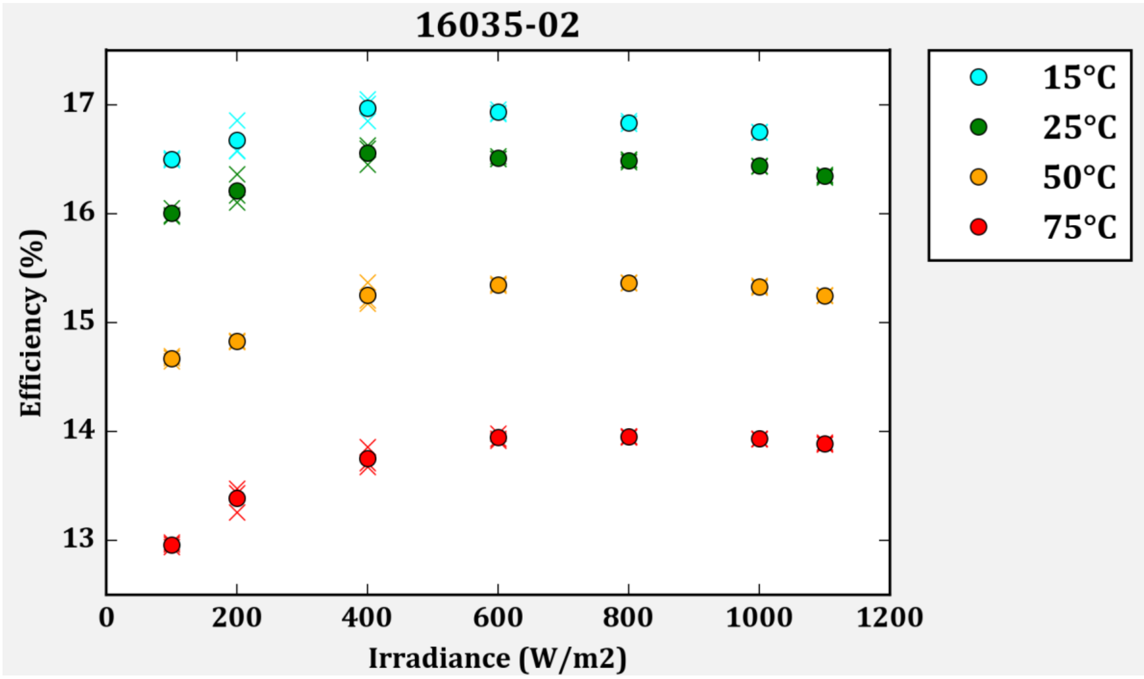

Fig. 4.5.2 Multi-irradiance and multi-temperature efficiency plot for the 16035-02 module; Circles show the average values, and the X markers show the individual values.

