The 1st International Round-Robin on Bi-Facial Modules

M. Pravettoni, C. Deline, G. Arnoux, K. Berger, C. Fell, E. Garcia Goma, A. Halm, W. Herrmann, D. Hu, M. Joanny, K. Lee, J. Levrat, J. Lopez Garcia, G. Mei, C. Monokruossos, R. Roldán, A. Schmidt, H. Tobita, B. Van Aken, L. Votta, S. Wendlandt, and M. Yoshita

bifi PV workshop 2018 Denver

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Pre-standard nameplates: example 1

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Electrical Characteristics

Model Number	LR6-60BP-290M		LR6-60BP-295M		LR6-60BP-300M		LR6-60BP-305M		LR6-60BP-310M	
Testing Condition	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back
Maximum Power (Pmax/W)	290	218	295	222	300	226	305	229	310	233
Open Circuit Voltage (Voc/V)	39.2	38.9	39.4	39.1	39.6	39.3	39.8	39.5	40.0	39.7
Short Circuit Current (Isc/A)	9.36	7.16	9.47	7.25	9.58	7.33	9.69	7.42	9.80	7.50
Voltage at Maximum Power (Vmp/V)	32.6	33.3	32.7	33.5	32.9	33.7	33.1	33.8	33.2	34.0
Current at Maximum Power (Imp/A)	8.90	6.54	9.01	6.63	9.11	6.71	9.22	6.77	9.33	6.85
Module Efficiency(%)	17.5	13.1	17.8	13.4	18.1	13.6	18.4	13.8	18.7	14.0

STC (Standard Testing Conditions): Irradiance 1000W/m², Cell Temperature 25℃, Spectra at AM1.5

Electrical characteristics with different rear side power gain (reference to 300W front)

Pmax /W	Voc/V	Isc /A	Vmp/V	Imp /A	Pmax gain
315	39.6	9.94	32.9	9.58	5%
330	39.6	10.40	32.9	10.04	10%
360	39.7	11.35	32.8	10.98	20%
375	39.7	11.82	32.8	11.44	25%

- STC from both sides
- Electrical characteristics with typical bifi power gains

LONGi Solar

Pre-standard nameplates: example 2

SPECIFICATIONS

Module Type	JKM295M-60-BDV		JKM300M-60-BDV		JKM305M-60-BDV		JKM310M-60-BDV		JKM315M-60-BDV	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	295Wp	219Wp	300Wp	223Wp	305Wp	227Wp	310Wp	230Wp	315Wp	234Wp
Maximum Power Voltage (Vmp)	32.1V	29.2V	32.3V	29.4V	32.5V	29.6V	32.7V	29.7V	32.9V	29.9V
Maximum Power Current (Imp)	9.20A	7.51A	9.30A	7.59A	9.39A	7.68A	9.49A	7.75A	9.58A	7.82A
Open-circuit Voltage (Voc)	39.3V	36.2V	39.5V	36.4V	39.7V	36.6V	39.9V	36.7V	40.1V	37.8V
Short-circuit Current (Isc)	9.82A	7.95A	9.92A	8.03A	10.02A	8.12A	10.11A	8.18A	10.21A	8.27A
Module Efficiency STC (%)	17.66%		17.96%		18.26%		18.56%		18.85%	
Operating Temperature(℃)	-40℃~+85℃									
Maximum system voltage	1500VDC (IEC)									
Maximum series fuse rating	20A									
Power tolerance	0~+3%									
Temperature coefficients of Pmax	-0.38%/℃									
Temperature coefficients of Voc	-0.28%/℃									
Temperature coefficients of Isc	0.048%/℃									
Nominal operating cell temperature (NOCT)	46±2℃									
Refer. Bifacial Factor	90±3%									

- Only STC values, front side (though not specified)
- Ref. Bifacial Factor

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Pre-standard nameplates: example 3

