Harmonizing Power Stabilization Methods on Thin-film Photovoltaics: A Round-Robin Test

PEARL TF-PV

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PROJECT TITLE: **PEARL TF-PV**

Performance and Electroluminescence Analysis on Reliability and Lifetime of Thin-Film Photovoltaics

Partner

1. FZJ, Forschungszentrum Juelich
2. AIT, Austrian Institute of Technology
3. TNO
4. Solar Tester
5. International Solar BV (KiesZon)
6. PI Photovoltaik-Institut Berlin AG
7. Helmholtz-Zentrum Berlin für Materialien und Energie GmbH
8. Crystalsol GmbH
9. eigenenergie.net
10. Straightforward

Measurement goals

1. Comparison of power rating and pre-conditioning according to the IEC standard measurement procedures and distinctive pre-conditioning routines.

2. Finding common measurement practice to allow inter-comparison between institutes.

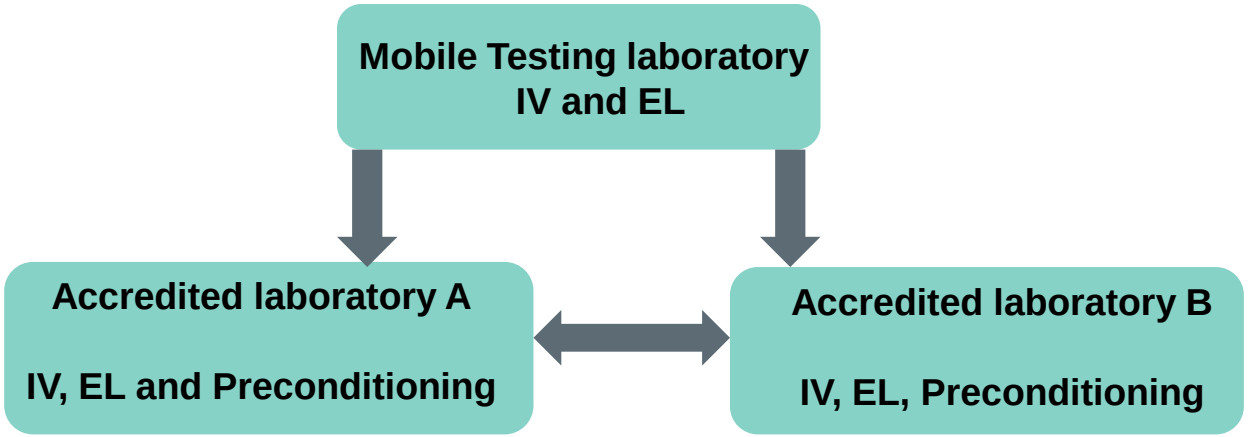
3. Formulating a stable measurement procedure to overcome the gap between pre-conditioning and power rating.

4. The common sets of routines will increase the reliability of power determination and therefore bankability of TF power plants.

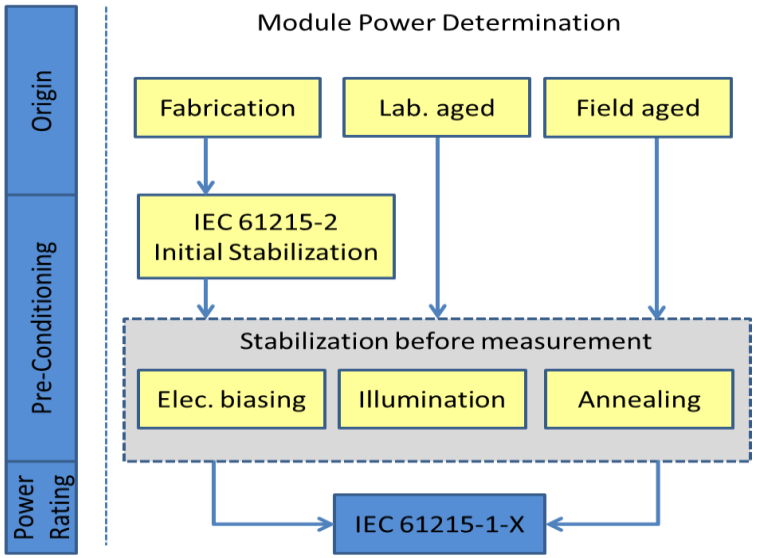
5. Determine arguments to force producers to validate their procedures acc. 61215-1, 61215-1-4 and 61215-2.

MODULES EXCHANGE

During the first RR test all the standard and non-standard preconditioning procedures will be followed. It will include the above mentioned—light induced and voltage/current bias stabilization method. In total 8 modules for each technology will be used for the first round.



	Lab A	Lab B	Lab C
Phase A	All modules only IV and EL		
Phase B		CZTS and CIGS 1	CIGS 2 and CdTe
Phase C		CIGS 2 and CdTe	CZTS and CIGS 2



Measurement Procedure Steps

Step 1. Out of box measurement

Power measurement at STC in accordance with IEC 61215-2:2016 and EL imaging

Step 2. Preconditioning standardized

The modules will be stabilized at their MPP (maximum power point) during illumination according to the IEC 61215-1 and IEC 61215-2.

Step 3. Preconditioning non-standardized

The modules will be stabilized using

- Light stabilized preconditioning at open circuit
- Alternative preconditioning procedure using bias
- Light stabilized preconditioning at MPP at 25°C (LAB B only)

MODULE TEST SCHEME

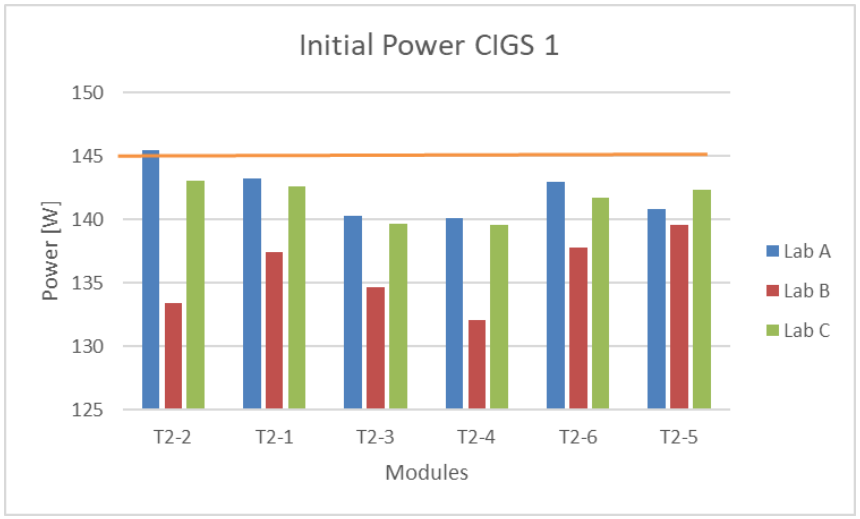
The modules to be targeted for the round-robin (RR) protocol are of CIGS, CdTe and CZTSSe technology type as classified in table 1. Each module manufacturer will contribute to 6 modules for the round-robin protocol. They can be segregated according to the different tests:

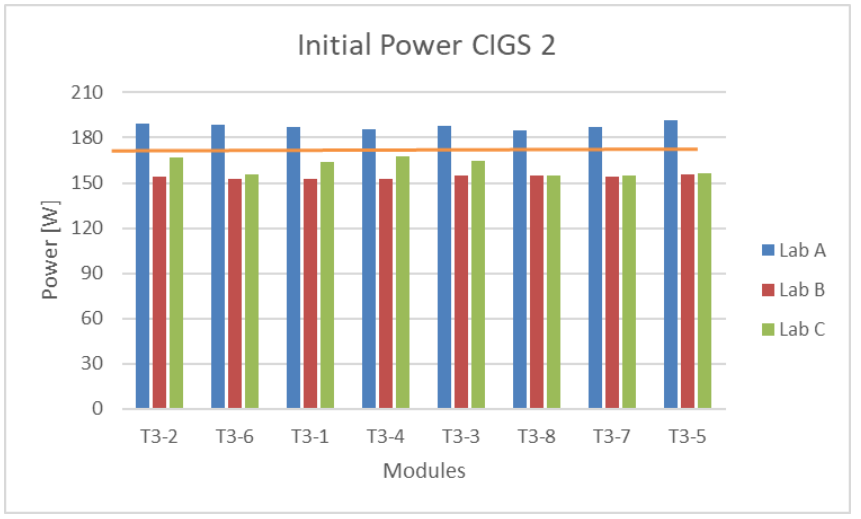
1. Two modules of each technology for a standard light induced preconditioning test according to 61215-1-4 (for CIGS and CZTS) and 61215-1-2 (CdTe)
2. Two modules of each technology for a non-standardized preconditioning test as an extension to the 61215-1-4 and 61215-1-2
3. Two modules of each technology for a the voltage bias stabilization as an alternative to the standard illumination based preconditioning
4. Two modules of each technology was tested for a non-standardized preconditioning test at 25°C as an extension to the 61215-1-4 and 61215-1-2

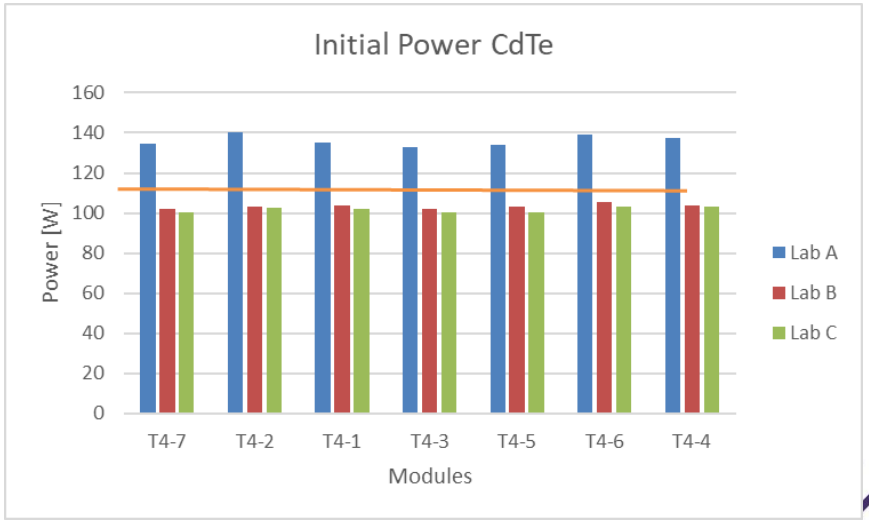
Technology	Standard preconditioning	Open Circuit preconditio-ning	Dark Bias	Standard precondit-ioning at 25 °C
CIGS A	2 modules	2 modules	2 modules	2 modules
CIGS B	2 modules	2 modules	2 modules	2 modules
CdTe	2 modules	2 modules	2 modules	2 modules
CZTS	2 modules	2 modules	2 modules	2 modules

INITIAL TESTING RESULTS

Lab A, Lab B and Lab C







Standard Preconditioning

According to the IEC 61215-1-4 and IEC 61215-1-2

- Light induced stabilization for minimum of two intervals of 10 kW/m² or 20 kW/m² (depending upon the technology) at an irradiance of 1000 W/m² (Class BBB) and in temperature range of 50 ºC

- Modules power is measured at the Standard Test Conditions (STC) of A.M. 1.5, 25 ˚C and 1000 W/m² with a Pulsed Sun Simulator (Class AAA+++)

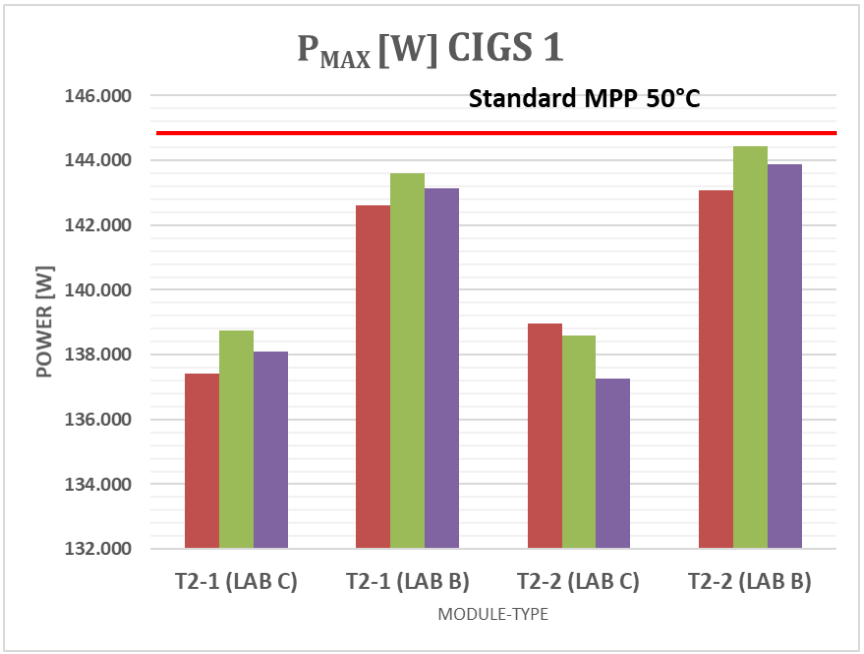
- The modules should be cooled down for a minimum of 30 minutes and maximum of 60 minutes.

