

# GENERATING MODULE FILES IN PLANTPREDICT

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LEADING THE WORLD'S  
SUSTAINABLE ENERGY FUTURE



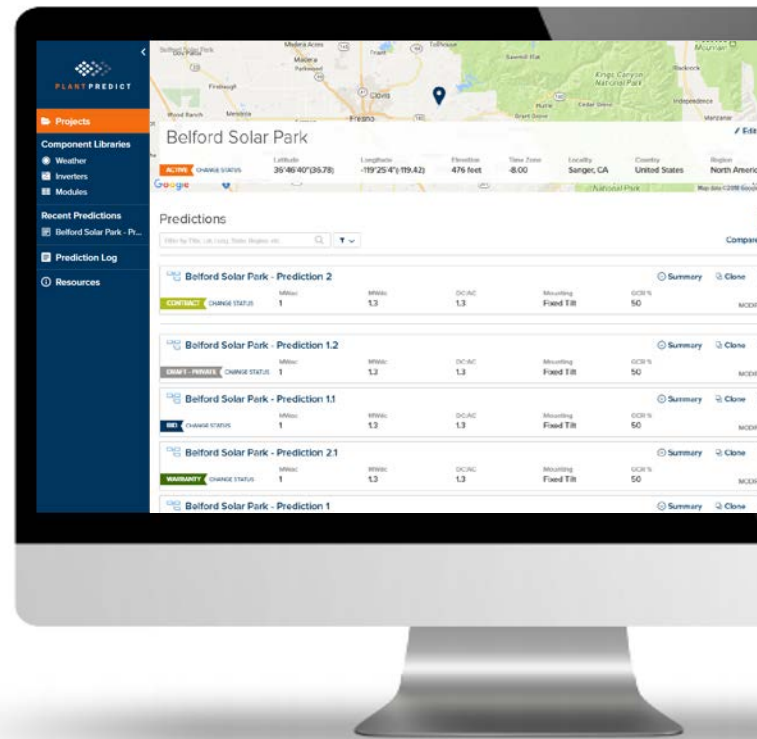
# TOPICS OF DISCUSSION

- PlantPredict Introduction
- New & Upcoming Features
- **Generating Module Files in PlantPredict**



# INTRODUCING PLANTPREDICT

- Free, cloud-hosted, energy prediction software for **utility-scale** PV power plants
- Used in over 350 MWAC of contracted utility-scale PV projects
- All algorithms documented and published on [www.plantpredict.com](http://www.plantpredict.com)
- *End-to-end utility-scale modeling*
  - Sub-hourly and multi-year predictions
  - Built-in spectral correction
  - No need for pre- or post-processing
  - Pre-loaded with industry-standard weather, module, and inverter files
- API available for automation
- Independently reviewed and benchmarked against over 1 GW of operating facilities



Reviewed by:





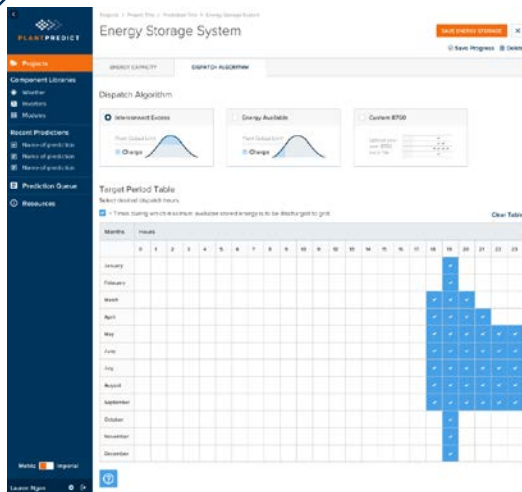
## NEW FEATURES IN PLANTPREDICT

# Recently-Added Features

## PV Energy Storage

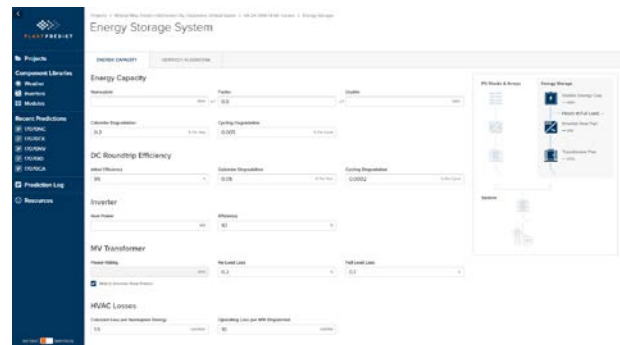
## Module File Generator

## Bifacial PV



### Charging/Dispatch Options

1. LGIA Excess
2. Energy Available
3. Custom



### AC-coupled storage systems

*More storage modeling features planned for release in September 2019.*

# Recently-Added Features

PV Energy Storage

*Module File Generator*

Bifacial PV

The screenshot displays the 'Module Generator' software interface. It is divided into several sections:

