QUALITY CONTROL TESTS FOR IV CURVES AND EXTRACTION OF MODELING PARAMETERS FOR FIVE PHOTOVOLTAIC TECHNOLOGIES AT SIRTA, PALAISEAU

MUHAMMAD AMMAR KHAN (muhammad-ammar.khan@polytechnique.edu) – Laboratoire de Météorologie Dynamique, LMD
Jordi Badosa (LMD), Anne Migan (GEEPS), Vincent Bourdin (LIMSI) – Supervisors

INTRODUCTION

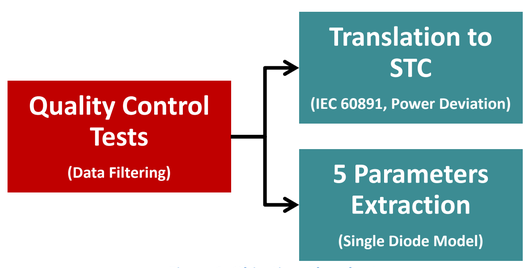
At SIRTA Observatory, a photovoltaics test bench comprising of 5 commercial modules of different technologies was set up. This test bench allowed continuous monitoring of current-voltage (I-V) characteristics of modules along with a number of different of meteorological parameters. Main Characteristics of the five modules are listed in Table 1 whereas Figure 1 shows there arrangement at the observatory.

Name	Technology	I_{SC} (A)	V_{OC} (V)	P_{MAX} (W)
Sharp	Tandem Microamorphous (a-Si/μ-Si)	3.45	59.80	128
FranceWatts	Monocrystalline silicon (c-Si)	8.64	37.67	250
SolarFrontier	Thin Film chalcogenide (CIS)	2.20	108.0	150
Panasonic	Heterojunction Silicon/ Amorphous (HIT)	5.85	52.40	240
FirstSolar	Thin Film cadmium telluride (CdTe)	1.94	60.80	82.5

Table 1: Characteristics of Five modules at SIRTA Observatory

OBJECTIVES

Availability of large data sets generated an opportunity to perform a study to develop quality control tests for I-V curves and to extract modelling parameters.



STC refers to Standard Conditions where Irradiance = **1000 W/m²** and Temperature = **25 ° C**

Extraction refers to employment of model to estimate parameters values

Figure 1: Objectives Flowchart

METHODOLOGY

Quality Control Tests

Quality Control Filters were developed using the information and requirements highlighted in:

a. International Standards (IEC 61724)[1]
   i. IEC 61724
   ii. Australian Technical Guidelines for Photovoltaics. [2]
b. Best Practices [4] and Previous Works
c. Self-Analysis

Filters were applied to the data of all 5 technologies and results were compared.

Translation to STC

Using Procedure 1 and 2 explained in IEC 60891[3], measured IV curves were translated to STC and;

a. Comparison between Procedure 1 and 2 conducted
b. Maximum Power Point (P_{MAX}) of translated IV curves was calculated and deviation from datasheet provided P_{MAX} for all 5 technologies was analyzed.

Procedure 1 – Correction Equations

$$I_2 = I_1 + I_{SC}.\left(\frac{G_2}{G_1} - 1\right) + \alpha.(T_2 - T_1)$$

$$V_2 = V_1 - R_S.(I_2 - I_1) - \kappa.I_2.(T_2 - T_1) + \beta.(T_2 - T_1)$$

Procedure 2 – Correction Equations

$$I_2 = I_1.(1 + \alpha.(T_2 - T_1)).\left(\frac{G_2}{G_1}\right)$$

$$V_2 = V_1 + V_{OC1}.\left(\beta.(T_2 - T_1) + a.ln\left(\frac{G_2}{G_1}\right)\right) - R'_S.(I_2 - I_1) - \kappa'.I_2.(T_2 - T_1)$$

5 Parameters Extraction

Estimation of characteristic parameters using Single Diode Model, which is one of most basic equivalent circuit model including:

a. Current Source (I_{PV})
b. Diode (having current I_D)
c. Series Resistance (R_S)
d. Parallel Resistance (R_P)

Parameters were extracted using two estimation methods.

i. Method 1 involved use of Gaussian Iterations to solve the equations for finding unknown parameters.
ii. Method 2 involved matching of maximum power point to determine the unknown parameters.