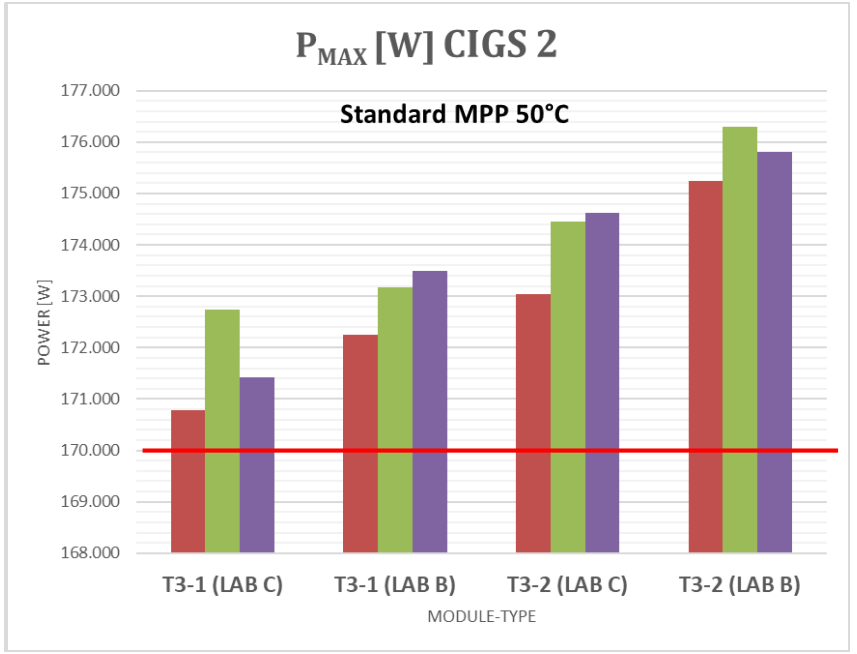
Stabilization criterion:

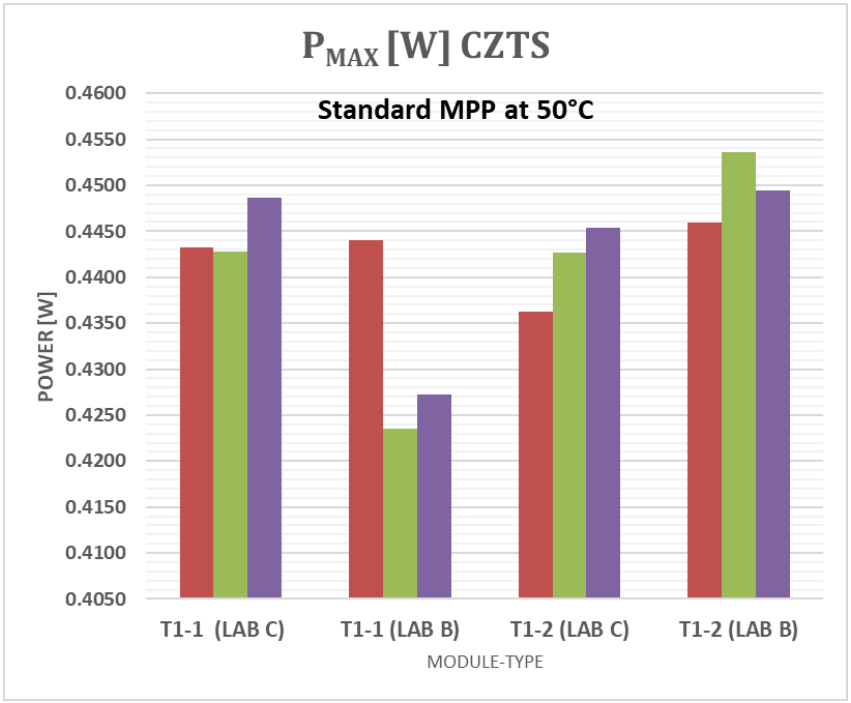
$$(P_{MAX} - P_{MIN}) / P_{AVERAGE} < 0.02$$

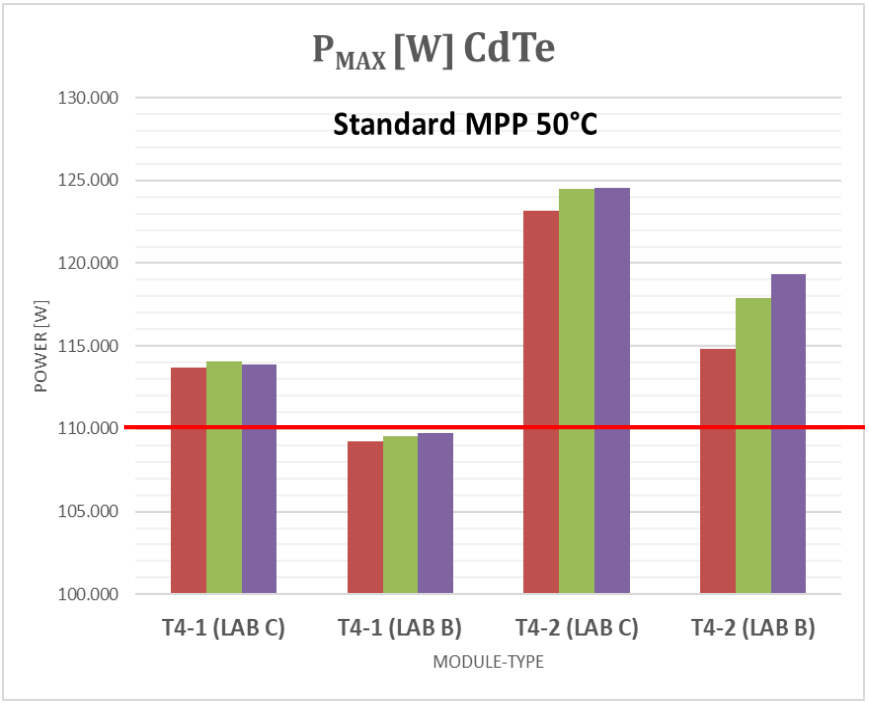
Here, Pmax, Pmin and Paverage are defined as extreme values of three consecutive output power measurements P1, P2 and P3 taken from a sequence of alternating stabilization.

Comparison between LAB B and LAB C Standard preconditioning






P_{MAX} [W] CZTS
Standard MPP at 50°C
POWER [W]
0.4600
0.4550
0.4500
0.4450
0.4400
0.4350
0.4300
0.4250
0.4200
0.4150
0.4100
0.4050
T1-1 (LAB C)
T1-1 (LAB B)
T1-2 (LAB C)
T1-2 (LAB B)
MODULE-TYPE


P_{MAX} [W] CdTe
Standard MPP 50°C
POWER [W]
130.000
125.000
120.000
115.000
110.000
105.000
100.000
T4-1 (LAB C)
T4-1 (LAB B)
T4-2 (LAB C)
T4-2 (LAB B)
MODULE-TYPE

Non Standard Preconditioning

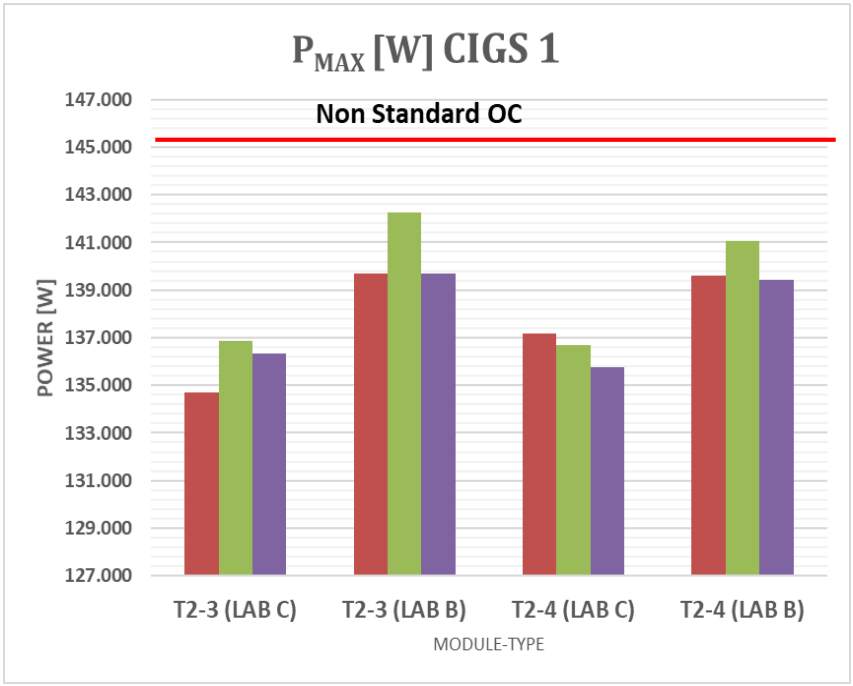
- Light induced stabilization for minimum of two intervals of 20 kW/m² at an irradiance of 800 W/m² (Class BBB) and in temperature range of 45 ºC under open circuit.
- Modules power is measured at the Standard Test Conditions (STC) of A.M. 1.5, 25 ˚C and 1000 W/m² with a Pulsed Sun Simulator (Class AAA+++)

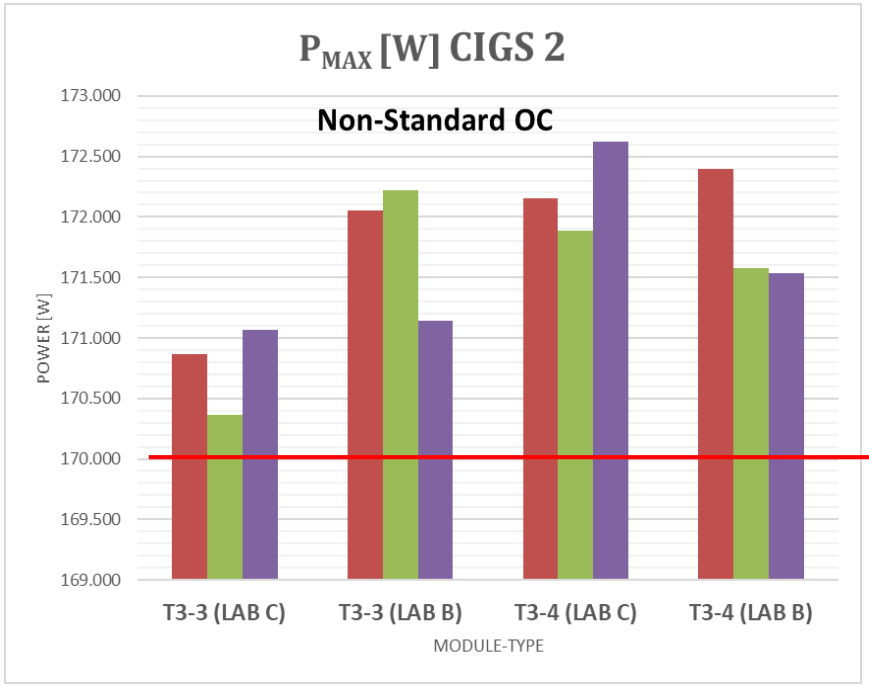
Stabilization criterion:

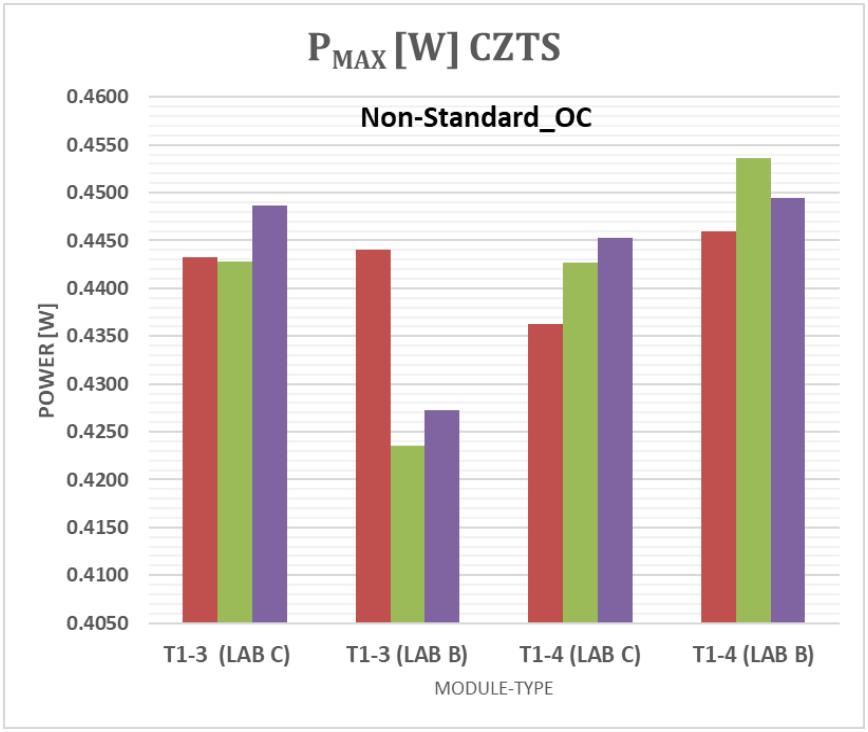
$$(P_{MAX} - P_{MIN}) / P_{AVERAGE} < 0.02$$

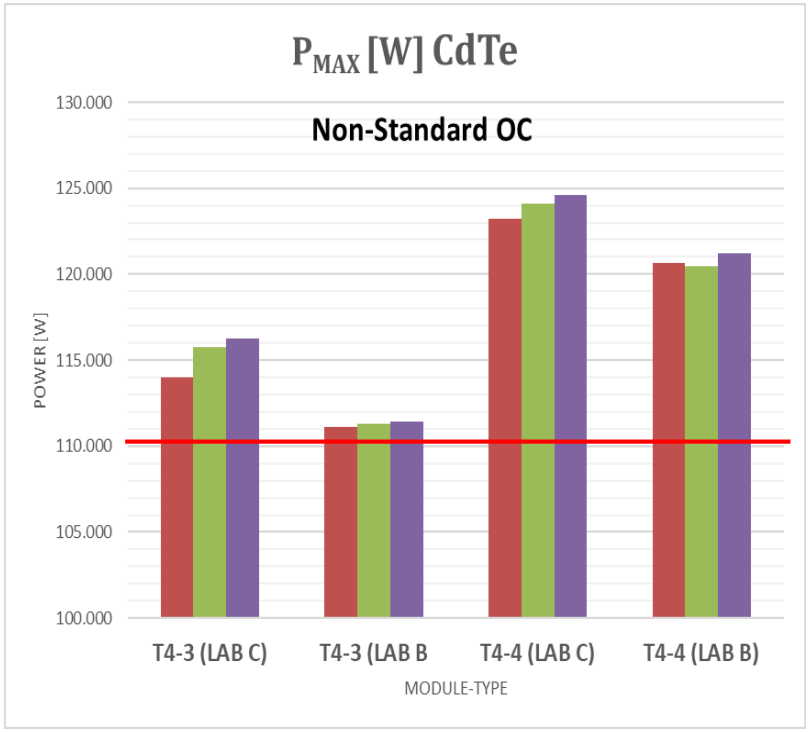
Here, Pmax, Pmin and Paverage are defined as extreme values of three consecutive output power measurements P1, P2 and P3 taken from a sequence of alternating stabilization.

Comparison AIT and PIB Non-Standard preconditioning






P MAX [W] CZTS
Non-Standard_OC
POWER [W]
0.4600
0.4550
0.4500
0.4450
0.4400
0.4350
0.4300
0.4250
0.4200
0.4150
0.4100
0.4050
T1-3 (LAB C)
T1-3 (LAB B)
T1-4 (LAB C)
T1-4 (LAB B)
MODULE-TYPE


P MAX [W] CdTe
Non-Standard OC
POWER [W]
130.000
125.000
120.000
115.000
110.000
105.000
100.000
T4-3 (LAB C)
T4-3 (LAB B
T4-4 (LAB C)
T4-4 (LAB B)
MODULE-TYPE

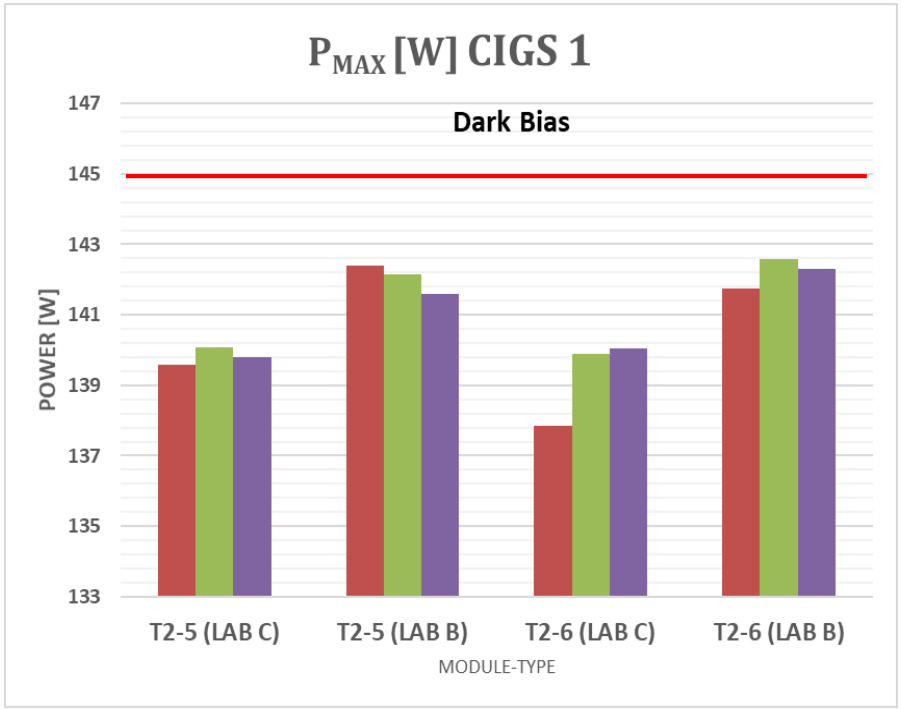
Dark Bias

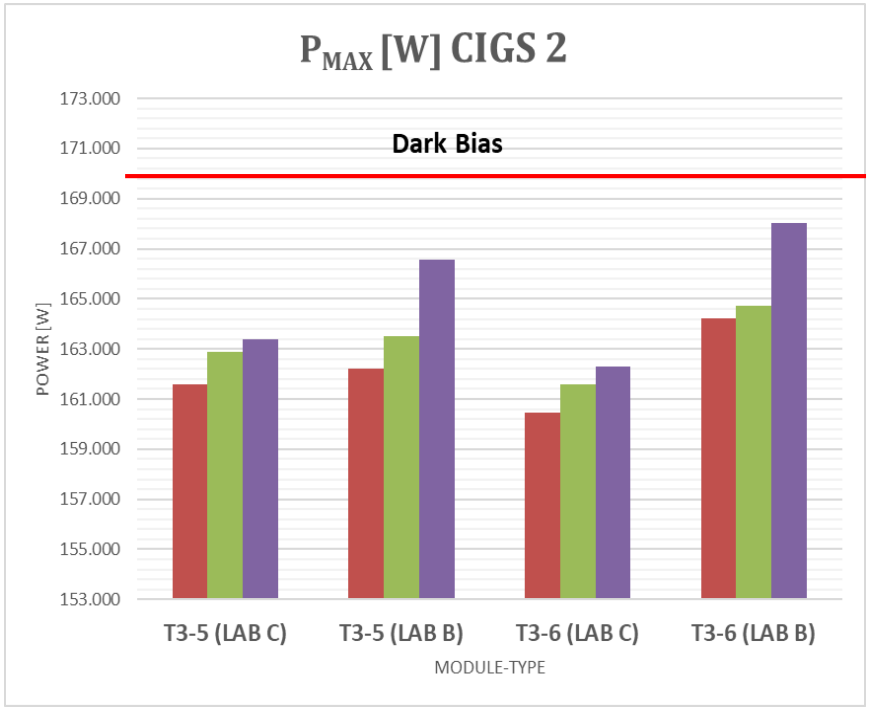
This procedure is used instead of exposing modules to a voltage or current bias is applied to reach stabilization. It is prescribed to be validated on three modules. Also, the alternate procedure shall be provided by the manufacturer. Following tests should be performed:

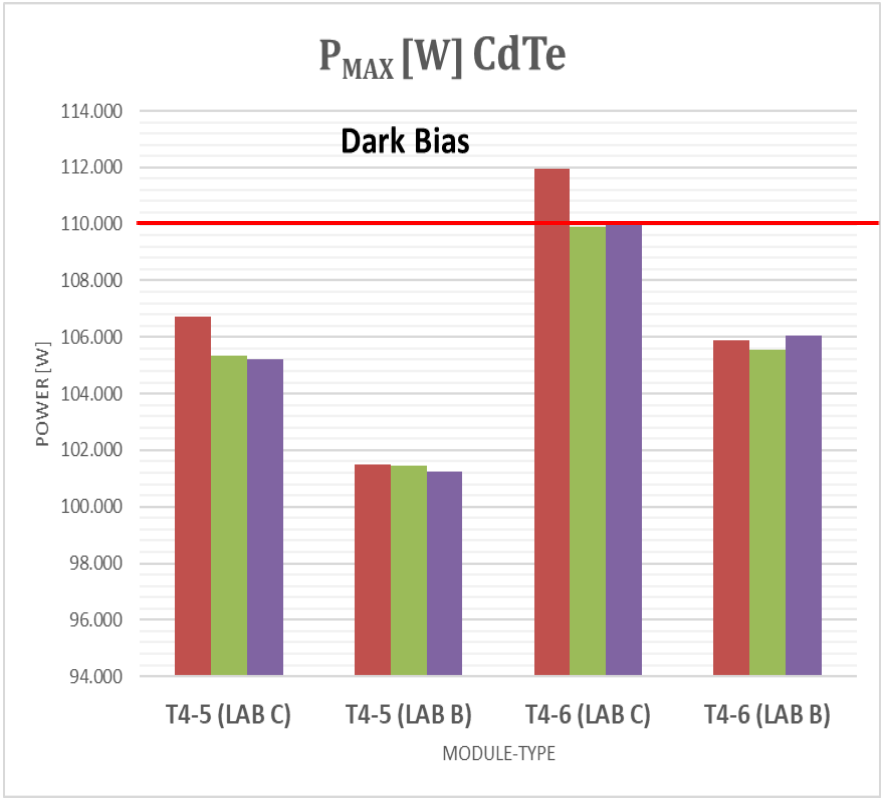
a) Modules should be biased at 1/3 of their I_{SC} for 30 minutes at 45°C in dark for a minimum of two periods.