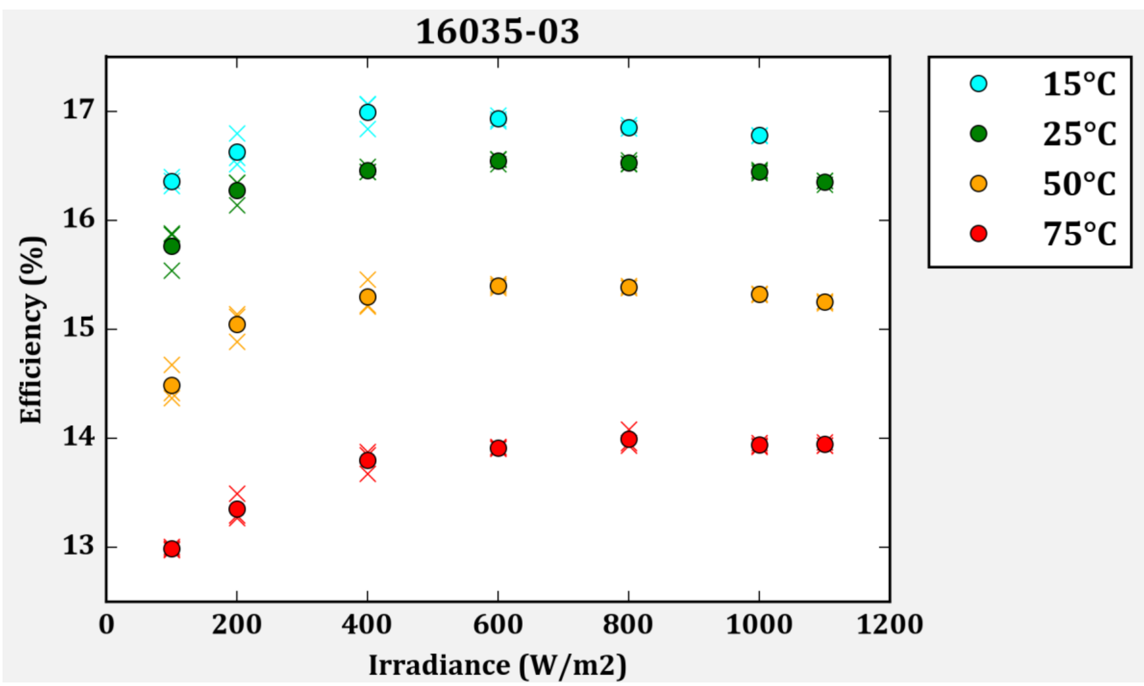

Fig. 4.5.3 Multi-irradiance and multi-temperature efficiency plot for the 16035-03 module; Circles show the average values, and the X markers show the individual values.

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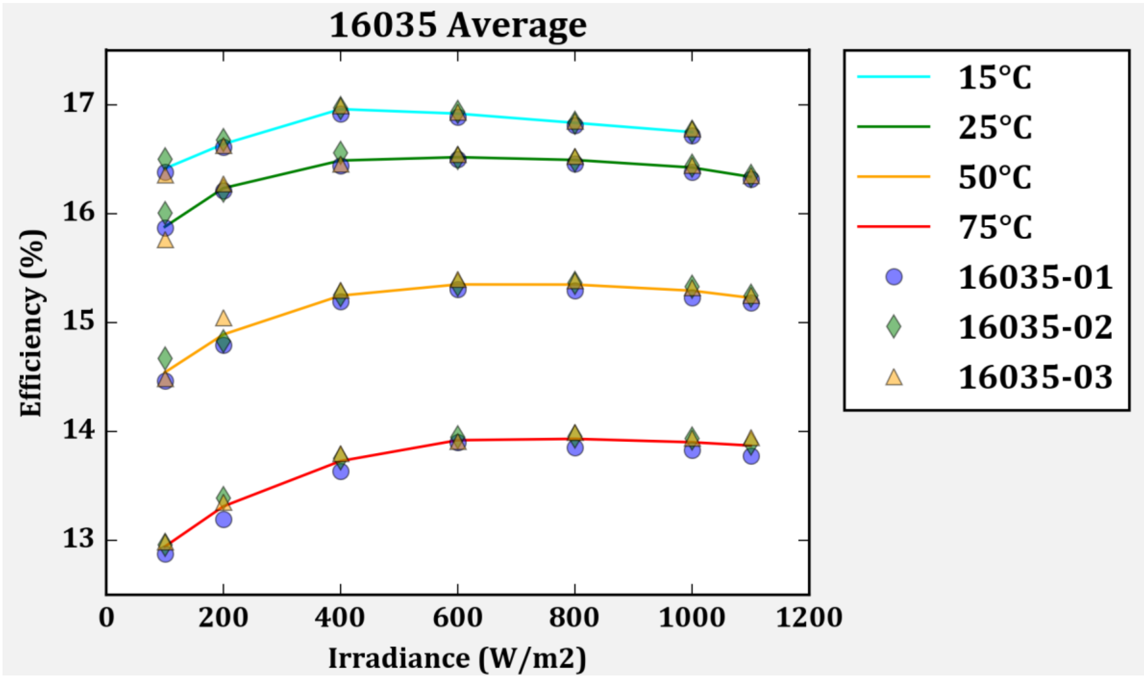

Fig. 4.5.4 Multi-irradiance and multi-temperature efficiency plot for all the modules; Solid lines connect the values averaged over the three modules.

