CFV Labs

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

19074 PAN File Report: Hanwha Q CELLS Q.PLUS BFR-G4.1 280 Module

Report Number: 19074-PR-E-003-R1

Report Date: 2020-01-13

Test Period: 2019-11-04 to 2019-12-02

Project ID: 19074 (CFV), 2109144 (Customer PO)

Customer: Joshua Stein / Sandia National Laboratories / PO Box 5800 MS1484 / Albuquerque, NM 87185-1484

Report Prepared by:	Report Reviewed by:
Colin Sillerud – Project Engineer	Jim Crimmins – General Manager
Colin Sillerud Digitally signed by Colin Sillerud Date: 2020.01.14 11:53:09 -07'00'	James P Crimmins Digitally signed by James P Crimmins DN: cn=James P Crimmins, o, ou, email=jim.crimmins@cfvsolar.com, c=US Date: 2020.01.15 09:14:24 -07'00'

1 Project Summary

CFV Solar conducted PAN file testing on one **Q.PLUS BFR-G4.1 280** module produced by **Hanwha Q CELLS**. I-V curves at multiple irradiance and temperature conditions were obtained on one sample per IEC 61853-1:2011. The PVsyst 6 single-diode model coefficients were derived with PANOpt®, a software developed at CFV.

2 Executive Summary of Results

The performance matrix data were scaled to prepare PAN file source data for the 280 W power class of the Q.PLUS BFR-G4.1 280 type. The "Measured STC" scaling method (explained in Procedures section) was used. Optimized PAN files were created for the specified module type and power class with PANOpt®, CFV's proprietary software.

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

Table of Contents

Disclaimer and Conditions of Report Reproduction

The results in this report relate only to the items tested.
This report contains no opinions, interpretations, or failure analysis.
This report may not be reproduced except in full, without the written consent of the testing laboratory.

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

3 Sample Information

Other samples were also tested as part of project 19074. For full information on all samples, refer to reports 19074-PR-E-001 through 19074-PR-E-009.

Labeling

Module ID	SNL ID	Manufacturer	Module Type	Serial Number
19074-003	00004283	Hanwha Q CELLS	Q.PLUS BFR-G4.1 280	822717135262702340

Constructional Details

Module Type	Length [m]	Width [m]	Thickness [mm]
Q.PLUS BFR-G4.1 280	1.670	1.000	32

Nameplate Values

Module Type	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmp [W]	Max Sys Volt [V]	Fuse Rating [A]
Q.PLUS BFR-G4.1 280	9.41	38.97	8.84	31.67	280	1000	20