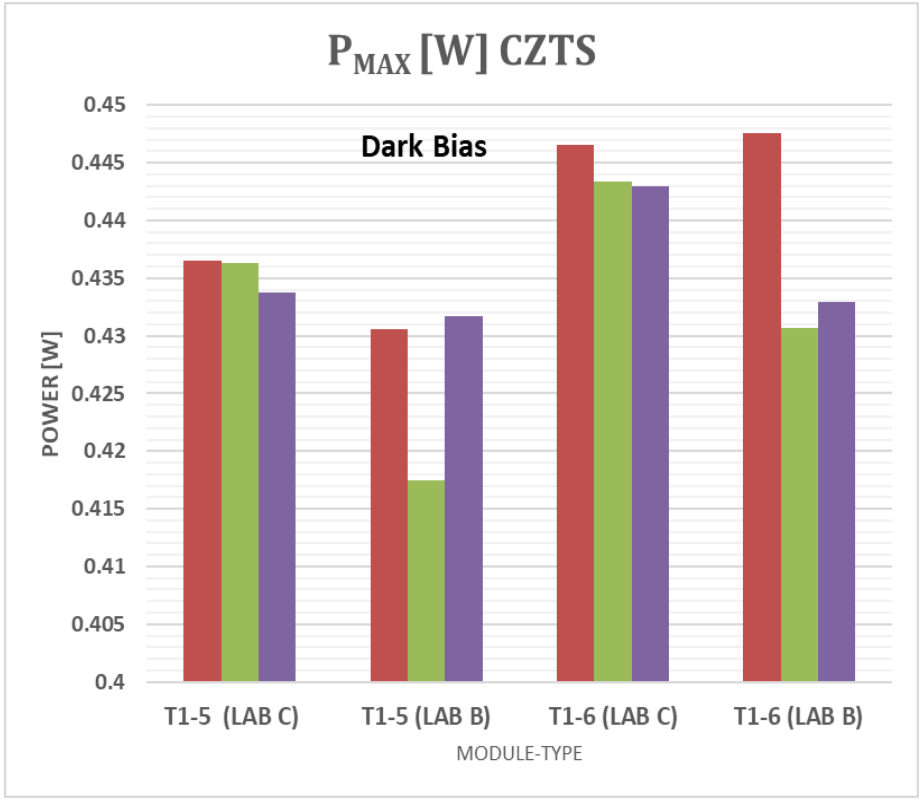
b) After each period measure the IV curve at the STC.

Comparison LAB B and LAB C dark bias preconditioning






P MAX [W] CdTe
Dark Bias
114.000
112.000
110.000
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
POWER [W]
T4-5 (LAB C)
T4-5 (LAB B)
T4-6 (LAB C)
T4-6 (LAB B)
MODULE-TYPE


P MAX [W] CZTS
Dark Bias
0.45
0.445
0.44
0.435
0.43
0.425
0.42
0.415
0.41
0.405
0.4
POWER [W]
T1-5 (LAB C)
T1-5 (LAB B)
T1-6 (LAB C)
T1-6 (LAB B)
MODULE-TYPE

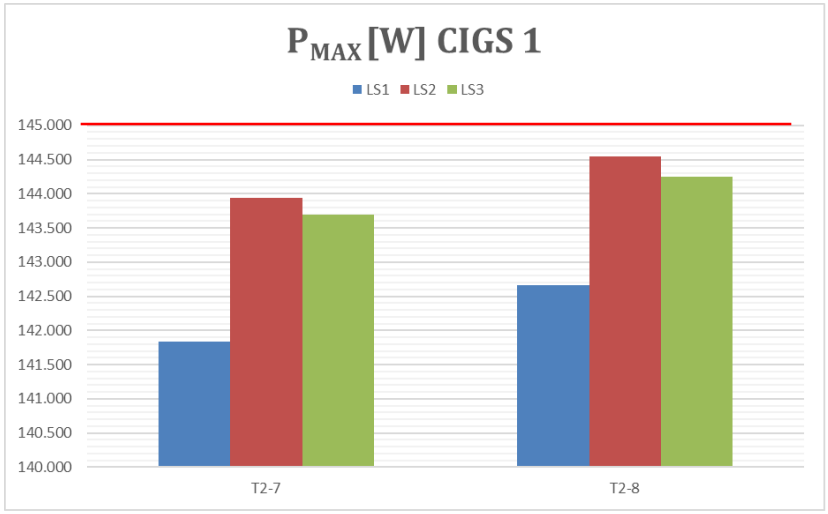
Non Standard Preconditioning at 25ºC

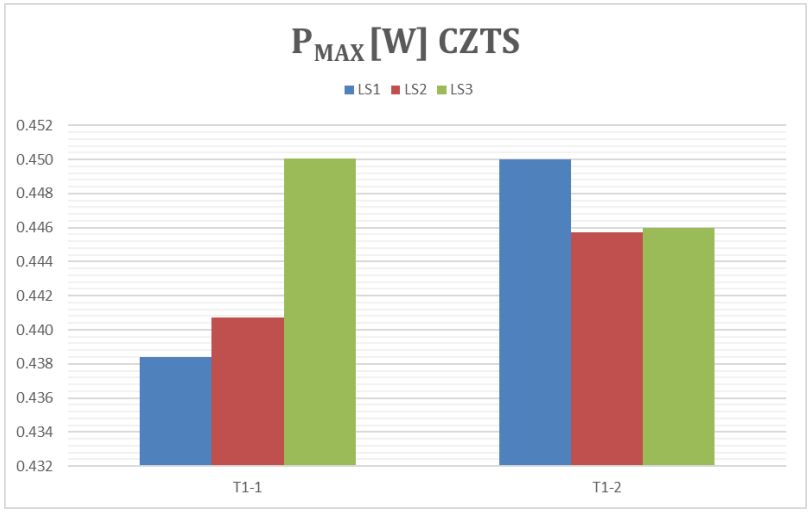
- Light induced stabilization for minimum of two intervals of 20 kW/m² at an irradiance of 800 W/m² (Class BBB) and in temperature range of 25 ºC under open circuit.
- Modules power is measured at the Standard Test Conditions (STC) of A.M. 1.5, 25 ˚C and 1000 W/m² with a Pulsed Sun Simulator (Class AAA+++)

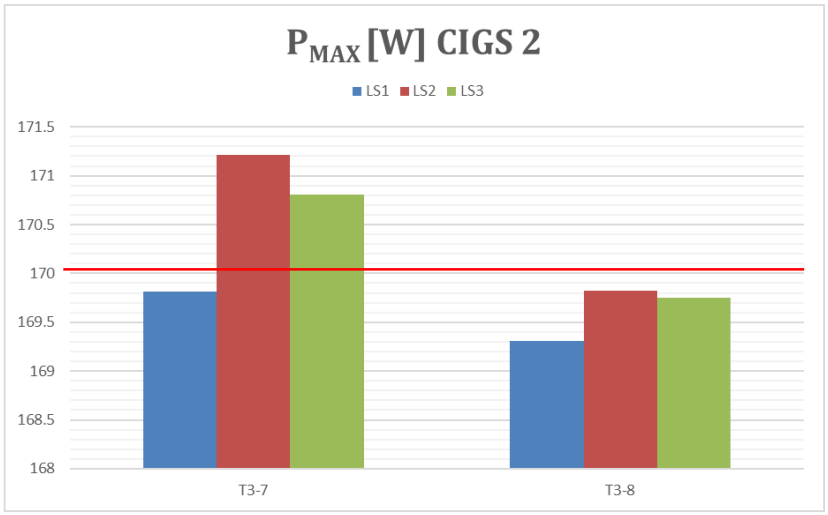
Stabilization criterion:

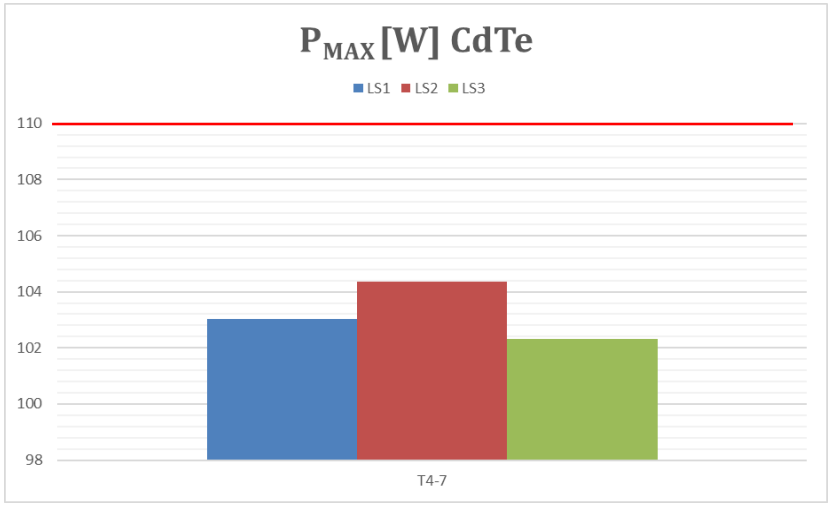
$$(P_{MAX} - P_{MIN}) / P_{AVERAGE} < 0.02$$

Here, Pmax, Pmin and Paverage are defined as extreme values of three consecutive output power measurements P1, P2 and P3 taken from a sequence of alternating stabilization.


P MAX [W] CIGS 1
LS1 LS2 LS3
145.000
144.500
144.000
143.500
143.000
142.500
142.000
141.500
141.000
140.500
140.000
T2-7
T2-8