4.6 Spectral Response

The spectral response (SR) data measured by Fraunhofer ISE CalLab are shown in Fig. 4.6.1. The curves were nearly identical for the three modules, except at the 350 nm wavelength where the 16035-03 module showed slightly lower response.

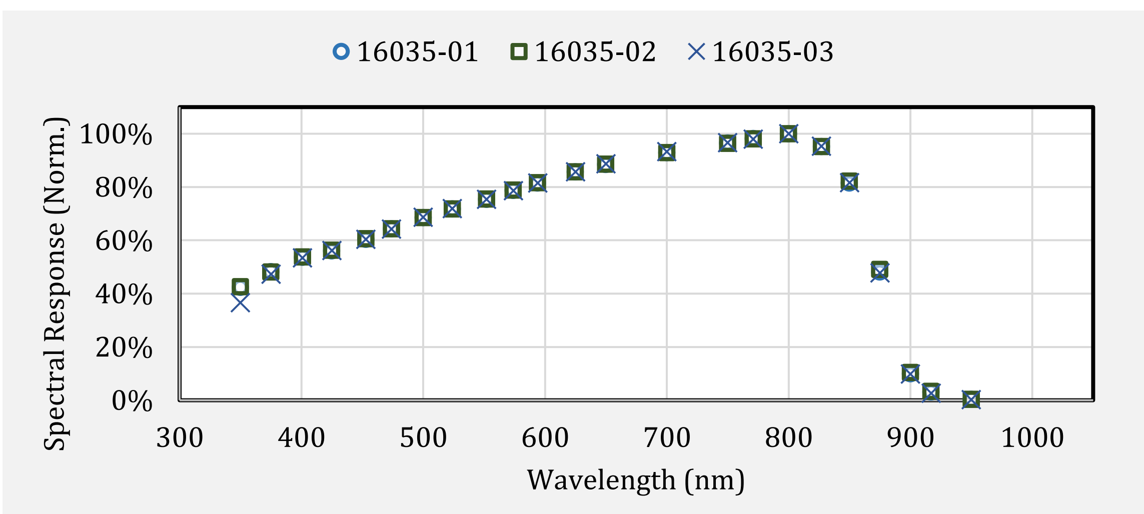

Fig. 4.6.1 SR data from Fraunhofer ISE CalLab reports CFV016011CFV0616-V01 (16035-01), CFV017011CFV06016-V01 (16035-02), and CFV018011CFV0616-V01 (16035-03)

Report Prepared by: Kyumin Lee - Senior PV Test Engineer

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4.7 Nominal Module Operating Temperature (NMOT)

The coefficients for the IEC 61853-2 thermal model, and the NMOT values calculated using the coefficients are summarized in Table 4.7.1. The regression plots are shown in Figs. 4.7.1 through 4.7.4.

Table 4.7.1 IEC 61853-2 thermal model coefficients and calculated NMOTs

Module ID	Number of Days for Regression	Total Number of Data Points	r^2	u0 [W m^{-2} °C^{-1}]	u1 [W m^{-3} °C^{-1} s]	NMOT [°C]
16035-01	12	12863	0.89	24.4	6.904	45.6
16035-02	12	12863	0.86	30.0	5.332	42.6
16035-03	12	12863	0.84	23.1	7.439	46.2
16035 All	12	38589	0.86	28.1	5.856	43.5