Photographs

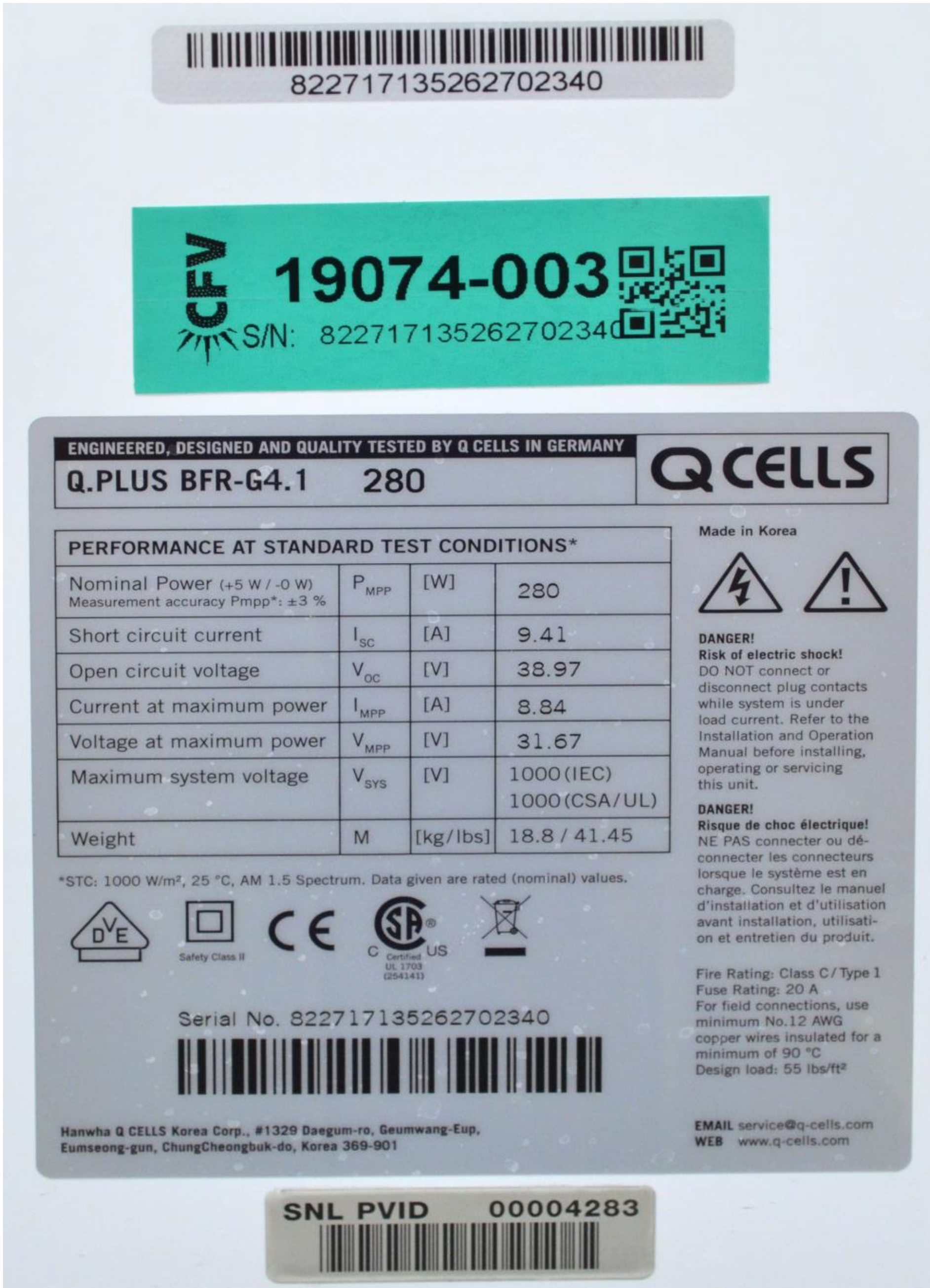
Front

Back

Connectors

Junction Box

Nameplate(s)



Sampling

A single fielded sample of the type, Q.PLUS BFR-G4.1 280, was tested for this project and used in the PAN file creation.

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

4 Procedures

There were other tests included in project 19074. This report includes only the procedures relevant to the PAN file generation and Electroluminescence Imaging.

4.1 Electroluminescence Imaging

Electroluminescence (EL) images were taken with a Peltier-cooled CCD camera that has a resolution of 8.3 MPixels. A long pass filter blocked incoming light with wavelength below 850 nm. A constant DC bias was applied to the modules while the imaging was performed in the dark.

A relevant IEC document (IEC TS 60904-13:2018) has been published recently. The EL imaging was carried out at 1.0x Isc per a procedure in this document, but this test is not yet included in CFV's scope of ISO 17025 accreditation.

4.2 Preconditioning

The sample was installed outdoors on a fixed rack in open circuit to receive a minimum of 40 kWh/m^2 of irradiation. The plane-of-array irradiance was measured with a calibrated pyranometer. CFV is ISO 17025-accredited to carry out Preconditioning per IEC 61215:2005. The preconditioning carried out for this project deviated from IEC 61215:2005 in that a higher irradiation dose was received (IEC 61215:2005 specifies a dose of 5.0 to 5.5 kWh/m^2).

4.3 MQT 06.1 Performance at STC

Performance at STC test was carried out in conformity with IEC 61215-2:2016 MQT 06.1. CFV is ISO 17025-accredited to carry out the test. This test also qualifies as MQT 02 Maximum Power Determination.