- General Characteristics:** Includes fields for Cell Technology (C-G6), Number of Cells in Series (82), Model Type (1Diode Recombination), and Maximum Power (14.12968062).
- Electrical Data at STC:** Lists parameters like  $V_{oc}$  (89.76294672),  $V_{mp}$  (72.03893574), and  $I_{sc}$  (1.5281012918).
- Temperature Coeffs.:** Shows coefficients for Power Temp. Coeff. (-0.34023448370320434),  $V_{oc}$  Temp. Coeff. (0.002747479008842), and  $I_{sc}$  Temp. Coeff. (0.0459185187692).
- 1-Diode Parameters:** Configures parameters such as Series Resistance at STC (0.443), Recombination Transition (1.6187000000000000E-08), and Dark Saturation Current (1000).
- Calculated Performance:** Features a graph of Current (A) vs. Voltage (V) and a table of performance metrics:
 

Module Temp.	Incidence	Max Power	$V_{oc}$	$I_{sc}$	Max Temp. Coeff.	$V_{oc}$ Temp. Coeff.
25	1000	14.13	89.76	1.53	-0.34	0.0027
- 1-Diode Parameters (Simulation):** A table showing simulation results for different temperatures:
 

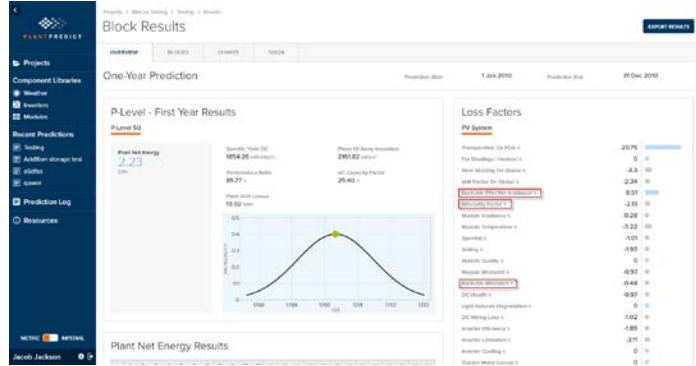
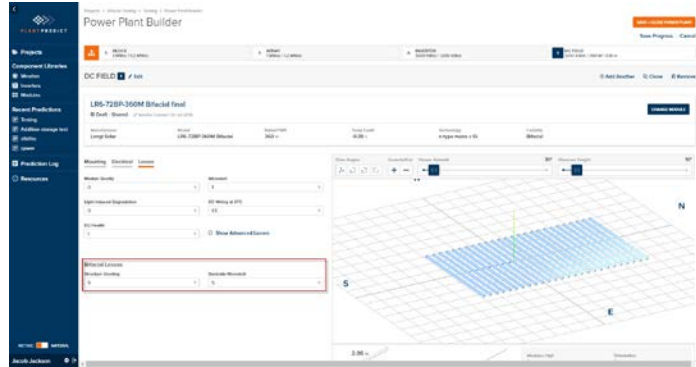
Temperature	Series Resistance at STC	Recombination Trans.	Dark Resistance at STC	Eq. Area of Short Circuit	Dark Sat. Recomb.
25	0.443	1.6187000000000000E-08	1000	0.5	10000

# Recently-Added Features

PV Energy Storage

Module File Generator

*Bifacial PV*



Model

*NREL 2D View Factor Model*

New Module Properties

*“Bifaciality”*

*Transmission Factor*

New DC Field Properties

*Structure Shading*

*Backside Mismatch*

*Post Height*



**COMING SOON TO PLANTPREDICT**



# Upcoming Features in 2019

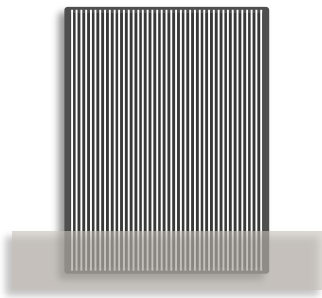
## Electrical (c-Si) Shading

### New Time Series Inputs

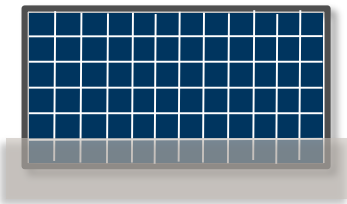
- Tracker Angle
- Plant Output Limit
- Inverter Set Point
- Module Surface Temperature
- Albedo (?)