P MAX [W] CZTS
LS1 LS2 LS3
0.452
0.450
0.448
0.446
0.444
0.442
0.440
0.438
0.436
0.434
0.432
T1-1
T1-2


P MAX [W] CIGS 2
LS1 LS2 LS3
171.5
171
170.5
170
169.5
169
168.5
168
T3-7
T3-8


P MAX [W] CdTe
LS1 LS2 LS3
110
108
106
104
102
100
98
T4-7

Summary of all the Preconditioning procedures

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LAB B Summary

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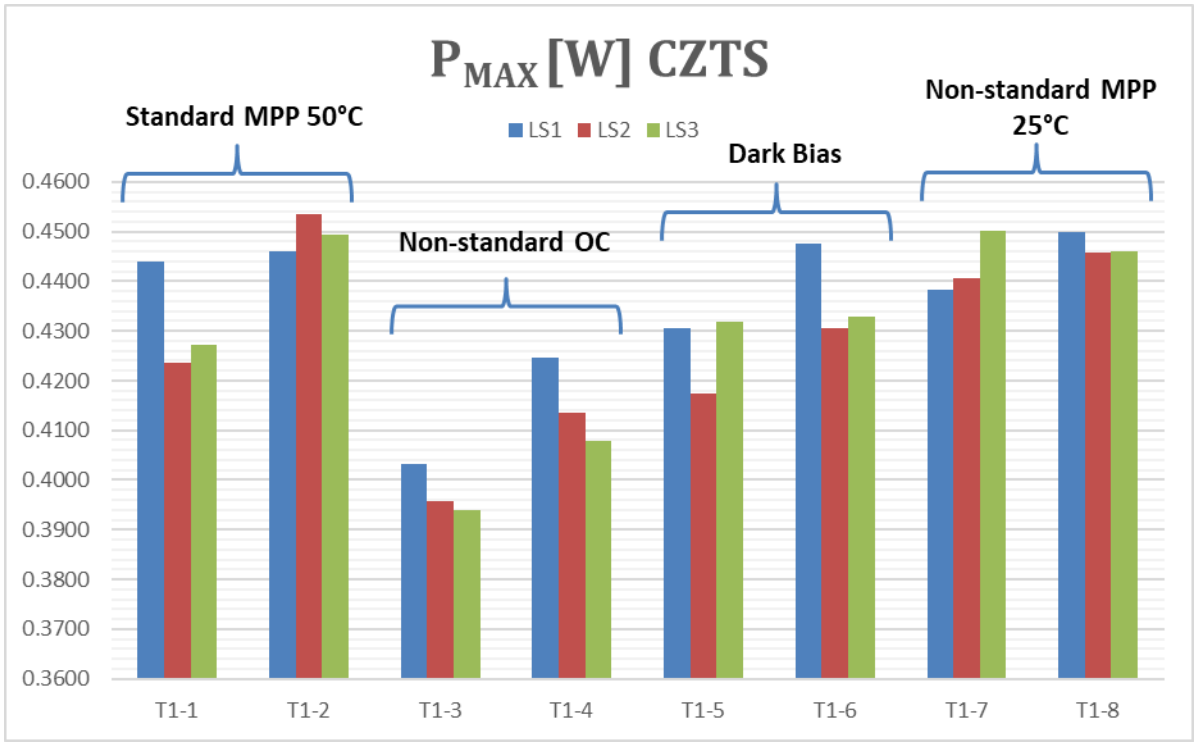
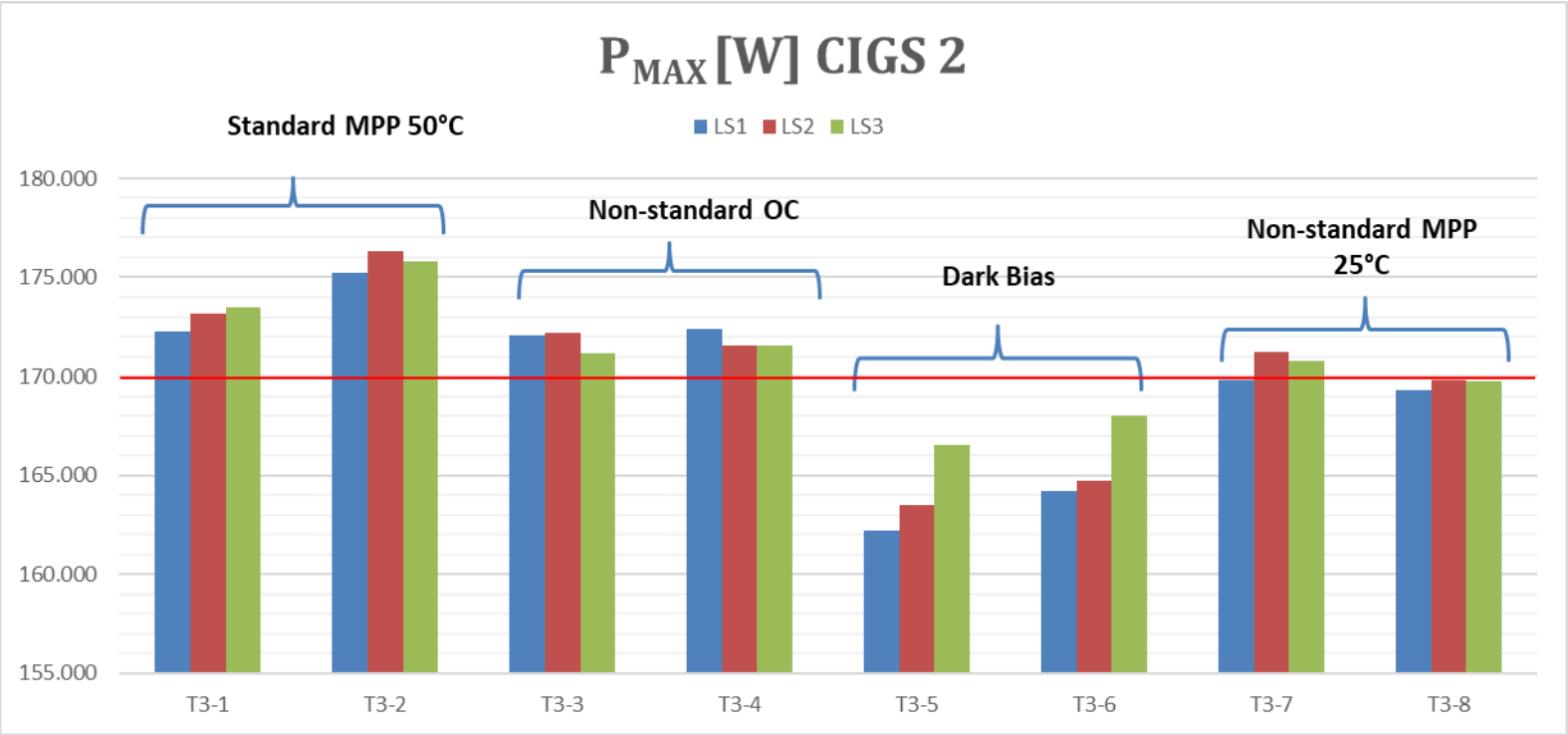
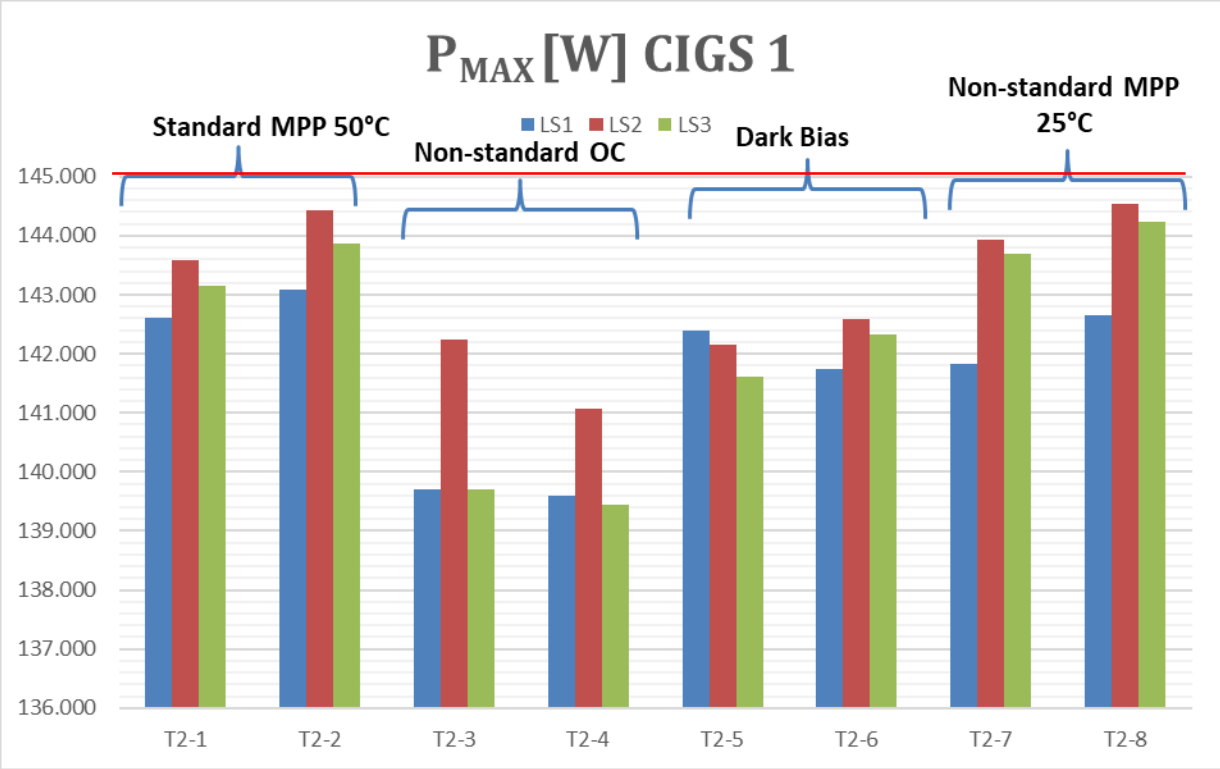
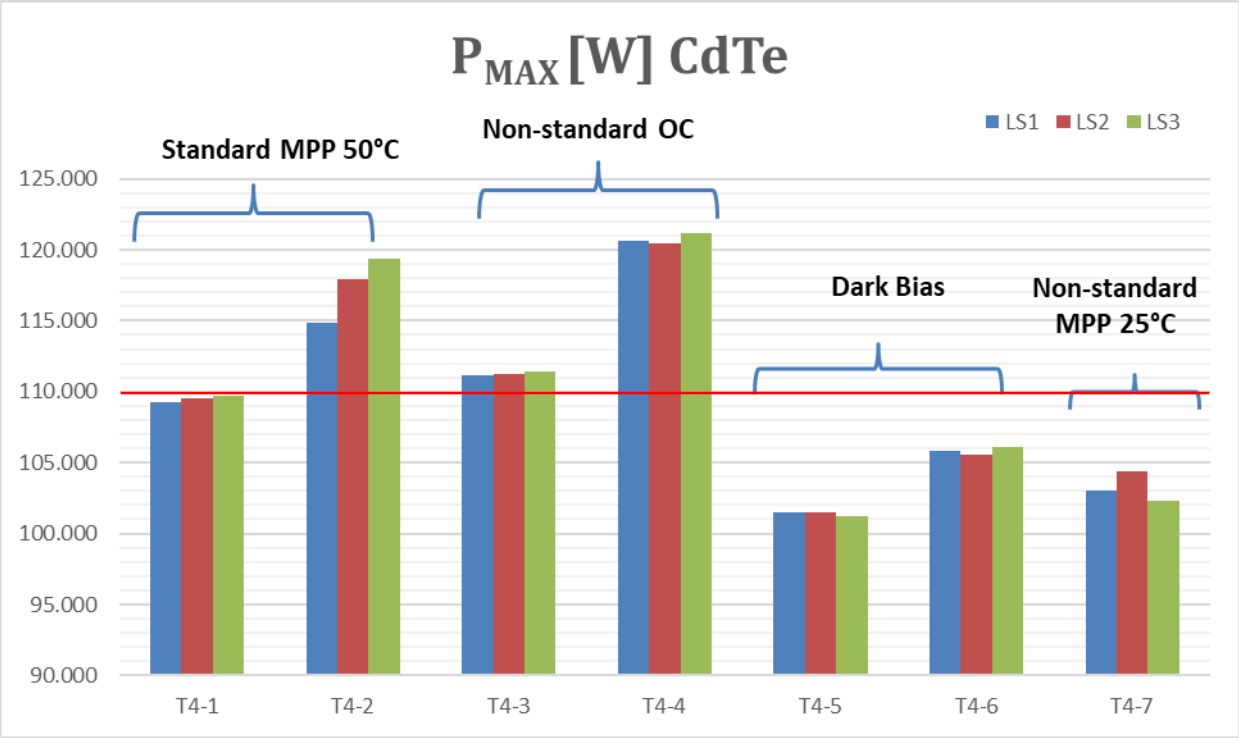

P MAX [W] CZTS
Standard MPP 50°C
LS1 LS2 LS3
Dark Bias
Non-standard MPP 25°C
Non-standard OC
0.4600
0.4500
0.4400
0.4300
0.4200
0.4100
0.4000
0.3900
0.3800
0.3700
0.3600
T1-1
T1-2
T1-3
T1-4
T1-5
T1-6
T1-7
T1-8


P MAX [W] CIGS 2
Standard MPP 50°C
LS1
LS2
LS3
Non-standard OC
Dark Bias
Non-standard MPP 25°C
180.000
175.000
170.000
165.000
160.000
155.000
T3-1
T3-2
T3-3
T3-4
T3-5
T3-6
T3-7
T3-8


P MAX [W] CIGS 1
Standard MPP 50°C
Non-standard OC
Dark Bias
Non-standard MPP 25°C
LS1
LS2
LS3
145.000
144.000
143.000
142.000
141.000
140.000
139.000
138.000
137.000
136.000
T2-1
T2-2
T2-3
T2-4
T2-5
T2-6
T2-7
T2-8


P MAX [W] CdTe
LS1
LS2
LS3
Standard MPP 50°C
Non-standard OC
Dark Bias
Non-standard MPP 25°C
125.000
120.000
115.000
110.000
105.000
100.000
95.000
90.000
T4-1
T4-2
T4-3
T4-4
T4-5
T4-6
T4-7