We used a pulse-type solar simulator (Halm moduleTest 3; Fig. 4.3.1), classified as class AAA per IEC 60904-9:2007. The irradiance of the Xenon arc lamp flash at the module plane was measured with a co-planar reference cell (Fraunhofer WPVS type, manufactured by Czibula & Grundmann GmbH) that meets the requirements of IEC 60904-2:2015. The reference cell was calibrated at PTB of Germany. The solar simulator was in a room constantly maintained at 25 ± 1°C, and prior to the tests we waited for the modules to thermally stabilize to the room temperature. During the test, the module backside temperature was measured at four points with calibrated RTDs with accuracy better than ± 0.2°C.

The reported I-V characteristics show the average of three consecutive measurements. Each measurement was carried out in conformity with IEC 60904-1:2006. One measurement involved a forward sweep (Isc to Voc) and a reverse sweep (Voc to Isc), whose I-V data were averaged to calculate the Isc, Voc, Imp, and Vmp values. The irradiance was controlled to be within 1000 ± 3 W/m^2 for the measurements. The minimal differences between the STC and the actual test conditions were further corrected per IEC 60891:2009.

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

Prior to measurements, testing was carried out to check for I-V curve hysteresis between the forward and reverse sweeps. It was found that the Q.PLUS BFR-G4.1 280 module type needed only one section for both the forward and reverse sweeps. The effective sweep time for the measurements on the Q.PLUS BFR-G4.1 280 module type was 25 ms forward and 25 ms reverse.

A spectral mismatch factor of 1.0 was used as no EQE data was available for this module type.

Fig. 4.3.1 Class AAA solar simulator from h.a.l.m. used at CFV

Table 4.3.1 shows the uncertainty and repeatability of CFV's STC performance data. 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, etc. CFV maintains a rigorous daily, weekly, and quarterly quality control program to guarantee top-tier flash measurement accuracy. The quarterly control modules are also measured annually at Fraunhofer ISE CalLab of Germany.

4.4 Performance Matrix

Multi-irradiance and multi-temperature Performance Matrix test was conducted in conformity with IEC 61853-1:2011 § 8.1. CFV is ISO 17025-accredited to carry out this test.

The test points cover irradiances from 100 to 1100 W/m^2, and temperatures from 15 to 75°C. In addition to the test points defined in IEC 61853-1:2011 § 8.1, measurements were obtained at five additional points, as shown in Table 4.4.1. The irradiance was varied by adjusting the voltage applied to the Xenon arc lamp. The spectral match remains class A or

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

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 RTDs having uncertainties of ± 0.13°C. For each measurement, the max-min temperature spread was less than 1.5°C.

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

Table 4.4.1: 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

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

4.5 MQT 04 Temperature Coefficients

Temperature Coefficients test was conducted in conformity with IEC 61215-2:2016 MQT 04 and IEC 60891:2009 § 4. CFV Solar is ISO 17025-accredited to carry out the test.

The test was carried out along with the Performance Matrix test. In addition to the 15, 25, 50, and 75°C temperatures required for the matrix, the modules were flashed with 1000 W/m^2 irradiance at additional intermediate temperatures. The temperature coefficients for Isc, Voc, Imp, Vmp, and Pmp were determined by linear regression over the 15-75°C temperature range.

4.6 Performance Data Scaling

When creating PAN files for PVsyst, one requirement is that the Pmp at STC needs to match the nameplate power. This requirement translates into the technical issues of (1) how to scale the Pmp values at the various temperature and irradiance points and (2) how to scale the STC Isc, Voc, Imp, and Vmp values, if the measured values at STC do not match the nameplate values.