Sloped Tables

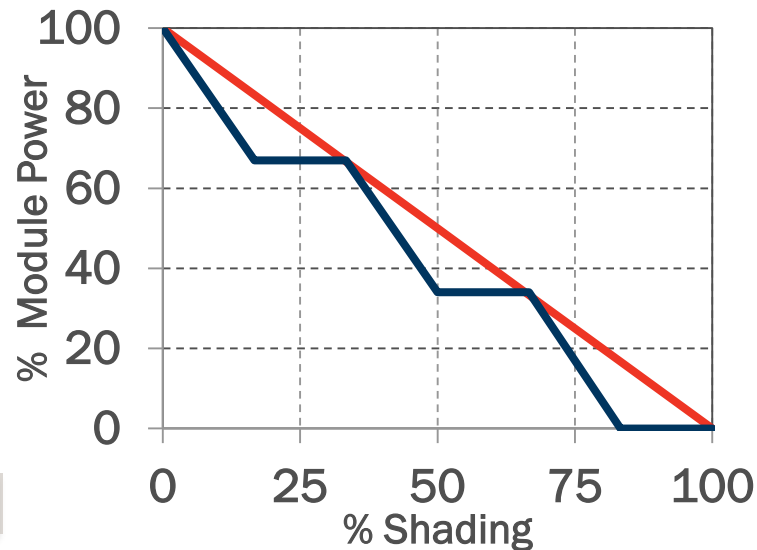
Object Shading



CdTe – linear shading



c-Si – nonlinear shading  
(bypass diodes)



# Upcoming Features in 2019

## Electrical (c-Si) Shading

### New Time Series Inputs

- *Tracker Angle*
- *Plant Output Limit*
- *Inverter Set Point*
- *Module Surface Temperature*
- *Albedo (?)*

## Sloped Tables

## Object Shading



	A	B	C	D	K	L	M	N	O
1	Station Type	Latitude (dd)	Longitude (d)	Time Stamp	Mounting Technology	Rotational Limits Min	Rotational Limits Max	Tracking Method	Tilt Angle
2	NREL	15.84	78.03	IntervalBegin	Tracker	-60	60	True-Tracking	
3	MM/DD/YYYY	hh:mm:ss	GHI (W/m <sup>2</sup> )	Temp (°C)	POAI (W/m <sup>2</sup> )	Tracker Angle (°)	Plant Output Limit (kwh)	Inverter Set Point (kw)	Module Surface Temp. (°C)
4	1/1/2010	0:00:00	0	5.7	0	-60	0	0	0
5	1/1/2010	1:00:00	0	5.8	0	-60	0	0	0
6	1/1/2010	2:00:00	0	5.9	0	-60	0	0	0
7	1/1/2010	3:00:00	0	7	0	-60	0	0	0
8	1/1/2010	4:00:00	0	5	0	-60	0	0	0
9	1/1/2010	5:00:00	0	6	0	-60	0	0	0
10	1/1/2010	6:00:00	0	6	0	-60	0	0	0
11	1/1/2010	7:00:00	71	5	67.21342852	-55	1000	800	50
12	1/1/2010	8:00:00	238	7	238.1915783	-45	1000	800	51
13	1/1/2010	9:00:00	395	8	421.4376151	-40	1000	790	52

# Upcoming Features in 2019

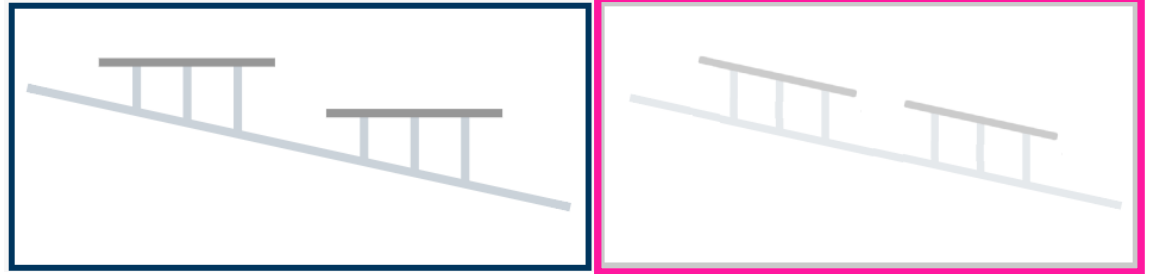
## Electrical (c-Si) Shading

## New Time Series Inputs

- Tracker Angle
- Plant Output Limit
- Inverter Set Point
- Module Surface Temperature
- Albedo (?)