ELECTRICAL PARAMETERS

		JNHM60-340	JNHM60-345	JNHM60-350	JNHM60-355	JNHM60-360
BSTC AM1.5, E=(1+0.135BiFi) 1000W/m² Cell Temperature 25°C	Max. Power at BSTC (Pmpp/W)	340	345	350	355	360
	Output Tolerance (W)	0~+5	0~+5	0~+5	0~+5	0~+5
	Max. Power Voltage (Vmp/V)	36.10	36.28	36.50	36.72	36.93
	Max. Power Current (Imp/A)	9.42	9.51	9.59	9.67	9.75
	Open Circuit Voltage (Voc/V)	42.72	43.01	43.29	43.57	43.84
	Short Circuit Current (Isc/A)	9.93	9.99	10.03	10.07	10.12
	Module Efficiency (%)	20.7	21.0	21.3	21.6	21.9
STC AM1.5, 1000W/m² Cell Temperature 25°C	Max. Power at STC (Pmpp/W)	305	310	315	320	325
	Max. Power Voltage (Vmp/V)	35.83	36.06	36.25	36.49	36.70
	Max. Power Current (Imp/A)	8.52	8.60	8.69	8.77	8.86
	Open Circuit voltage (Voc/V)	42.30	42.54	42.82	43.10	43.38
	Short Circuit Current (Isc/A)	8.91	8.95	9.00	9.04	9.08

- Both STC and "BSTC" values

IEC TS 60904-1-2 almost ready!

- January 2019 publication date, final vote approved

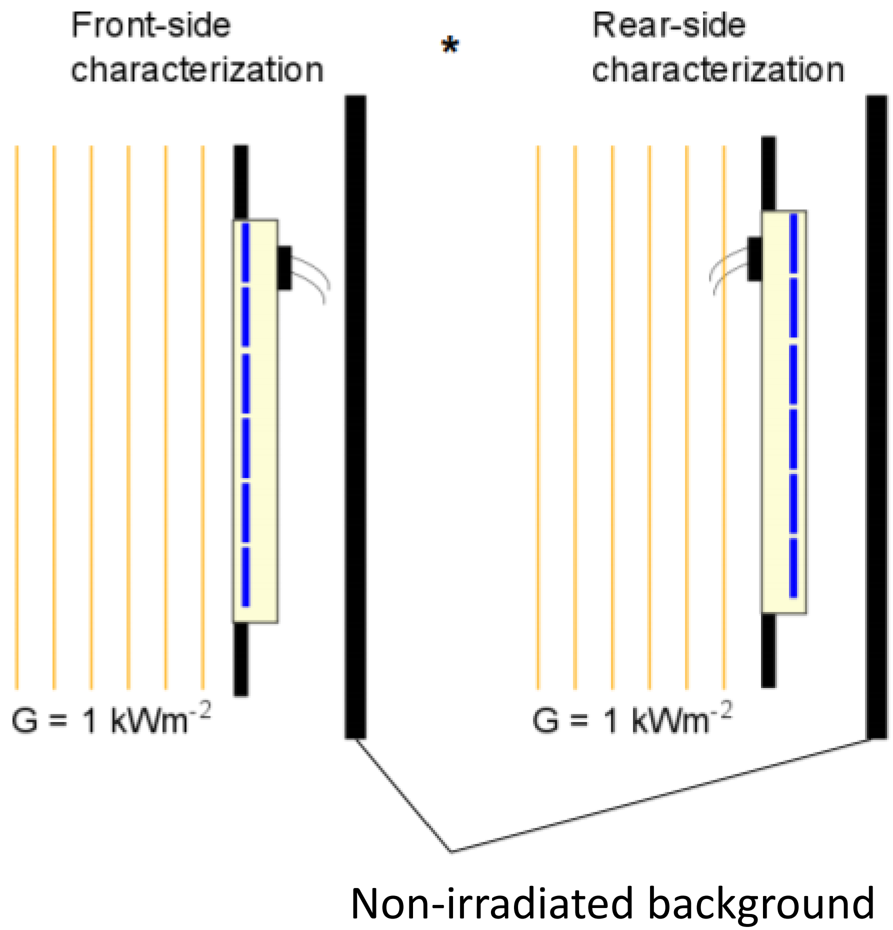
Step 1: Bifaciality measurement

$$\varphi_{Isc} = \frac{Isc_r}{Isc_f}$$

$$\varphi_{Voc} = \frac{Voc_r}{Voc_f}$$

$$\varphi_{Pmax} = \frac{Pmax_r}{Pmax_f}$$

$$\varphi = Min(\varphi_{Isc}, \varphi_{Pmax})$$



V. Fakhfouri, bifiPV workshop, October 2017 Konstanz DE

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Step 2: Bifacial Gain determination