In this project, we scaled the performance matrix data for use with PANOpt®, by the following approach:

Measured STC Approach

Pmp	A constant gain factor was applied to the Pmp values in the matrix, to obtain the nameplate rating at STC. The gain factor used was: [Pmp Gain] = [NP Pmp]/[Measured STC Pmp]
Isc, Voc, Imp, Vmp	A constant gain factor equal to the square root of [Pmp Gain] was applied to the Isc, Voc, Imp, and Vmp values. [Isc Gain] = [Voc Gain] = [Imp Gain] = [Vmp Gain] = [Pmp Gain]$^{1/2}$

4.7 PAN file Generation and Optimization

Optimized PAN files were prepared using PANOpt®, an in-house-developed software for deriving from the test data optimum solutions for the PVsyst 6 single-diode performance model. Starting with the measured values of Isc, Voc, Imp, Vmp, muIsc, and an Rs value calculated from the I-V curves with the Swanson method, the PANOpt® solver iterated over a given parameter space for Rs, Rsh, RshG0 (and $di^2/\mu\tau_{eff}$ for thin-film technologies) until the PVsyst 6 model-predicted Pmp values over the Performance Matrix points matched the measured values (average of three samples) with minimum error.

The IAM profile of the test module was not experimentally determined. The default PVsyst IAM profile for normal glass was adopted.

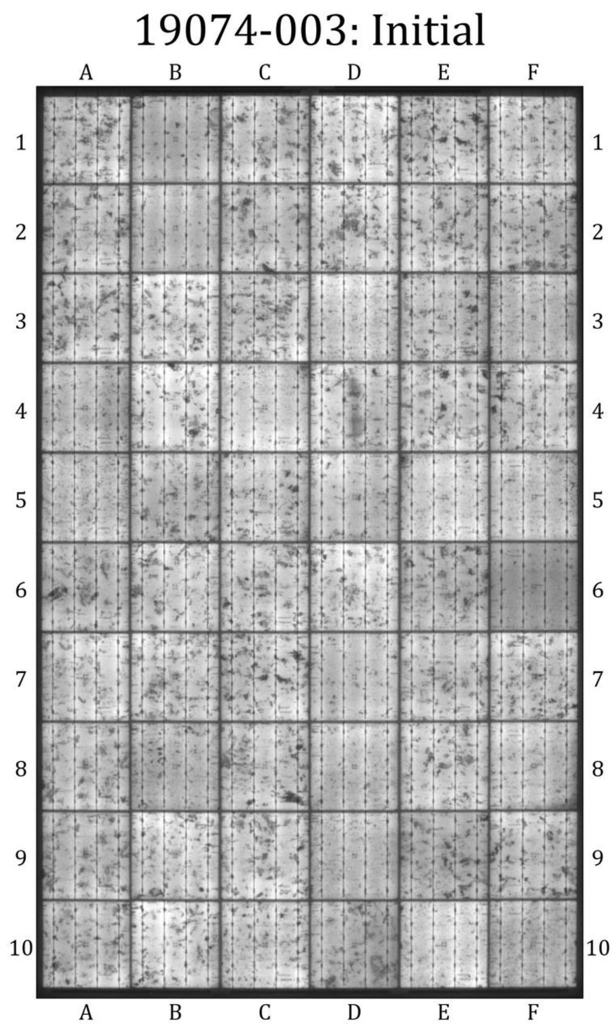
CFV Labs

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

5 Results

5.1 Electroluminescence Imaging

The module was imaged in the dark while a constant DC bias current of 9.41 A (Isc) was applied to the module.



5.2 Preconditioning

The module received 41.33 kWh/m2 of outdoor preconditioning prior to indoor performance testing. The preconditioning was performed with the module in open circuit.

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

5.3 MQT 06.1 Performance at STC

The following values were measured after preconditioning and during the Performance Matrix test.

Module ID	Isc [A]	Voc [V]	Imp [V]	Vmp [V]	Pmp [W]	FF [%]
19074-003	9.488	38.76	8.928	31.13	277.92	75.58

Table 5.3.1 Uncertainty and repeatability of flash measurements on Si modules

	Isc	Voc	Imp	Vmp	Pmp
Uncertainty	± 1.8 %	± 0.7 %	± 2.2 %	± 1.3 %	± 2.2 %
Repeatability	± 0.20 %	± 0.20 %	± 0.30 %	± 0.40 %	± 0.45 %

5.4 MQT 04 Temperature Coefficients

Relative Units

Module ID	α Isc [%/°C]	β Voc [%/°C]	α Imp [%/°C]	β Vmp [%/°C]	δ Pmp [%/°C]
19074-003	+0.0379	-0.2880	-0.0159	-0.3823	-0.3955