## *Sloped Tables*

## Object Shading



Available in PlantPredict

Coming Soon!

# Upcoming Features in 2019

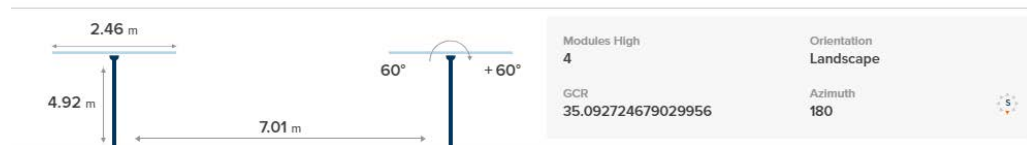
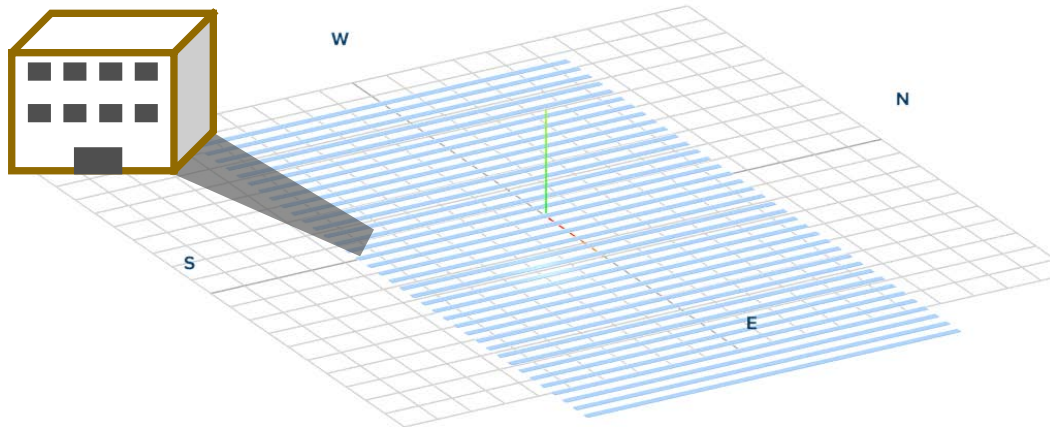
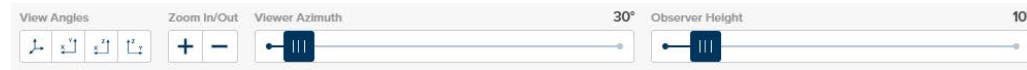
## Electrical (c-Si) Shading

## New Time Series Inputs

- Tracker Angle
- Plant Output Limit
- Inverter Set Point
- Module Surface Temperature
- Albedo (?)

## Sloped Tables

## Object Shading





# GENERATING MODULE FILES IN PLANTPREDICT

# Comparing Existing PV Module Modeling Tools



System Advisor Model (SAM)



	PVLIB	NREL SAM	PVsyst	PlantPredict
Open-Source/Free	✓	✓		✓
Software Library (SDK)	✓	✓		✓
IEC-61853-1 Data Input		✓		✓
IV Curve Input			only @ STC	✓
Optional Recombination Term?	Only for explicit IV curve calculation		✓	✓
Performance Optimization Tools		limited	✓	✓
Graphics/Visualization		✓	✓	✓

<https://pvpmc.sandia.gov>

<https://sam.nrel.gov/>

<http://www.pvsyst.com>

<https://www.plantpredict.com>

# Problem Statement

I know how a module performs based on laboratory measurements...

How can I take a limited set of module electrical characteristics and generate a model that accurately represents the expected performance?