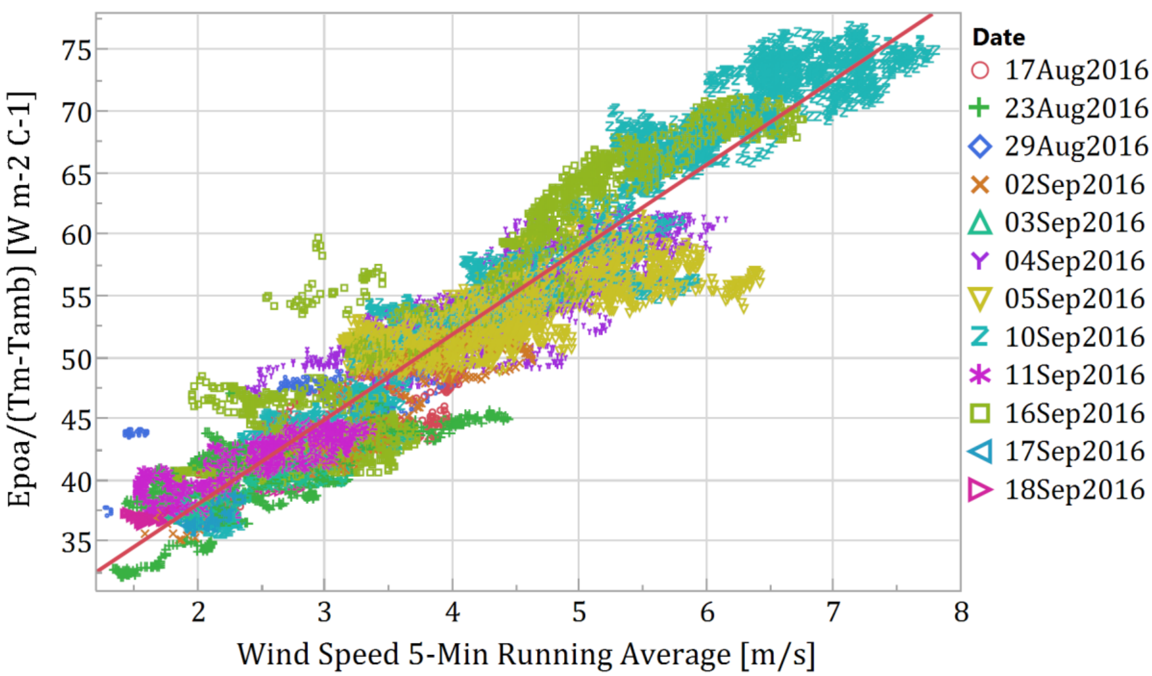

Fig. 4.7.1 NMOT regression plot for the 16035-01 module

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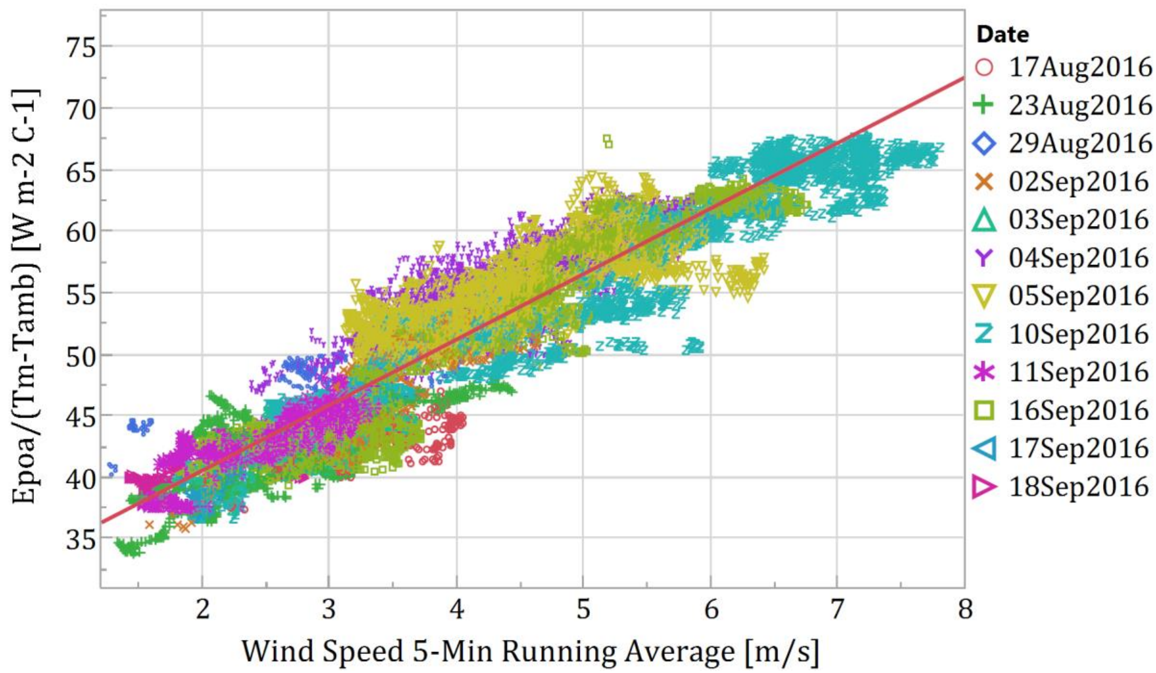