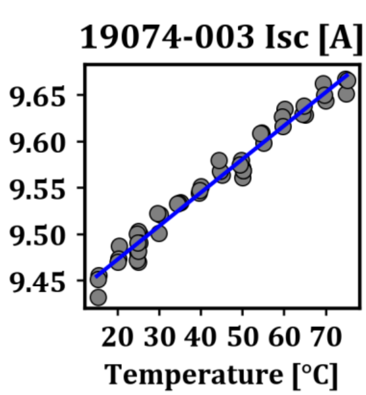
Absolute Units

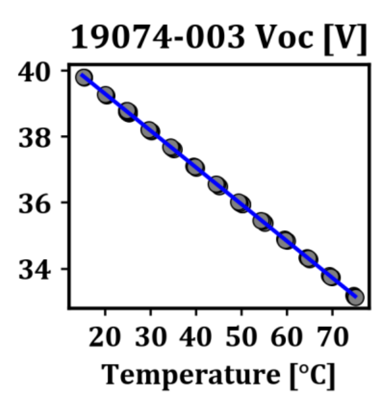
Module ID	α Isc [A/°C]	β Voc [V/°C]	α Imp [A/°C]	β Vmp [V/°C]	δ Pmp [W/°C]
19074-003	+0.00360	-0.1116	-0.00142	-0.1190	-1.0990

Table 5.4.1 Estimated uncertainty of temperature coefficients (relative)

	α Isc	β Voc	α Imp	β Vmp	γ Pmp
Uncertainty (k = 2)	± 10 %	± 5 %	N/A	N/A	± 5 %

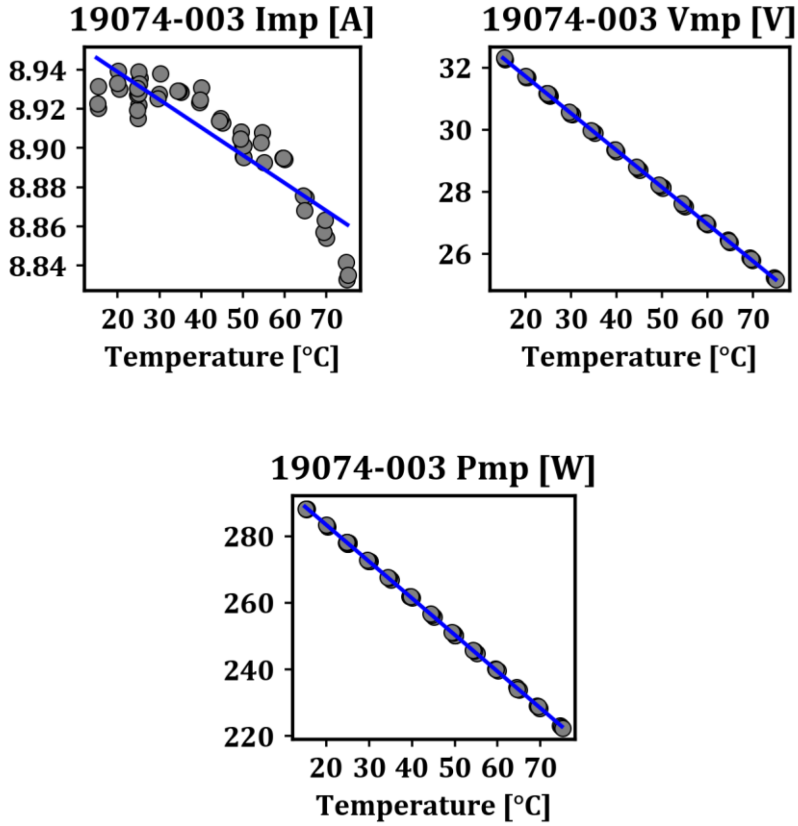
Plots





CFV Labs

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com



Measured Data

The following table shows the I-V values measured on the tested sample.