**FIRST SOLAR SERIES 6™**

**WARRANTY**

**WARRANTY PERIOD** 10 Years (120 Months) or 100,000 Hours (100,000 Hours)

PARAMETER	10 Years (120 Months)	100,000 Hours
Power (P <sub>max</sub> )	420.0 W	420.0 W
Efficiency (%)	21.2	21.2
Voltage at P <sub>max</sub> (V <sub>mp</sub> )	37.4 V	37.4 V
Current at P <sub>max</sub> (I <sub>mp</sub> )	11.22 A	11.22 A
Open Circuit Voltage (V <sub>oc</sub> )	45.4 V	45.4 V
Short Circuit Current (I <sub>sc</sub> )	11.95 A	11.95 A
Maximum System Voltage (V <sub>max</sub> )	1000 V	1000 V
Working Voltage (V <sub>m</sub> )	800 V	800 V
Minimum System Voltage (V <sub>min</sub> )	0 V	0 V
Working Voltage Range (V <sub>m</sub> )	0 V	0 V

**MECHANICAL DRAWING**

Width: 1524mm  
Thickness: 40mm  
Area: 2.31m<sup>2</sup>  
Module Weight: 20kg  
Layers: 2 (Glass (1) & Backsheet (1))  
Glass: MC4 (100)  
Backsheet: TPO (100)  
Cells: 60 (6x10)  
Cells per Module: 60  
Cells per String: 60  
Cells per Panel: 60  
Cells per Array: 60  
Cells per String: 60  
Cells per Panel: 60  
Cells per Array: 60



**FS-6430 CdTe Dec2017**

**NON-LINEAR TEMPERATURE COEFFICIENT**

TEMPERATURE (°C)	EFFICIENCY (%)
0	21.2
10	21.2
20	21.2
30	21.2
40	21.2
50	21.2
60	21.2
70	21.2
80	21.2
90	21.2
100	21.2
110	21.2
120	21.2
130	21.2
140	21.2
150	21.2
160	21.2
170	21.2
180	21.2
190	21.2
200	21.2
210	21.2
220	21.2
230	21.2
240	21.2
250	21.2
260	21.2
270	21.2
280	21.2
290	21.2
300	21.2

# Modeling a PV Module

What is a “module file”? The entity used in PlantPredict to model a PV module.

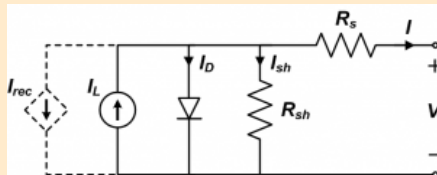
## INPUTS

- STC Electrical Characteristics
- non-STC performance (low-light efficiency, temperature coefficients)
- # Cells in Series

\*describe expected performance but not used by simulation engine to calculate DC field power

## MODEL

- Single Diode Equivalent Circuit Model
- optional recombination term
- linear temperature dependence on the diode ideality factor (“ $\mu_V$ ”)
- DeSoto 5-parameter model for temperature/irradiance adjustment



## OUTPUTS (1-diode params)

- Series Resistance
- Shunt Resistance
- Diode Saturation Current
- Diode Ideality Factor (and temperature coefficient)
- Recombination Parameter
- Light-Generated Current

\*single diode parameters are used by prediction engine and determine actual performance; “model-calculated” MPP, etc.

## Resources

“Performance Assessment of a Simulation Model for PV Modules of Any Available Technology” (Mermoud et al.)

“Improvement and validation of a model for photovoltaic array performance” (De Soto et al.)

“Parameter Estimation for Single Diode Models of Photovoltaic Modules” (Hansen)

“Handbook of Photovoltaic Science and Engineering” (Gray et al.)

“Single Diode Equivalent Circuit Models” – PVPMC Website (<https://pvpmc.sandia.gov>)



# Manufacturer Datasheet as Input

## Data Sources/Inputs

### Manufacturer Datasheet

IEC-61853-1 Test Matrix

I-V Curve Data

## Generating a Module File

Initial Calculation with Defaults

Matching Expected Performance

What if I am given a module datasheet?