Fig. 4.7.2 NMOT regression plot for the 16035-02 module

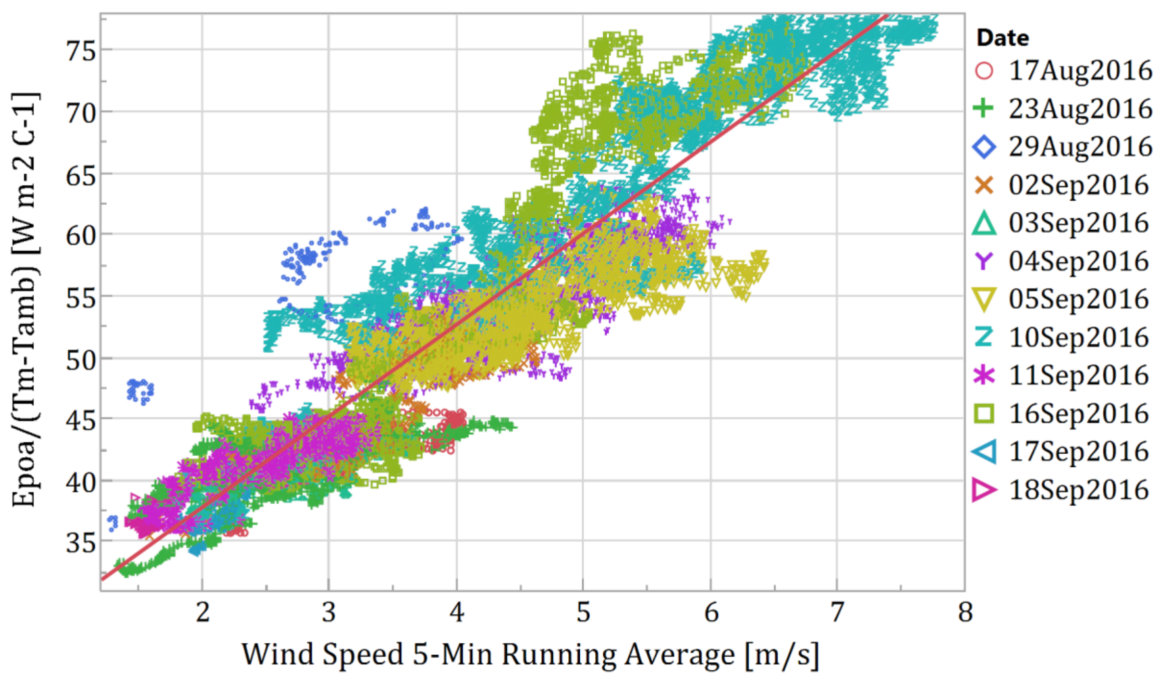

Fig. 4.7.3 NMOT regression plot for the 16035-03 module

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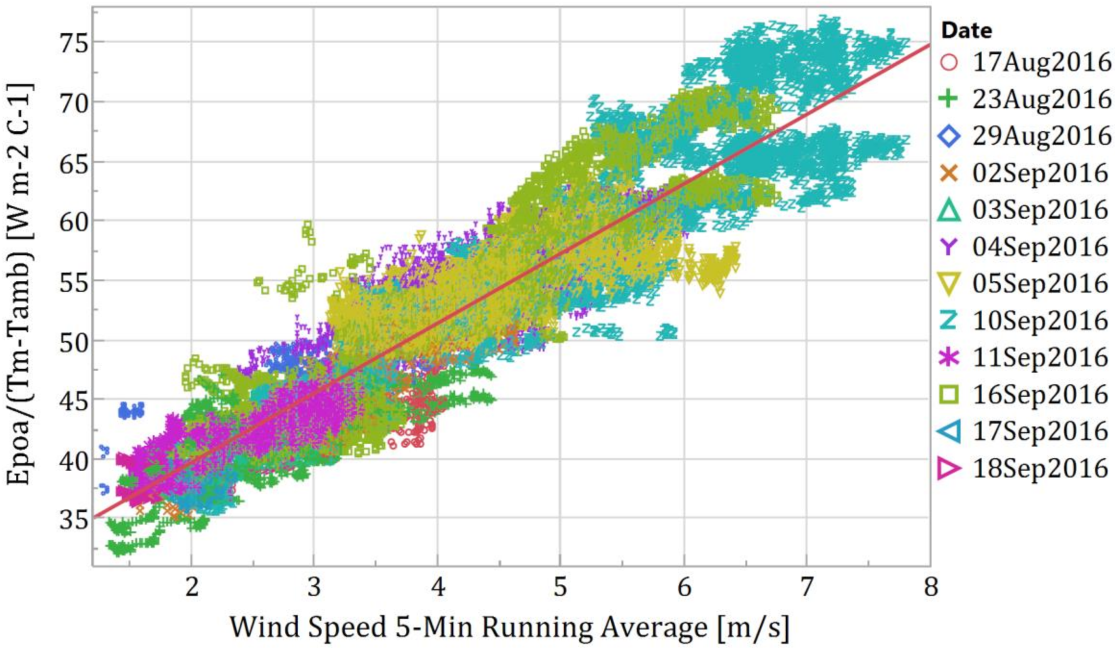

Fig. 4.7.4 NMOT regression plot for all the 16035 modules

Appendix D

FS-395-Plus		FS PAN File							
Temperature Corrected to (°C)	Irradiance (W/m2)	Isc (A)	Voc (V)	Imp (A)	Vmp (V)	Pmp (W)	FF (%)	Isc Normalized (A)	Pmp Normalized
65	1100	2.56	52.72	2.28	40.17	91.75	68.04	0.9999	0.88
65	1000	2.33	52.41	2.08	40.18	83.58	68.58	1.0000	0.88
65	800	1.86	51.69	1.67	40.14	66.96	69.62	1.0002	0.88
65	600	1.40	50.76	1.25	39.99	50.03	70.61	1.0005	0.88
50	1100	2.54	54.77	2.28	42.26	96.55	69.31	0.9999	0.92
50	1000	2.31	54.49	2.08	42.32	87.99	69.85	1.0000	0.93