- Dual simultaneous illumination, or single-side at equivalent irradiance levels G_{E_i} :

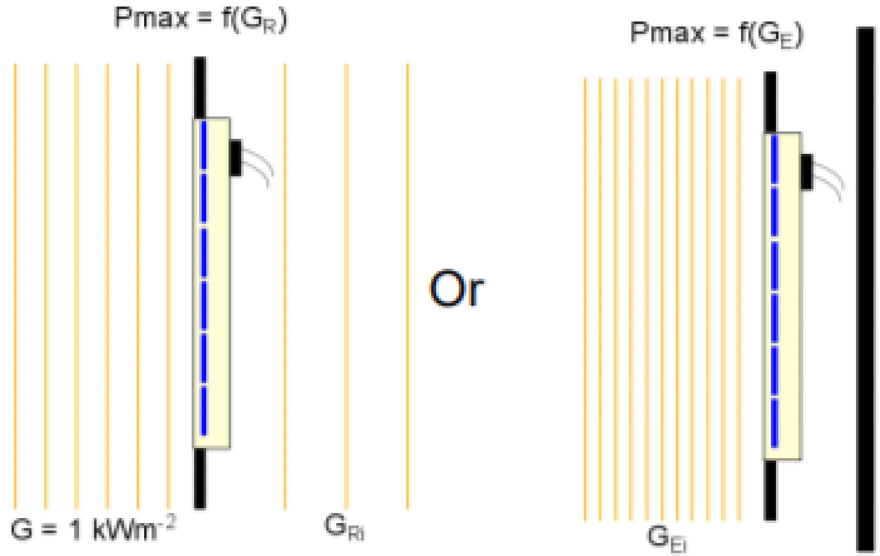
$$G_{E_i} = 1000\,Wm^{-2} + \varphi \cdot G_{R_i}$$

$$\varphi = Min(\varphi_{Isc}, \varphi_{Pmax})$$

- Example for φ = 80%,

$G_{R_1} = 100\,Wm^{-2}$ $\rightarrow G_{E_1} = 1080\,Wm^{-2}$

$G_{R_2} = 200\,Wm^{-2}$ $\rightarrow G_{E_2} = 1160\,Wm^{-2}$



V. Fakhfouri, bifiPV workshop, October 2017 Konstanz DE

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Step 3: To report

- Bifaciality coefficients: φ_{Isc}, φ_{Voc}, and φ_{Pmax}
- I_{sc}, V_{oc}, and P_{max} as a function of the rear side irradiance G_R or equivalent irradiance $G_E = 1000 + \varphi \cdot G_R$
- The power gain yield (i.e. the slope of P_{max} vs G_R)
- The power values at G_R=100 W/m^2 and G_R=200 W/m^2 : $P_{maxBiFi10}$ and $P_{maxBiFi20}$
- Values at STC from both sides

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Motivation for the 1st BiFi RR

ISO/IEC 17025:2017

7.2.2 Validation of methods

7.2.2.1 The laboratory shall **validate non-standard methods**, laboratory-developed methods and **standard methods used outside their intended scope** or otherwise modified.

NOTE 2 The techniques used for method validation can be one of, or a combination of, the following:
[…]
e) **Interlaboratory comparisons**;

7.7 Ensuring the validity of results

7.7.2 The laboratory **shall monitor its performance** by comparison with results of other laboratories, where available and appropriate. This monitoring shall be planned and reviewed and shall include, either or both of the following:
(a) Participation in proficiency testing; […]

Participants to the 1st BiFi RR

ISO 17025 accredited laboratories		Non-accredited laboratories
NREL JRC Fraunhofer-ISE TÜV-Rheinland AIST	SERIS (coordinator) Kiwa SUPSI CEA-INES PI-Berlin PI-China CPVT JET AIT CFV	Pasan CSEM-EPFL CSIRO ISC ECN-TNO Eternal Sun
Group 1	Group 2	Group 3