**FIRST SOLAR SERIES 6™**

**KEY FEATURES AND BENEFITS OF STANDARD TEST CONDITIONS (STC) (MPP, 1000 W/m²)**

KEYWORD VALUE	IEC 61215	IEC 61215	IEC 61215	IEC 61215	IEC 61215	IEC 61215	IEC 61215
	STC (W/m²)	STC (W/m²)	STC (W/m²)	STC (W/m²)	STC (W/m²)	STC (W/m²)	STC (W/m²)
Nominal Power (P <sub>nom</sub> )	420.0	420.0	420.0	420.0	420.0	420.0	420.0
Efficiency (%)	17.0	17.2	17.4	17.6	17.8	18.0	18.0
Voltage at Max Power (V <sub>mp</sub> )	18.64	18.65	18.67	18.69	18.71	18.73	18.75
Current at Max Power (I <sub>mp</sub> )	22.53	22.54	22.55	22.56	22.57	22.58	22.59
Open Circuit Voltage (V <sub>oc</sub> )	218.9	218.9	218.9	218.9	218.9	218.9	218.9
Short Circuit Current (I <sub>sc</sub> )	23.6	23.6	23.6	23.6	23.6	23.6	23.6
Maximum System Voltage (V <sub>max</sub> )	600V	600V	600V	600V	600V	600V	600V
Maximum System Current (I <sub>max</sub> )	6.0	6.0	6.0	6.0	6.0	6.0	6.0

**TEMPERATURE CHARACTERISTICS**

Module Operating Temperature Range (T <sub>o</sub> )	°C
Temperature Coefficient of P <sub>max</sub> (k <sub>p</sub> )	-0.22%/°C (Temperature Range: 0°C to 70°C)
Temperature Coefficient of V <sub>oc</sub> (k <sub>v</sub> )	-0.28%/°C
Temperature Coefficient of I <sub>sc</sub> (k <sub>i</sub> )	+0.04%/°C

**MECHANICAL DRAWING**

**MECHANICAL DESCRIPTION**

- Length: 2000mm
- Width: 1025mm
- Thickness: 45mm
- Area: 2.04m²
- Module Weight: 30kg
- Load: 5 kN/m² (200mm x 200mm)
- Connector: MC4-EVO 2
- Bypass Diode: N/A
- Cell Type: Mono-Si (100% monocrystalline, up to 204 cells)
- Frame Material: Anodized Aluminum
- Front Glass: 3.2mm heat strengthened
- Back Glass: 2.2mm heat strengthened
- Encapsulation: Laminated material with edge seal
- Frame to Glass Adhesive: Silicone
- Lead Pacing: 2400µm

**PACKAGING INFORMATION**

Module	36	60 Cells	2200 x 1000 x 45mm
Modules per Pallet	144	144	144
Pallet Weight	4200kg	4200kg	4200kg
Volume per 40'	18	18	18

### Add New Module

Other Options

- Upload PPM File
- Import Module
- Create Blank Template

Enter Basic Data  
I.e. from a datasheet

Enter Key I-V Points  
I.e. IEC 61853-1 Data

Enter Full I-V Curves  
Temp, irradiance, voltage, current

Related PWD | Temp. Coeff | Technology

# Manufacturer Datasheet as Input

## Data Sources/Inputs

### Manufacturer Datasheet

IEC-61853-1 Test Matrix

I-V Curve Data

## Generating a Module File

Initial Calculation with Defaults

Matching Expected Performance

*What if I am given a module datasheet?*

Cell Type: Thin film CdTe semiconductor, up to 264 cells

MODEL TYPES AND RATINGS AT STANDARD TEST CONDITIONS (1000 W/m <sup>2</sup> , 25°C)		
NOMINAL VALUES		FS-6420 FS-6420A
Nominal Power <sup>3</sup> (-0/+5%)	P <sub>MAX</sub> (W)	420.0
Efficiency (%)	%	17.0
Voltage at P <sub>MAX</sub>	V <sub>MAX</sub> (V)	180.4
Current at P <sub>MAX</sub>	I <sub>MAX</sub> (A)	2.33
Open Circuit Voltage	V <sub>OC</sub> (V)	218.5
Short Circuit Current	I <sub>SC</sub> (A)	2.54

TEMPERATURE CHARACTERISTICS		
Module Operating Temperature Range	(°C)	-40 to +85
Temperature Coefficient of P <sub>MAX</sub>	T <sub>x</sub> (P <sub>MAX</sub> )	-0.32%/°C [Temperature Range: 25°C to 75°C]
Temperature Coefficient of V <sub>OC</sub>	T <sub>x</sub> (V <sub>OC</sub> )	-0.28%/°C
Temperature Coefficient of I <sub>SC</sub>	T <sub>x</sub> (I <sub>SC</sub> )	+0.04%/°C