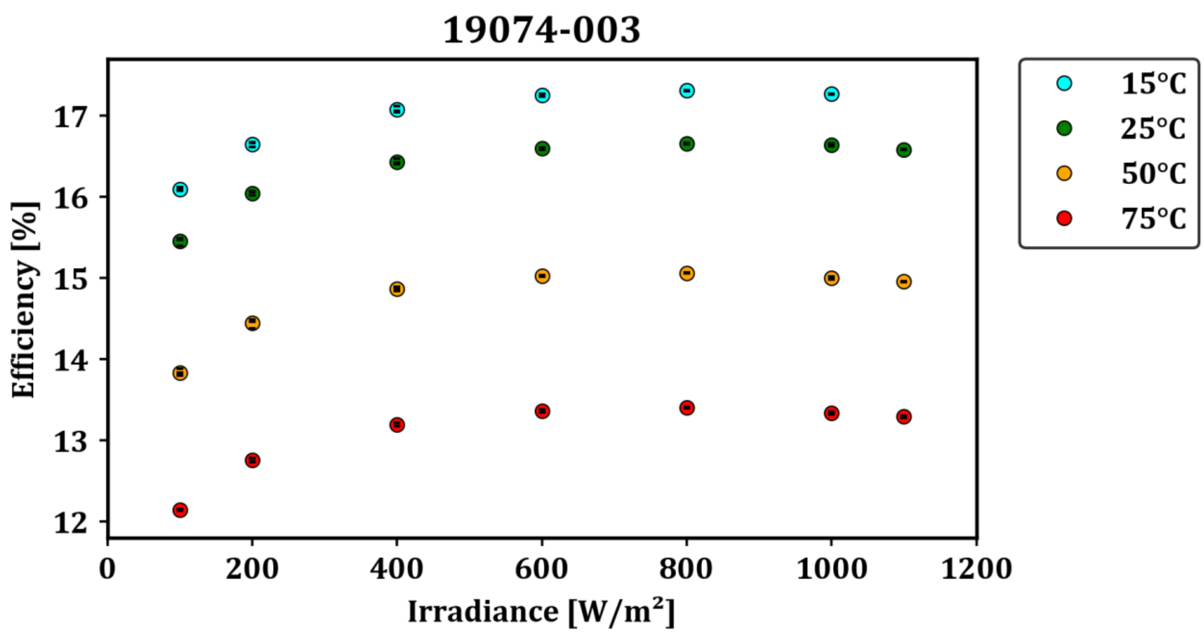
Module ID	T (°C)	G (W/m2)	Isc (A)	Voc (V)	Imp (A)	Vmp (V)	Pmp (W)
19074-003	15.33	1000	9.447	39.81	8.925	32.29	288.17
19074-003	20.15	1000	9.477	39.27	8.934	31.69	283.16
19074-003	24.94	1000	9.488	38.76	8.928	31.13	277.96
19074-003	29.87	1000	9.515	38.19	8.930	30.52	272.56
19074-003	34.71	1000	9.534	37.66	8.929	29.94	267.33
19074-003	39.74	1000	9.548	37.10	8.926	29.33	261.83
19074-003	44.71	1000	9.571	36.54	8.914	28.75	256.30
19074-003	49.84	1000	9.571	35.98	8.901	28.15	250.60
19074-003	54.66	1000	9.606	35.44	8.901	27.57	245.38
19074-003	59.72	1000	9.626	34.87	8.895	26.98	239.95
19074-003	64.70	1000	9.632	34.32	8.873	26.40	234.24
19074-003	69.58	1000	9.652	33.76	8.858	25.83	228.79
19074-003	74.88	1000	9.662	33.17	8.837	25.21	222.76

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

5.5 Performance Matrix

Efficiency Curves

In the following plot, circles indicate the average of three measurements at each irradiance and temperature test condition. Bars inside the circles indicate the values from each of the three measurements.



Measured Data

The following table shows the Performance Matrix data measured on the tested sample.