50	800	1.85	53.81	1.66	42.40	70.57	70.89	1.0002	0.93
50	600	1.39	52.93	1.25	42.20	52.82	71.89	1.0005	0.93
50	400	0.93	51.70	0.83	41.74	34.84	72.81	1.0007	0.92
25	1100	2.52	58.25	2.27	45.95	104.29	71.08	0.9999	1.00
25	1000	2.29	58.00	2.07	46.01	95.10	71.60	1.0000	1.00
25	800	1.83	57.40	1.66	46.11	76.41	72.64	1.0002	1.00
25	600	1.37	56.63	1.24	46.11	57.33	73.66	1.0004	1.00
25	400	0.92	55.52	0.83	45.71	37.97	74.60	1.0008	1.00
25	200	0.46	53.62	0.41	44.66	18.52	75.32	1.0011	0.97
25	100	0.23	51.69	0.21	43.24	8.91	75.14	1.0013	0.94
15	1000	2.28	59.41	2.06	47.46	97.76	72.13	1.0000	1.03
15	800	1.83	58.85	1.65	47.67	78.60	73.17	1.0002	1.03
15	600	1.37	58.12	1.24	47.62	59.04	74.19	1.0005	1.03
15	400	0.91	57.07	0.83	47.34	39.17	75.16	1.0007	1.03
15	200	0.46	55.26	0.41	46.39	19.17	75.94	1.0011	1.01
15	100	0.23	53.43	0.21	45.00	9.25	75.78	1.0013	0.97