LAB C SUMMARY

25.05.2020:
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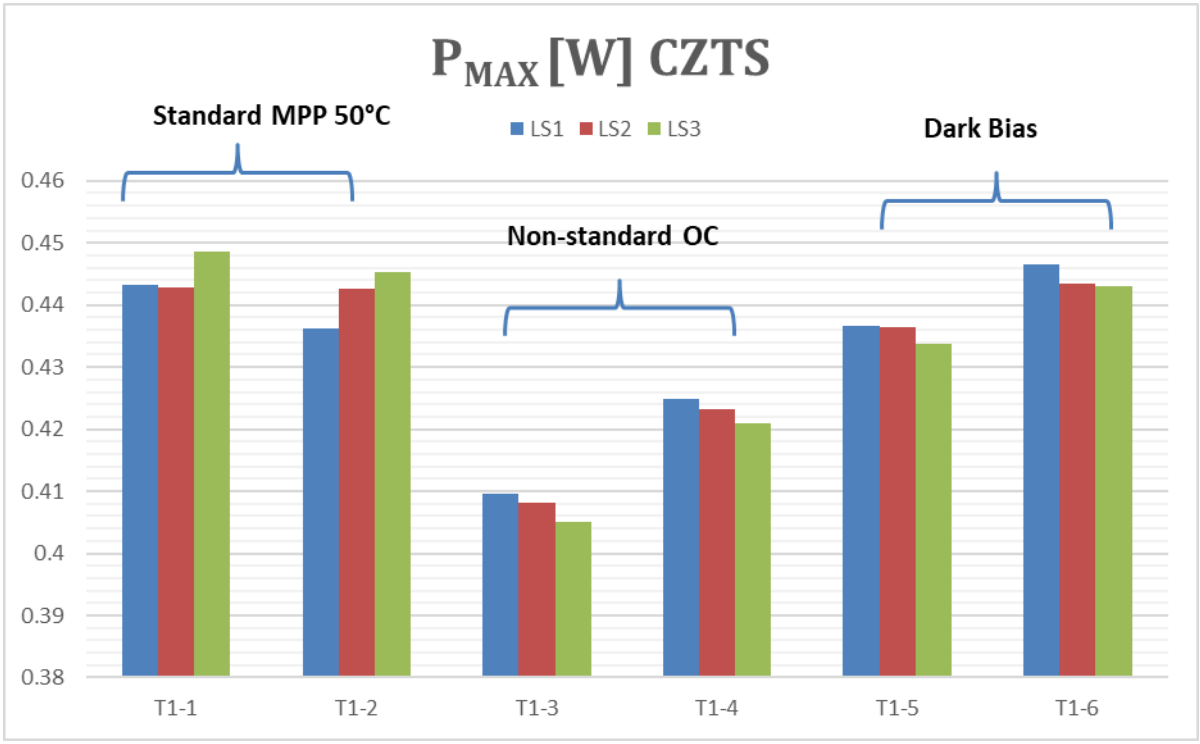
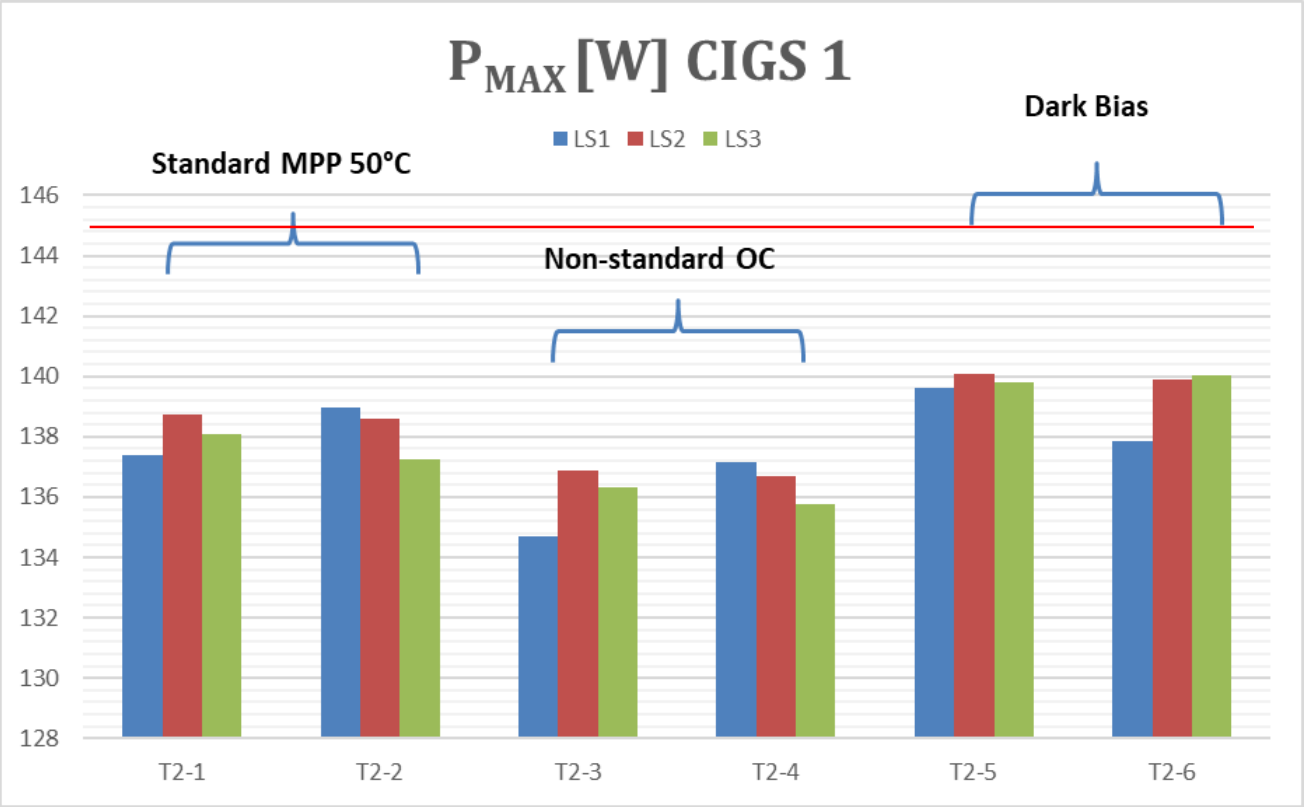
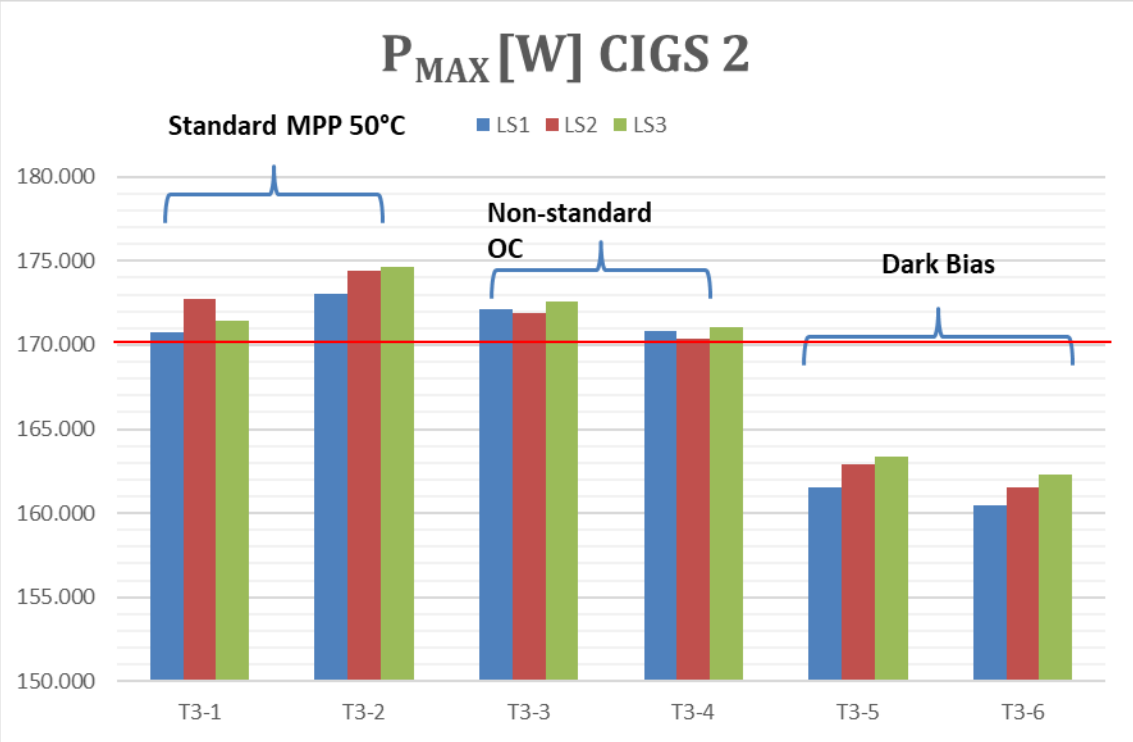
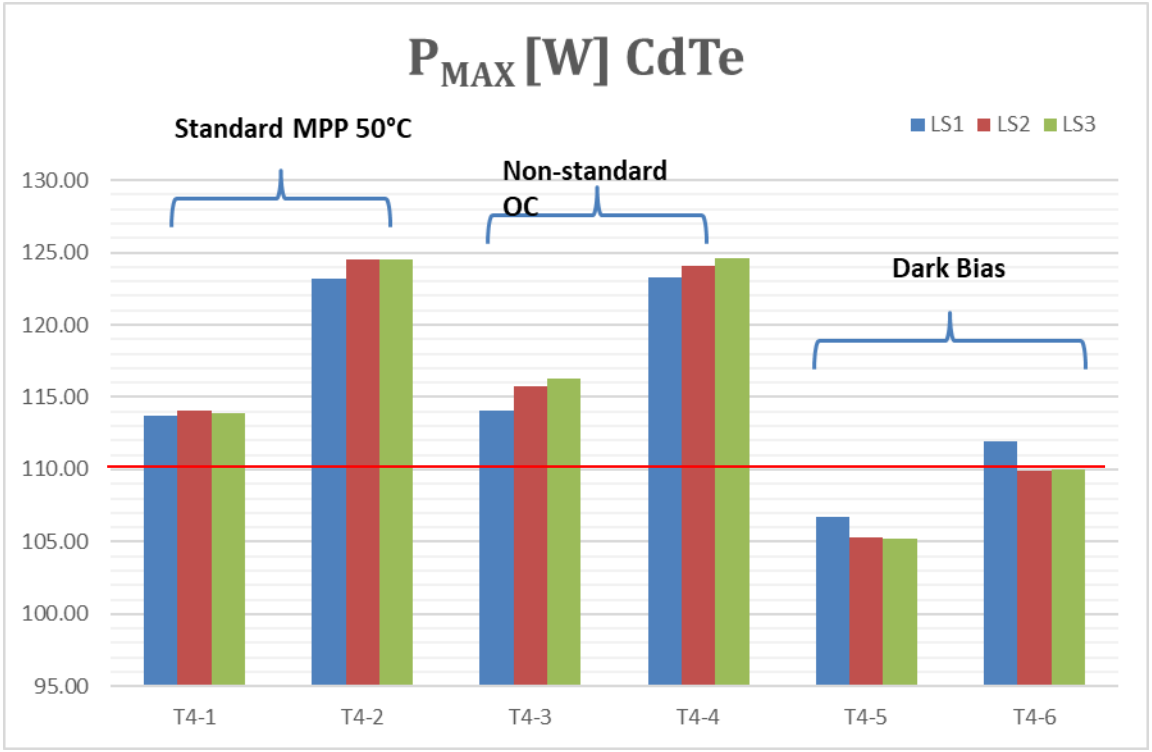
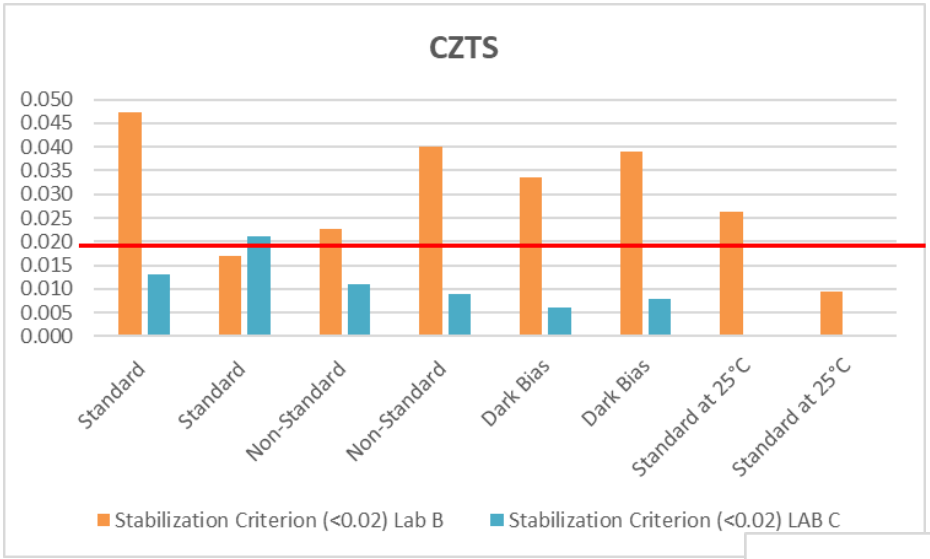