Module ID	T (°C)	G (W/m2)	Isc (A)	Voc (V)	Imp (A)	Vmp (V)	Pmp (W)
19074-003	15	100	0.933	35.82	0.879	30.57	26.88
19074-003	15	200	1.862	37.03	1.766	31.48	55.61
19074-003	15	400	3.739	38.24	3.545	32.17	114.05
19074-003	15	600	5.630	38.95	5.338	32.39	172.88
19074-003	15	800	7.534	39.46	7.137	32.40	231.24
19074-003	15	1000	9.446	39.85	8.924	32.32	288.41
19074-003	25	100	0.934	34.61	0.881	29.29	25.80
19074-003	25	200	1.867	35.85	1.772	30.24	53.59
19074-003	25	400	3.754	37.11	3.545	30.97	109.77
19074-003	25	600	5.653	37.84	5.337	31.15	166.28
19074-003	25	800	7.559	38.34	7.133	31.20	222.55
19074-003	25	1000	9.488	38.76	8.928	31.13	277.92
19074-003	25	1100	10.427	38.93	9.807	31.06	304.64
19074-003	50	100	0.948	31.60	0.882	26.19	23.11

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

Module ID	T (°C)	G (W/m2)	Isc (A)	Voc (V)	Imp (A)	Vmp (V)	Pmp (W)
19074-003	50	200	1.893	32.93	1.772	27.23	48.25
19074-003	50	400	3.800	34.24	3.553	27.95	99.31
19074-003	50	600	5.718	35.01	5.346	28.16	150.56
19074-003	50	800	7.644	35.56	7.131	28.22	201.25
19074-003	50	1000	9.572	35.96	8.902	28.14	250.50
19074-003	50	1100	10.525	36.16	9.781	28.09	274.73
19074-003	75	100	0.958	28.46	0.881	23.03	20.28
19074-003	75	200	1.909	29.89	1.767	24.10	42.60
19074-003	75	400	3.838	31.32	3.536	24.92	88.11
19074-003	75	600	5.775	32.13	5.317	25.18	133.90
19074-003	75	800	7.711	32.72	7.091	25.25	179.05
19074-003	75	1000	9.662	33.16	8.837	25.20	222.70
19074-003	75	1100	10.638	33.36	9.711	25.15	244.19

5.6 Performance Matrix Data Scaling

The gain factors were calculated as explained in the procedures section.

Measured STC values of the single test module

Measured Power Class	Measured STC Isc (A)	Measured STC Voc (V)	Measured STC Imp (A)	Measured STC Vmp (V)	Measured STC Pmp (W)
280	9.488	38.76	8.928	31.13	277.92

Applied gain factors for PAN file STC values by power class

PAN File Power Class	Isc Gain	Voc Gain	Imp Gain	Vmp Gain	Pmp Gain
280	1.0037	1.0037	1.0037	1.0037	1.0075

PAN file STC values by power class

PAN File Power Class	PAN File STC Isc (A)	PAN File STC Voc (V)	PAN File STC Imp (A)	PAN File STC Vmp (V)
280	9.524	38.90	8.961	31.25

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

5.7 PAN file Generation and Optimization

PAN File Parameters for 280 W Class

Tab	Parameter	280 W
Basic data	Model	Q.PLUS BFR-G4.1 280
	Manufacturer	Hanwha Q Cells
	File name	Hanwha Q Cells_Q.PLUS BFR-G4-1 280_Dec2019_CFV.PAN
	Data source	CFV Solar Test Lab - Tested Class
	Nom. Power (Wp)	280
	Tol. - (%)	0
	Tol. + (%)	5.0
	Technology	Si-poly
	GRef (W/m2)	1000
	TRef (°C)	25
	Isc (A)	9.524
	Voc (V)	38.90
	Impp (A)	8.961
	Vmpp (V)	31.25
	muIsc (%/°C)	0.038
Sizes and Technology	Length (mm)	1670
	Width (mm)	1000
	Thickness (mm)	32
	Cells in series	60
	Maximum voltage IEC (V)	1000
	Maximum voltage UL (V)	1000
	Nb. of sub-modules	3
	Sub-module partition	Full Cells
Model parameters / Rshunt - Rserie	Rsh (Ohm)	216
	Rs (Ohm)	0.303
Model parameters / RShunt expon.	Rshunt at Ginc = 0 (Ohm)	769
	Exponential parameter	5.5
Model parameters / Temper. coeff	Apply Temperature Correction on Gamma	Checked
	Pmpp temper. Coeff[1]	-0.392