FS-4100		FS PAN File							
Temperature Corrected to (°C)	Irradiance (W/m2)	Isc (A)	Voc (V)	Imp (A)	Vmp (V)	Pmp (W)	FF (%)	Isc Normalized (A)	Pmp Normalized
65	1100	1.75	79.63	1.58	61.02	96.47	69.11	0.9999	0.89
65	1000	1.59	79.19	1.44	61.09	87.91	69.66	1.0000	0.89
65	800	1.28	78.16	1.15	61.17	70.49	70.72	1.0002	0.89
65	600	0.96	76.84	0.86	60.95	52.72	71.72	1.0004	0.88
50	1100	1.74	82.73	1.58	64.21	101.51	70.40	0.9999	0.93
50	1000	1.58	82.31	1.44	64.36	92.54	70.94	1.0000	0.93
50	800	1.27	81.35	1.15	64.49	74.27	71.99	1.0002	0.93
50	600	0.95	80.10	0.86	64.34	55.62	72.99	1.0004	0.93
50	400	0.63	78.34	0.58	63.80	36.70	73.86	1.0006	0.92
25	1100	1.73	87.96	1.57	69.73	109.69	72.22	0.9999	1.00
25	1000	1.57	87.60	1.43	69.88	100.04	72.74	1.0000	1.00
25	800	1.26	86.74	1.15	70.18	80.40	73.78	1.0002	1.01
25	600	0.94	85.63	0.86	70.15	60.34	74.76	1.0004	1.00
25	400	0.63	84.06	0.57	69.73	39.96	75.65	1.0006	1.00
25	200	0.31	81.33	0.28	68.29	19.43	76.03	1.0010	0.97
25	100	0.16	78.54	0.14	66.14	9.28	75.15	1.0013	0.93
15	1000	1.56	89.71	1.43	72.12	102.88	73.32	1.0000	1.02
15	800	1.25	88.91	1.14	72.47	82.72	74.35	1.0002	1.02
15	600	0.94	87.86	0.86	72.47	62.13	75.33	1.0004	1.02
15	400	0.63	86.36	0.57	72.25	41.20	76.21	1.0006	1.01
15	200	0.31	83.76	0.28	70.77	20.10	76.64	1.0009	0.97
15	100	0.16	81.10	0.14	68.76	9.62	75.74	1.0012	0.92