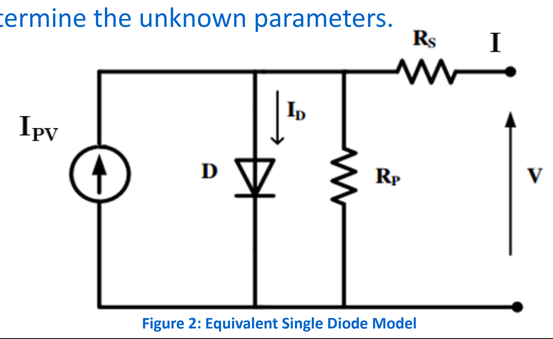


Figure 2: Equivalent Single Diode Model

RESULTS

Quality Control Tests

Total of **14** filters were developed (shown in Flowchart below)

- V_{OC} = Open Circuit Voltage Point
- I_{SC} = Short Circuit Current Point
- P_{MAX} = Maximum Power Point
- Some key points of an IV curve and used in filters are highlighted on the right
- POA = Plane of Array Irradiance in W/m²
- T_P = Panel Temperature in ° C
- PCHIP = Piece wise cubic hermite interpolating polynomial used for defining shape of an IV curve
- $I_{SC,Modelled} = I_{SC,STC} * \frac{POA}{1000}$

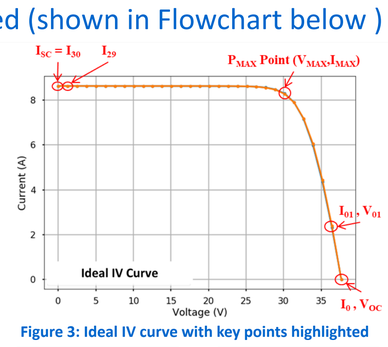


Figure 3: Ideal IV curve with key points highlighted

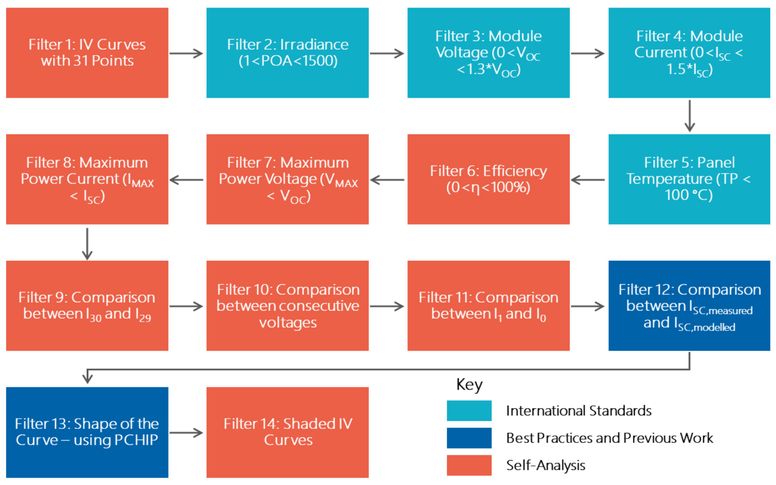


Figure 4: Quality Control Filters in methodological order

Result of Filters - 2018	
Technology	% Data Filtered
Sharp (a-Si/μc-Si)	36%
FranceWatts (c-Si)	25%
SolarFrontier (CIS)	47%
Panasonic (HIT)	26%
FirstSolar (CdTe)	37%

Table 2: Results of Filters

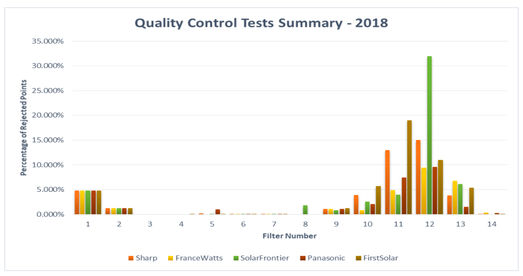


Figure 5: Summary of Quality Control Tests

Translation to STC

Values of Correction Factors for STC Translation					
Correction Factor	Sharp	FranceWatts	SolarFrontier	Panasonic	FirstSolar
	Tandem (a-Si/μ-Si)	Monocrystalline (c-Si)	Thin Film (CIS)	Heterojunction (HIT)	Thin Film (CdTe)
Procedure 1					
R_S (Ω)	4.150	0.454	6.480	0.600	4.375
K (Ω/° C)	-0.034	0.016	-0.089	0.027	0.064
Procedure 2					
a	0.040	0.035	0.054	0.035	0.027
R'$_S$ (Ω)	1.298	0.367	3.253	0.296	1.401
K' (Ω/° C)	-0.031	0.018	-0.134	0.023	0.073

Table 3: Values of Correction Factors for Procedure 1 and Procedure 2

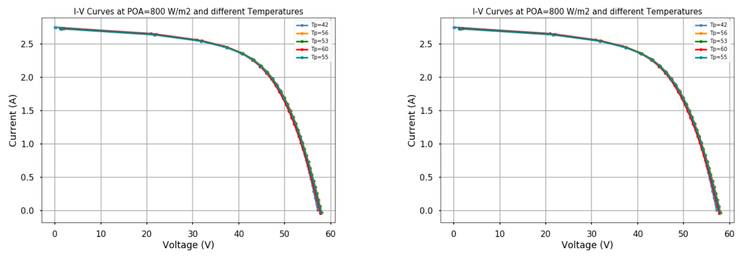


Figure 3: Translation of measured IV curves to STC using Procedure 1 (left) and Procedure 2 (right)