P MAX [W] CZTS
Standard MPP 50°C
LS1 LS2 LS3
Dark Bias
Non-standard OC
0.46
0.45
0.44
0.43
0.42
0.41
0.4
0.39
0.38
T1-1
T1-2
T1-3
T1-4
T1-5
T1-6

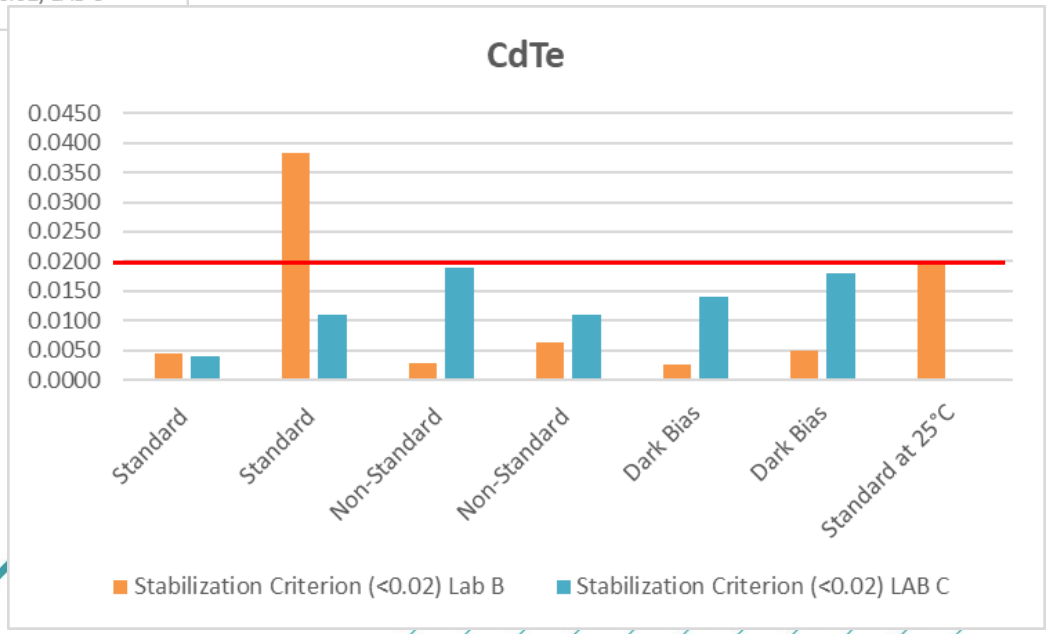

P MAX [W] CIGS 1
LS1
LS2
LS3
Standard MPP 50°C
Non-standard OC
Dark Bias
146
144
142
140
138
136
134
132
130
128
T2-1
T2-2
T2-3
T2-4
T2-5
T2-6


P MAX [W] CIGS 2
Standard MPP 50°C
LS1
LS2
LS3
180.000
175.000
170.000
165.000
160.000
155.000
150.000
Non-standard
OC
Dark Bias
T3-1
T3-2
T3-3
T3-4
T3-5
T3-6

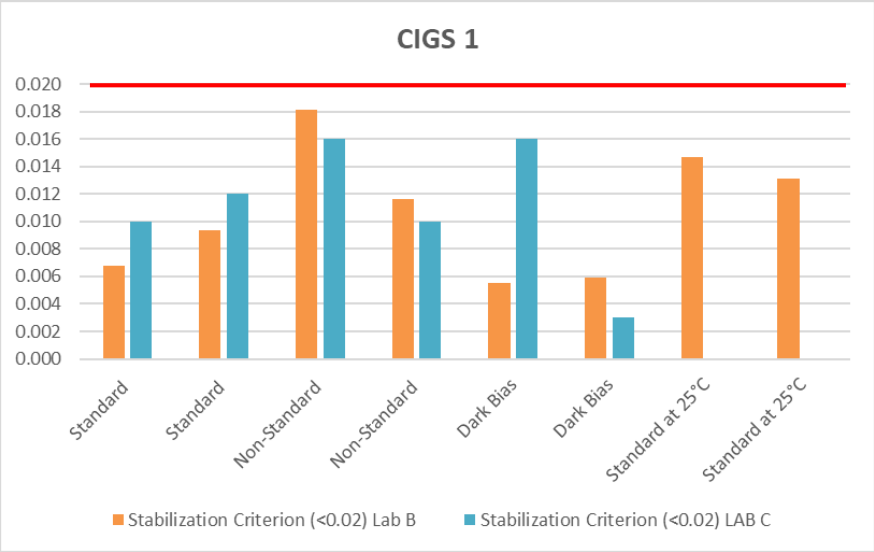

P MAX [W] CdTe
Standard MPP 50°C
Non-standard OC
Dark Bias
LS1
LS2
LS3
130.00
125.00
120.00
115.00
110.00
105.00
100.00
95.00
T4-1
T4-2
T4-3
T4-4
T4-5
T4-6

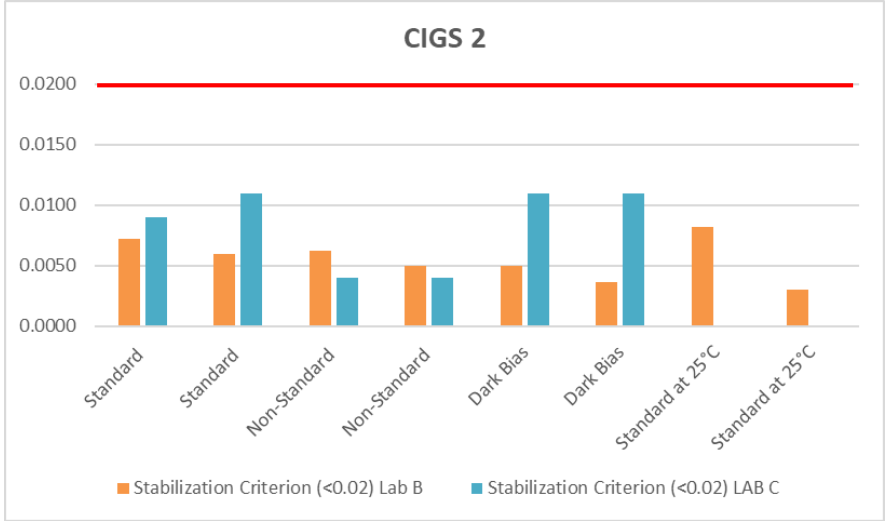
Stabilisation criterion





Stabilisation criterion





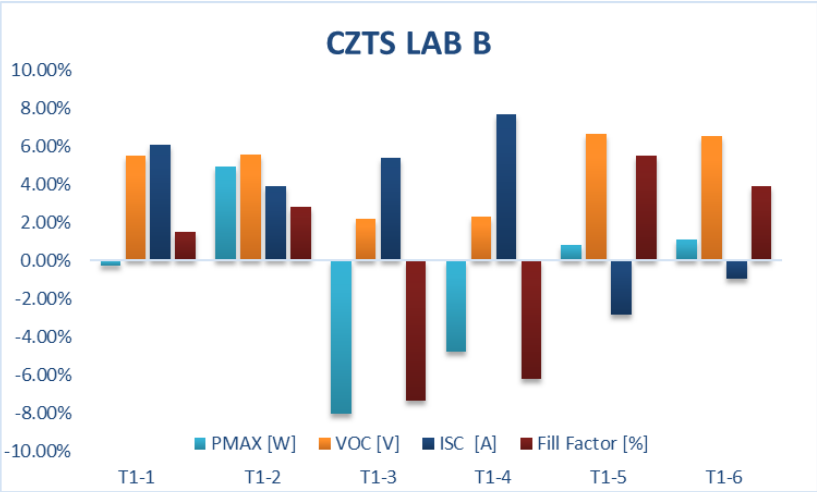
Preconditioning procedure	Technology	Stabilization Criterion (<0.02) LAB B	Stabilization Criterion (<0.02) LAB C
Standard	CIGS 2	0.0072	0.0090
Standard	CIGS 2	0.0060	0.0110
Non-Standard	CIGS 2	0.0063	0.0040
Non-Standard	CIGS 2	0.005	0.004
Dark Bias	CIGS 2	0.0050	0.0110
Dark Bias	CIGS 2	0.0037	0.0110
Standard at 25°C	CIGS 2	0.0082	
Standard at 25°C	CIGS 2	0.0030	

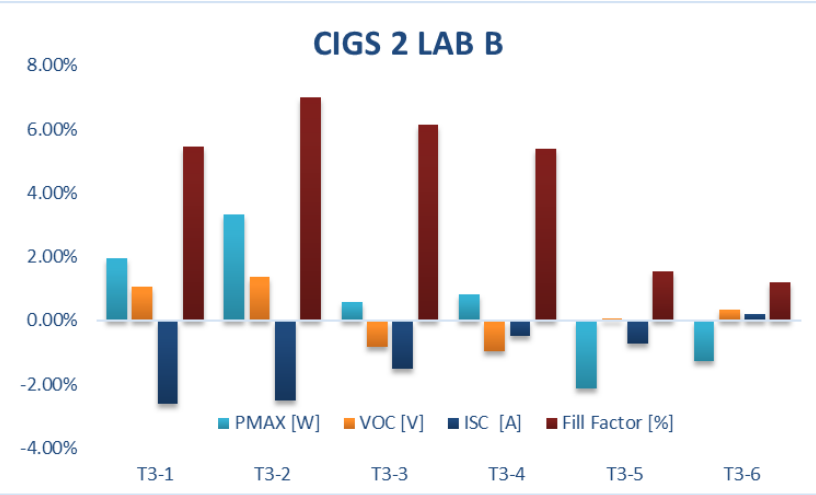
Preconditioning procedure	Technology	Stabilization Criterion (<0.02) LAB B	Stabilization Criterion (<0.02) LAB C
Standard	CdTe	0.0044	0.0040
Standard	CdTe	0.0384	0.0110
Non-Standard	CdTe	0.0028	0.0190
Non-Standard	CdTe	0.0063	0.0110
Dark Bias	CdTe	0.0025	0.0140
Dark Bias	CdTe	0.0050	0.0180
Standard at 25°C	CdTe	0.0198	
Standard at 25°C	CdTe		