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Testing samples

monofacial (REFERENCE)		bifacial					
P-type PERC	poly-Si	P-type PERC	HJT	N-type PERT	P-type PERC	N-type PERT	poly-Si
2 samples	2 samples	2 samples	2 samples	2 samples	2 samples	2 samples	2 samples
60 cells	60 cells	60 cells	60 cells	60 cells	72 cells	120 cells HC	144 cells HC
Frame	Frame	Frame	No frame	Frame	Frame	No frame	No frame

Shipment

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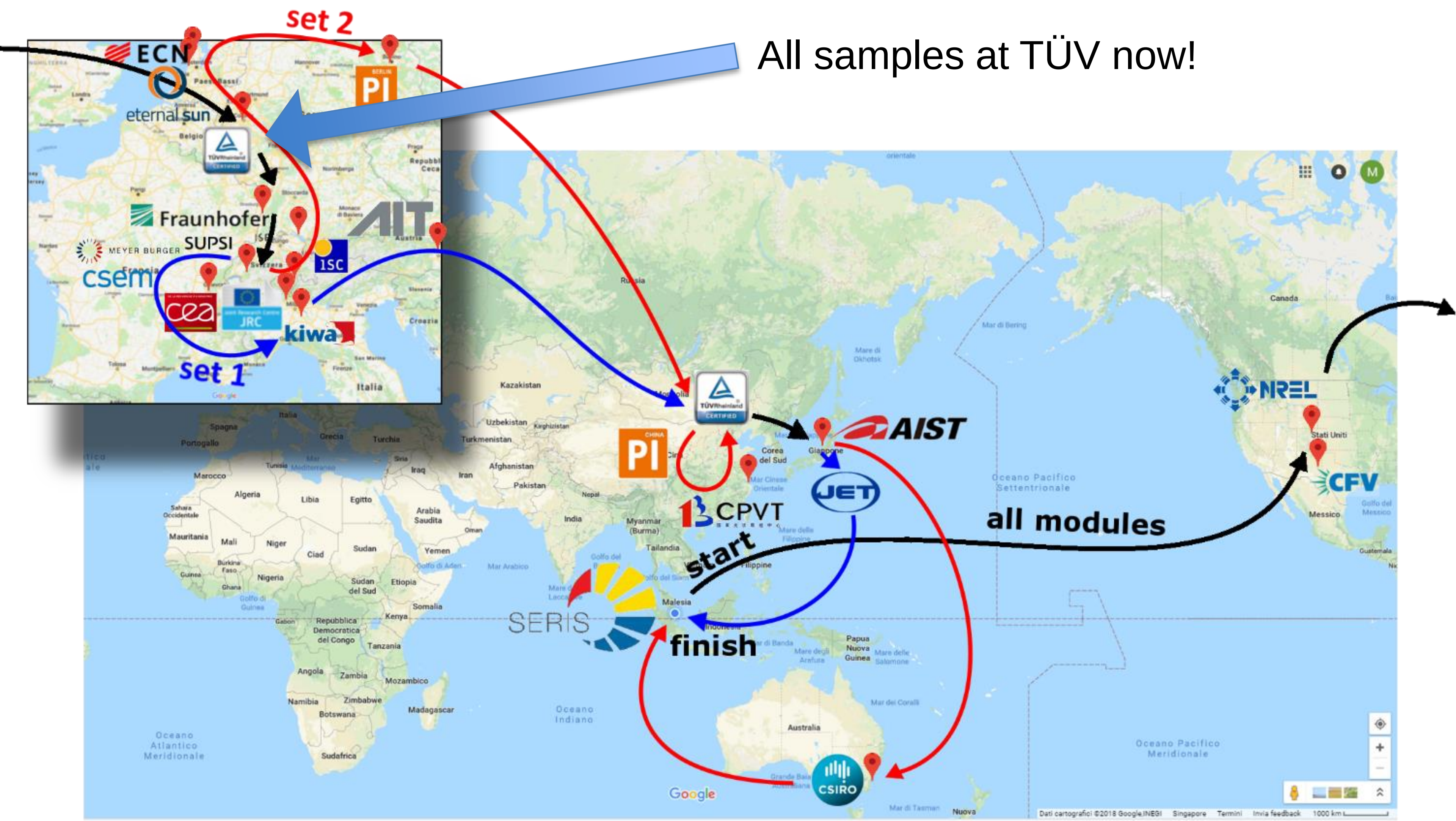
The circulating path