[1] The Pmp temperature coefficient in PVsyst is different from the definition in IEC 60891:2009. In PVsyst, the Pmp temperature coefficient is calculated from the Pmp values at 25°C and 45°C. Per IEC 60891:2009, the Pmp temperature coefficient is to be calculated by a linear fit through Pmp values measured over a temperature range greater than or equal to 30°C. There is in fact some nonlinearity in the Pmp dependence on temperature, which is why the Pmp temperature coefficient value for the PAN file is different from the value reported in Section 04.

5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

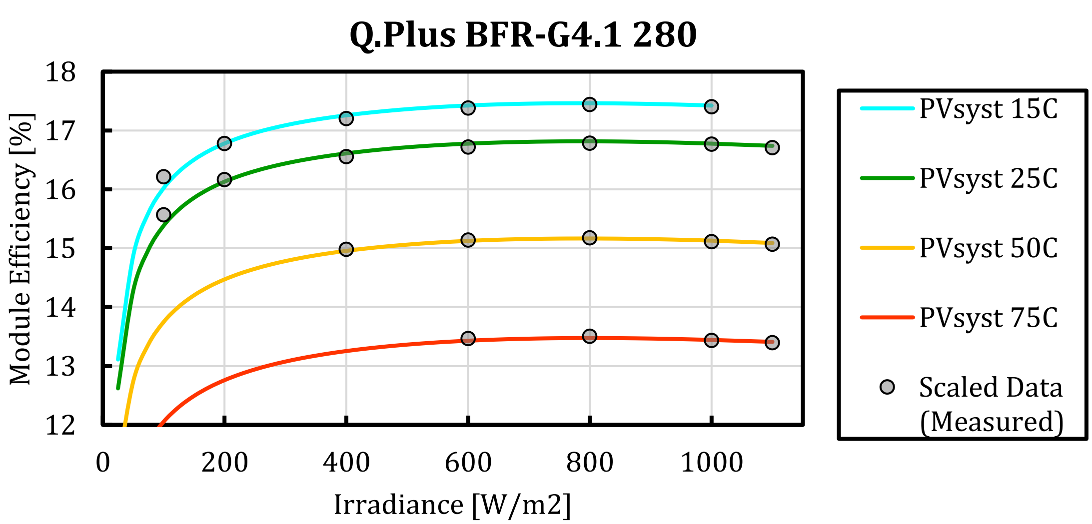
Tab	Parameter		280 W
Additional data / Customized IAM	Special IAM defined for this module		Unchecked
	Front Surface		Normal Glass
	Point 1	0°	1.000
	Point 2	30°	0.998
	Point 3	50°	0.981
	Point 4	60°	0.948
	Point 5	70°	0.862
	Point 6	75°	0.776
	Point 7	80°	0.636
	Point 8	85°	0.403
	Point 9	90°	0.000

PAN File Model Accuracy

PVsyst 6 model output was compared with the scaled data used as the PANOpt® input.

Power Class	RMS Error of Pmp (Error = PVsyst 6 model Pmp – Measured Pmp) [W]				
	15-75°C	15°C	25°C	50°C	75°C
280 W	0.34	0.35	0.41	0.25	0.30

Module Type	RMS Error of Eff. (Error = PVsyst 6 model Eff. – Measured Eff.) [%p]				
	15-75°C	15°C	25°C	50°C	75°C
280 W	0.064	0.085	0.079	0.018	0.024



5600-A University Blvd SE
Albuquerque, NM 87106, U.S.A.
505-998-0100
www.cfvsolar.com

6 Revision History

6.1 Revision 1

This report replaces 19074-PR-E-003.

Changes implemented:

1. In Section 5.7, the PAN file name was changed from, "Hanwah Q Cells_Q.PLUS BFR-G4-1 280_Dec2019_CFV.PAN" to "Hanwha Q Cells_Q.PLUS BFR-G4-1 280_Dec2019_CFV.PAN"

--END OF REPORT--