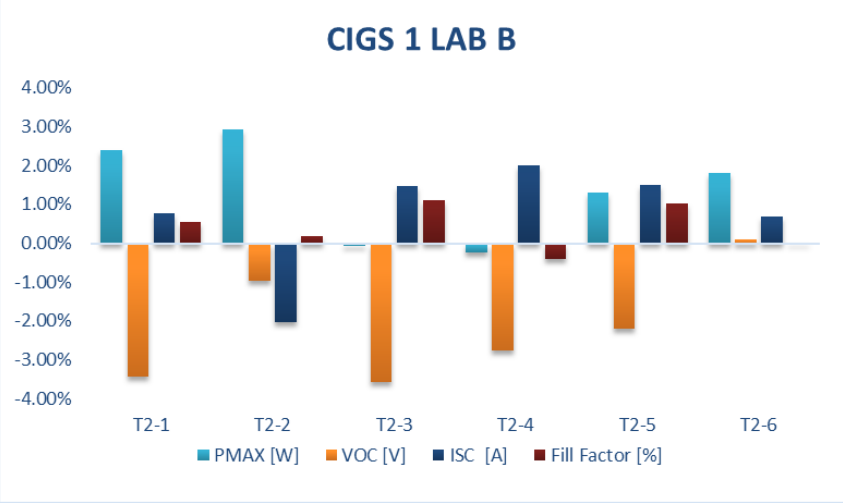
Preconditioning procedure	Technology	Stabilization Criterion (<0.02) Lab B	Stabilization Criterion (<0.02) LAB C
Standard	CZTS	0.047	0.013
Standard	CZTS	0.017	0.021
Non-Standard	CZTS	0.023	0.011
Non-Standard	CZTS	0.040	0.009
Dark Bias	CZTS	0.033	0.006
Dark Bias	CZTS	0.039	0.008
Standard at 25°C	CZTS	0.026	
Standard at 25°C	CZTS	0.009	

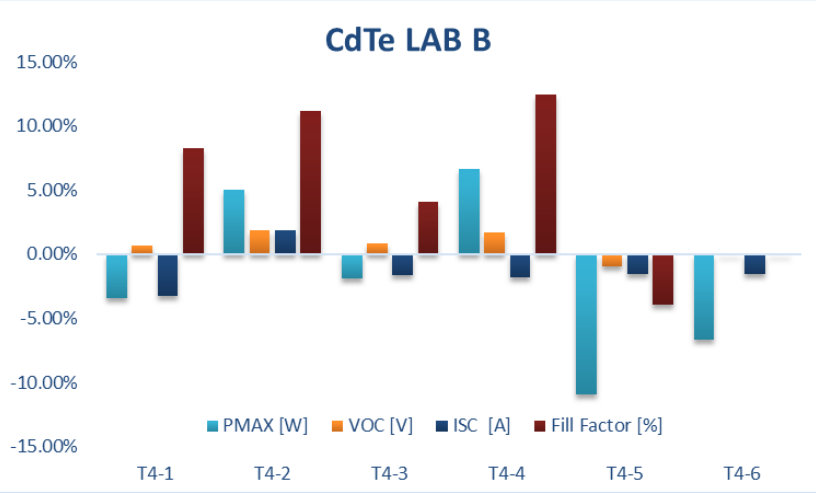
Preconditioning procedure	Technology	Stabilization Criterion (<0.02) LAB B	Stabilization Criterion (<0.02) LAB C
Standard	CIGS 1	0.007	0.010
Standard	CIGS 1	0.009	0.012
Non-Standard	CIGS 1	0.018	0.016
Non-Standard	CIGS 1	0.012	0.010
Dark Bias	CIGS 1	0.006	0.016
Dark Bias	CIGS 1	0.006	0.003
Standard at 25°C	CIGS 1	0.015	
Standard at 25°C	CIGS 1	0.013	

LAB B Deviation from Average value

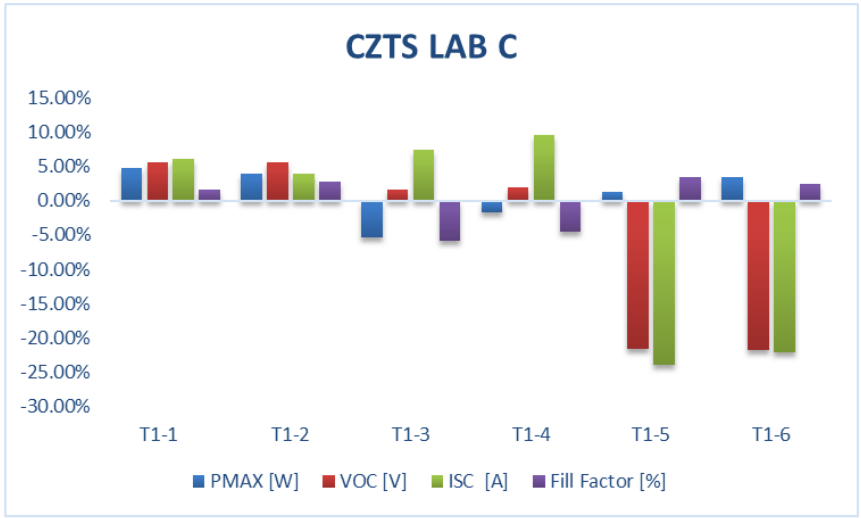


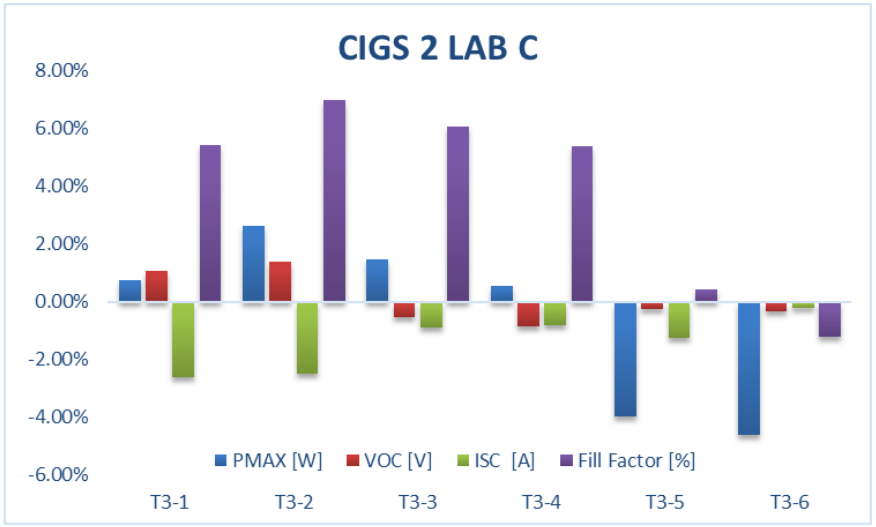


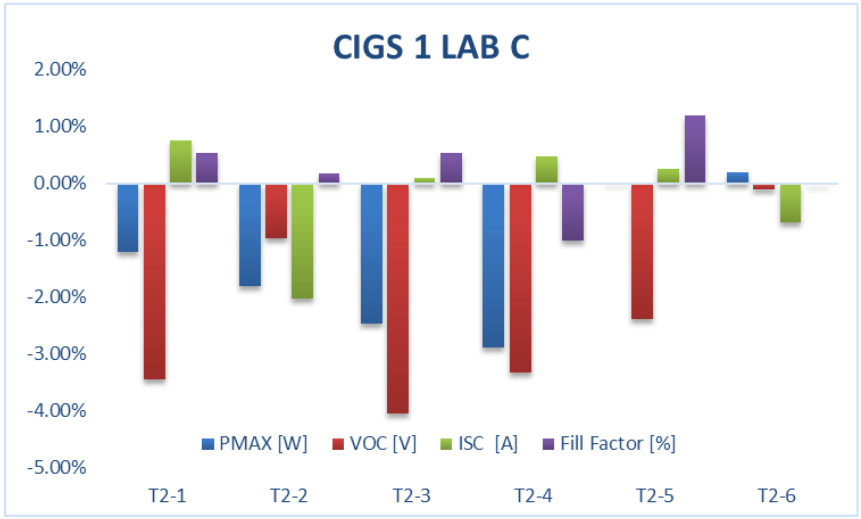


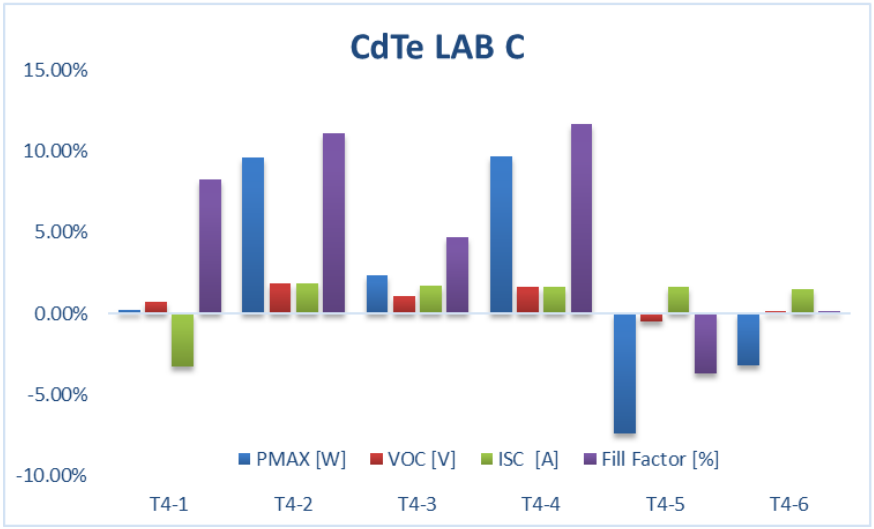


LAB C Deviation from Average Value

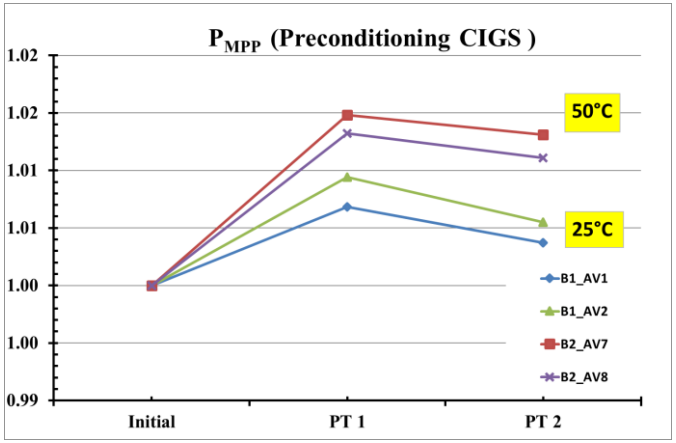




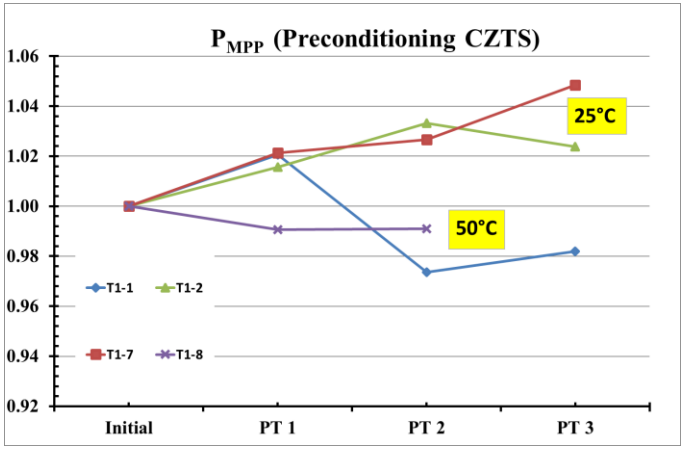




Comparison of Preconditioning procedure at 50ºC and 25ºC



P_{MPP} [W]



P_{MPP} [W]

CONCLUSIONS

We conclude that both, **temperature** and **high irradiance** influence strongly the power output measurement, driving several microscopic mechanisms. A reliable and harmonized method for accurate power rating of thin-film modules is necessary for minimizing uncertainties.

Possible routes of solution seem to follow two ways of understanding:

(i) Reproduction of the state of the module in the field

(ii) Reproduction of an electrical state per se

The emphasis of the work on thin film module power rating and its initial stabilization should go back to the idea of standardized reproducibility in the lab, which is route (ii).

Thank you for your attention!

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