# IEC-61853-1 Test Data as Input

## Data Sources/Inputs

Manufacturer Datasheet

**IEC-61853-1 Test Matrix**

I-V Curve Data

## Generating a Module File

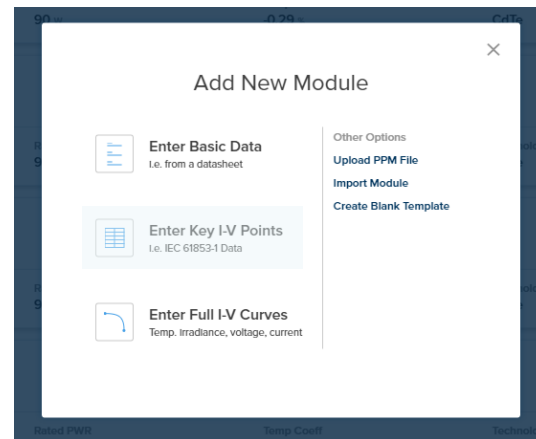
Initial Calculation with Defaults

Matching Expected Performance

What if my only source of data is an IEC-61853-1 test matrix?



Temperature [C]	Irradiance [W/m2]	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmp [W]	FF [%]	Eff [%]	Isc [A]	Iscx [A]
15	100	0.174	83.71	0.150	70.28	10.56	72.42	14.67	0.169	0.122
15	200	0.349	86.41	0.310	72.80	22.57	74.93	15.67	0.342	0.248
15	400	0.698	88.97	0.628	74.38	46.72	75.25	16.22	0.683	0.491
15	600	1.046	90.46	0.948	74.66	70.74	74.79	16.38	1.027	0.726
15	800	1.395	91.51	1.268	74.51	94.52	74.05	16.41	1.377	0.955
15	1000	1.743	92.29	1.586	74.21	117.68	73.14	16.34	1.722	1.173
25	100	0.175	80.95	0.151	67.75	10.24	72.36	14.23	0.170	0.122
25	200	0.350	83.67	0.311	70.32	21.88	74.78	15.19	0.343	0.248
25	400	0.700	86.27	0.630	71.92	45.29	75.05	15.73	0.685	0.490
25	600	1.049	87.75	0.951	72.25	68.68	74.59	15.90	1.031	0.725
25	800	1.399	88.85	1.272	72.20	91.85	73.88	15.95	1.380	0.952
25	1000	1.749	89.71	1.590	72.04	114.52	72.98	15.91	1.726	1.168
25	1100	1.924	90.04	1.747	71.86	125.55	72.48	15.85	1.898	1.274
50	100	0.177	73.83	0.153	61.08	9.32	71.47	12.95	0.172	0.121
50	200	0.354	76.77	0.314	63.77	20.01	73.72	13.89	0.347	0.246
50	400	0.707	79.55	0.636	65.41	41.58	73.90	14.44	0.694	0.489
50	600	1.061	81.06	0.957	65.84	62.98	73.25	14.58	1.042	0.720
50	800	1.414	82.14	1.279	65.83	84.19	72.48	14.62	1.393	0.944
50	1000	1.768	83.05	1.599	65.71	105.07	71.55	14.59	1.745	1.160
50	1100	1.945	83.40	1.756	65.59	115.19	71.01	14.54	1.918	1.263
75	100	0.179	65.50	0.155	52.94	8.22	70.10	11.42	0.175	0.120
75	200	0.358	68.74	0.317	55.57	17.62	71.60	12.23	0.352	0.243
75	400	0.717	71.87	0.637	57.60	36.69	71.20	12.74	0.701	0.478
75	600	1.075	73.80	0.960	58.46	56.12	70.76	12.99	1.055	0.766
75	800	1.433	75.10	1.283	58.72	75.33	69.99	13.08	1.412	0.926
75	1000	1.791	76.10	1.602	58.70	94.04	69.01	13.06	1.766	1.140
75	1100	1.970	76.76	1.763	58.87	103.77	68.61	13.10	1.944	1.246



# IEC-61853-1 Test Data as Input

## Data Sources/Inputs

Manufacturer Datasheet  
**IEC-61853-1 Test Matrix**  
I-V Curve Data

## Generating a Module File

Initial Calculation with Defaults  
Matching Expected Performance

What if my only source of data is an IEC-61853-1 test matrix?