What to measure

Electrical parameters to be reported as per IEC TS 60904-1-2:

Measurand	Units	Comment
Bifaciality coefficient, φ_{Isc}	[-]	
Bifaciality coefficient, φ_{Pmax}	[-]	
Bifaciality coefficient, φ_{Voc}	[-]	
Bifaciality coefficient, $\varphi = \min(\varphi_{Isc}, \varphi_{Pmax})$	[-]	
I_{sc} at $G_E = 1000$ W/m²	A	
I_{sc} at $G_E = 1000 + 100\varphi$ W/m²	A	
I_{sc} at $G_E = 1000 + 200\varphi$ W/m²	A	Optional
V_{oc} at $G_E = 1000$ W/m²	V	
V_{oc} at $G_E = 1000 + 100\varphi$ W/m²	V	
V_{oc} at $G_E = 1000 + 200\varphi$ W/m²	V	Optional
P_{max} at $G_E = 1000$ W/m²	W	
P_{max} at $G_E = 1000 + 100\varphi$ W/m²	W	
P_{max} at $G_E = 1000 + 200\varphi$ W/m²	W	Optional
I_{sc} of the rear side, STC	A	
V_{oc} of the rear side, STC	V	
P_{max} of the rear side, STC	W	
I_{sc} of the rear side at 100 and 200 W/m²	A	Optional
V_{oc} of the rear side at 100 and 200 W/m²	V	Optional
P_{max} of the rear side at 100 and 200 W/m²	W	Optional
SR of the front side	A/W	Optional
SR of the rear side	A/W	Optional
Mismatch factor to the front side at 1000 W/m²	[-]	Optional
Mismatch factor to the back side at 1000 W/m²	[-]	Optional
Slope[1] of P_{max} vs G_E	m²	

Statistical design: Proficiency Testing (PT)

ISO 17043

Monofacial Modules (reference):

To calculate:

- $z_i = \frac{x_i - x_{PT}}{\sigma_{PT}(x)}$ the **"*z*-score"** All laboratories
- $E_{n,i} = \frac{x_i - x_{PT}}{\sqrt{U^2(x_i) + U^2(x_{PT})}}$ the **"E_n-score"** Only Groups 1 & 2

where:

- x_{PT} is the robust average from the labs of Group 1 (**assigned value**)
- σ_{PT} is the robust standard deviation (**PT st dev**)

Bifacial Modules (acceptance criterium):

Groups 1 & 2 labs with $|E_n| < 0.5$ **on monofacial** will set the assigned values x_{PT} and σ_{PT} for bifacial modules…

Statistical design: Proficiency Testing (PT)

ISO 17043

- $z_i = \frac{x_i - x_{PT}}{\sigma_{PT}(x)}$ the **"*z*-score"** All laboratories
- $E_{n,i} = \frac{x_i - x_{PT}}{\sqrt{U^2(x_i) + U^2(x_{PT})}}$ the **"*E*$_n$-score"** Only Group 1 & 2

	$E_n \leq 1.0$ (satisfactory)	$E_n > 1.0$ (unsatisfactory)
$z \leq 2.0$ (satisfactory)	**The PT is satisfactory** Action: none	**The claimed uncertainty is too low, but the result fills the requirements of the PT** Action: check uncertainty
$z > 2.0$ (unsatisfactory)	**The result is within the claimed uncertainty, but not within the limits of the PT** Action: check procedure	**The result is too much biased and the reason should be clarified** Action: check uncertainty & procedure

Conclusions

- Importance of aligning to an agreed international standard
- IEC TS 60904-1-2 almost available: congratulations to Vahid Fakhfouri & team for the precious work
- 1st International RR on commercial BiFi modules to assess reproducibility is ongoing
- **See you to bifiPV 2019 for results!**

Acknowledgements

- For providing samples to be tested:
- For taking part to the round robin:

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Solar Energy Research Institute of Singapore

Thank you for your attention!

More information

mauro.pravettoni@nus.edu.sg