First Solar

FS-4102-2		FS PAN File							
Temperature Corrected to (°C)	Irradiance	Isc (A)	Voc (V)	Imp (A)	Vmp (V)	Pmp (W)	FF (%)	Isc Normalized (A)	Pmp Normalized
65	1000	1.77	77.23	1.56	56.63	88.43	64.78	1.0000	0.86
65	1100	1.94	77.77	1.71	56.52	96.91	64.10	0.9999	0.86
65	800	1.41	75.95	1.25	56.64	71.03	66.12	1.0002	0.87
65	600	1.06	74.31	0.94	56.37	53.15	67.41	1.0005	0.86
50	1000	1.76	80.21	1.57	59.71	93.64	66.43	1.0000	0.91
50	1100	1.93	80.73	1.72	59.61	102.59	65.75	0.9999	0.91
50	800	1.41	79.02	1.26	59.84	75.32	67.78	1.0003	0.92
50	600	1.05	77.47	0.95	59.65	56.47	69.10	1.0005	0.92
50	400	0.70	75.29	0.63	58.91	37.23	70.30	1.0007	0.91
25	1000	1.74	85.34	1.57	65.16	102.44	68.99	1.0000	1.00
25	1100	1.91	85.79	1.73	64.91	112.15	68.30	0.9999	1.00
25	800	1.39	84.28	1.26	65.37	82.54	70.34	1.0002	1.01
25	600	1.04	82.90	0.95	65.43	62.07	71.68	1.0005	1.01
25	400	0.70	80.95	0.63	64.85	41.12	72.93	1.0007	1.00
25	200	0.35	77.59	0.32	63.11	19.96	73.84	1.0009	0.97
25	100	0.17	74.20	0.16	60.57	9.52	73.66	1.0011	0.93
15	1000	1.73	87.43	1.57	67.33	105.94	69.92	1.0000	1.03
15	800	1.39	86.42	1.26	67.70	85.42	71.27	1.0002	1.04
15	600	1.04	85.12	0.95	67.74	64.30	72.61	1.0005	1.05
15	400	0.69	83.26	0.63	67.36	42.67	73.88	1.0007	1.04
15	200	0.35	80.06	0.32	65.65	20.78	74.84	1.0008	1.01
15	100	0.17	76.82	0.16	63.28	9.95	74.68	1.0011	0.97

FS-4112-3		FS PAN File							
Temperature Corrected to (°C)	Irradiance (W/m2)	Isc (A)	Voc (V)	Imp (A)	Vmp (V)	Pmp (W)	FF (%)	Isc Normalized (A)	Pmp Normalized
75	100	0.19	67.05	0.16	53.73	8.78	0.70	1.019	0.78
75	200	0.37	70.57	0.33	56.37	18.64	0.71	1.018	0.83
75	400	0.75	74.06	0.66	58.42	38.77	0.70	1.018	0.86
75	600	1.12	76.08	1.00	59.02	58.90	0.69	1.017	0.87
75	800	1.49	77.52	1.33	59.20	78.66	0.68	1.017	0.87
75	1000	1.86	78.64	1.66	58.97	97.89	0.67	1.017	0.87
75	1100	2.05	79.11	1.82	58.83	107.27	0.66	1.017	0.87
50	100	0.19	71.61	0.16	58.49	9.55	0.72	1.011	0.85
50	200	0.37	74.85	0.33	60.93	20.12	0.73	1.011	0.89
50	400	0.74	78.06	0.66	62.61	41.59	0.72	1.010	0.92
50	600	1.11	79.93	1.00	63.16	62.98	0.71	1.010	0.93
50	800	1.48	81.25	1.33	63.10	83.97	0.70	1.010	0.93
50	1000	1.85	82.30	1.66	62.88	104.38	0.69	1.011	0.93
50	1100	2.03	82.71	1.83	62.65	114.34	0.68	1.009	0.92
25	100	0.18	77.47	0.16	64.71	10.51	0.74	1.002	0.93
25	200	0.37	80.38	0.33	66.77	21.97	0.75	1.001	0.98
25	400	0.73	83.25	0.66	68.17	45.10	0.74	1.001	1.00
25	600	1.10	84.92	0.99	68.48	68.08	0.73	1.000	1.01
25	800	1.46	86.10	1.33	68.31	90.59	0.72	1.000	1.01
25	1000	1.83	87.00	1.66	67.89	112.47	0.71	1.000	1.00
25	1100	2.01	87.38	1.82	67.62	123.15	0.70	1.000	1.00
15	100	0.18	79.87	0.16	67.21	10.90	0.75	0.998	0.97
15	200	0.37	82.65	0.33	69.26	22.70	0.75	0.998	1.01
15	400	0.73	85.38	0.66	70.43	46.48	0.75	0.997	1.03
15	600	1.09	86.96	0.99	70.73	70.06	0.74	0.996	1.04
15	800	1.46	88.07	1.32	70.41	93.16	0.72	0.996	1.04
15	1000	1.82	88.92	1.65	70.05	115.61	0.71	0.996	1.03