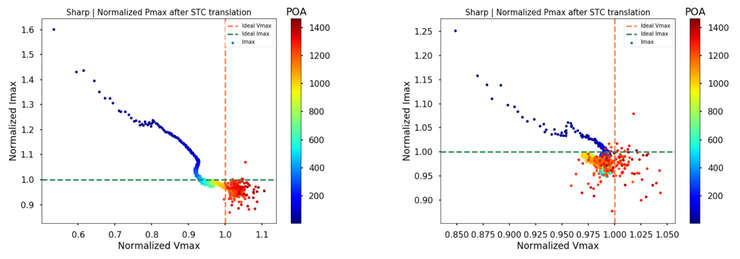


Figure 4: Normalized P_{MAX} after STC translation using Procedure 1 (left) and Procedure 2 (right) grouped by changes in POA

Technology	Sharp	FranceWatts	SolarFrontier	Panasonic	FirstSolar
% of Points having P_{MAX} Deviation <=10%	94%	59%	94%	86%	76%

Table 4: % of Total Points having P_{MAX} Deviation <=10 for all 5 technologies

Five Parameters

Step 1: Estimation of Parameters at STC

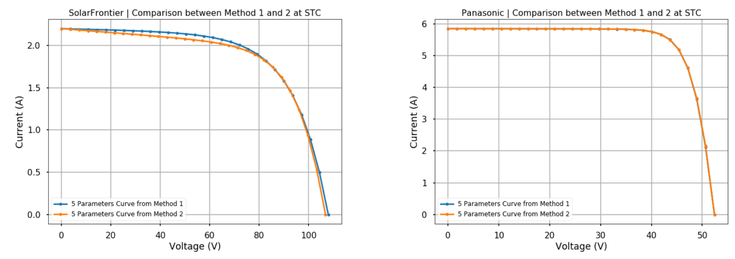


Figure 5: IV Plots using Estimation Method 1 and 2 for SolarFrontier (left) and Panasonic (right) at STC

Step 2: Estimation of Parameters using measured IV Curves

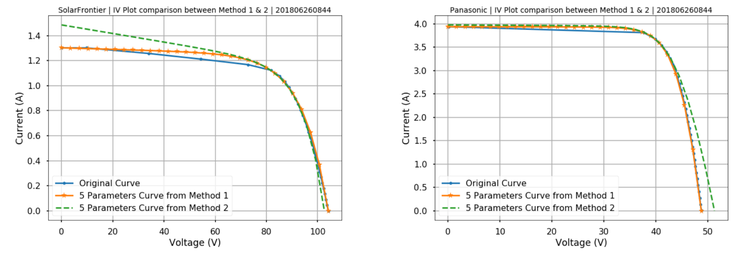


Figure 6: IV Plots using Estimation Methods 1 and 2 for SolarFrontier (left) and Panasonic (right) at 08:44 am 26th July, 2018

Values of 5 Parameters at STC						
Technology	**Method**	I_{PV} (A)	I_0 (A)	R_S (Ω)	R_P (Ω)	A
Sharp	1	3.45	0.000504	0.04932	184	1.48
	2	3.45	0.000165	0.151	155	1.30
FranceWatts	1	8.64	2.77e-11	0.348	3803	0.92
	2	8.64	2.11e-11	0.315	21825	1.00
SolarFrontier	1	2.20	0.000654	0.0499	1466	2.89
	2	2.21	0.000033	1.00	437	2.10
Panasonic	1	5.85	4.87e-09	0.287	3641	1.36
	2	5.85	9.55e-09	0.257	5853	1.40
FirstSolar	1	1.94	0.000011	0.049	370	1.28
	2	1.94	0.000014	0.034	815	1.30

Table 5: Values of 5 Parameters using Method 1 and Method 2 at STC

CONCLUSION

- Quality Control tests removed anomalies from data which was used for modelling. Technologies with lower value of I_{SC} are more sensitive to irradiance and have maximum percentage of data filtered.
- Procedure 2 of IEC 60891 is more suitable for STC Translation having less PMAX deviation and better fit of IV curves. FranceWatts have maximum P_{MAX} deviation and should be monitored to determine reason of performance losses.
- Estimation Method 1 is more suitable for determining parameter values at STC or any time step using measured IV curves as compared to Method 2.
- Values of parameters at STC can be set as reference and used with models like De Soto to predict IV Characteristics.

REFERENCES

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4. Gabi Friesen, W. H. (2018). Photovoltaic Module Energy Yield Measurements: Existing Approaches and Best Practice. INTERNATIONAL ENERGY AGENCY PHOTOVOLTAIC POWER SYSTEMS PROGRAMME, 1-134.

REMERCIEMENTS

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