The screenshot shows the 'Module Generator' interface in PlantPredict. The main area displays a table of IEC-61853-1 test data points. A green box highlights a row for 1000 W irradiance, and a green arrow points from this row to a 'Calculated Performance' summary box on the right. The summary box shows 'Electrical Data at STC' with values for Max Power (114.52 W), Voc (175 A), Imp (1.59 A), Vmp (89.71 V), and Vmp (72.04 V). Below this, 'Temperature Coefficients' are listed: Pdc Temp. Coef (-0.35 %/°C), Voc Temp. Coef (0.05 %/°C), and Vmp Temp. Coef (-0.3 %/°C).

IRRADIANCE	ISC	VOC	IMP	VMP	FMP	REL EFFICIENCY
1000	1.92374827648	A 90.0470742476	V 1.74767396897	A 71.8567432446	V 125.54549954	W 95.659702741709
800	1.39927947905	A 88.8504609702	V 1.27290208556	A 72.3978822879	V 91.849560793	W 90.25327880257952
600	1.0496384371	A 87.7528190282	V 0.950592277372	A 72.252944838	V 68.677281831	W 85.94775489701800
400	0.69954766276	A 86.272319791	V 0.629705552708	A 71.9234406541	V 45.2949038798	W 88.8701999050441
200	0.349650620736	A 83.6697545426	V 0.3118539323	A 70.320248812	V 21.877021265	W 95.514930580796
100	0.174864389084	A 80.947674792	V 0.155886377038	A 67.7536864403	V 10.2431687988	W 89.44205427737092

# IEC-61853-1 Test Data as Input

## Data Sources/Inputs

Manufacturer Datasheet  
**IEC-61853-1 Test Matrix**  
 I-V Curve Data

## Generating a Module File

Initial Calculation with Defaults  
 Matching Expected Performance

What if my only source of data is an IEC-61853-1 test matrix?

The screenshot displays the 'Module Generator' interface in Plant Predict. It features a table of I-V test data points. The columns are: IRRADIANCE, ISC, VOC, IMP, VMP, FMP, and REL EFFICIENCY. The REL EFFICIENCY column is highlighted with a pink box. To the right of the table, there is a 'Calculated Performance' section showing electrical data at STC (Max Power: 114.52 W, Voc: 89.71 V) and temperature coefficients (Pac Temp. Coef: -0.35 %/°C, Voc Temp. Coef: -0.3 %/°C).

$$EIR_i = \frac{P_{mp,i}}{P_{max,norm}}$$

$$P_{max,norm} = P_{mp,1000} \frac{i}{1000}$$

Relative Efficiency Calculation

# IEC-61853-1 Test Data as Input

## Data Sources/Inputs

Manufacturer Datasheet  
**IEC-61853-1 Test Matrix**  
 I-V Curve Data

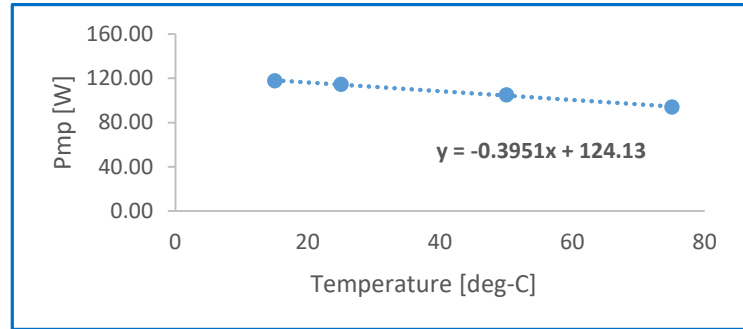
## Generating a Module File

Initial Calculation with Defaults  
 Matching Expected Performance

What if my only source of data is an IEC-61853-1 test matrix?

The screenshot shows the 'Module Generator' interface in PlantPredict. It features a table of test data with columns for Irradiance, ISC, VOC, IMP, VMP, FMP, and Rel. Efficiency. A 'Calculated Performance' box on the right displays electrical data at STC (Max Power: 114.52 W, Voc: 89.71 V, Imp: 1.59 A, Vmp: 72.04 V) and temperature coefficients (Pmp: -0.35 %/°C, Voc: 0.05 %/°C, Vmp: -0.3 %/°C).

IRRADIANCE	ISC	VOC	IMP	VMP	FMP	REL EFFICIENCY
1000	1.92374827648	90.049742476	1.34786396897	71.8567432446	125.54549954	95.6597027410708
800	1.24930325831	89.7052484312	1.58974185616	72.0389007794	114.529968092	95
600	1.39957947905	88.8504669702	1.27279028556	72.3978822879	91.849560793	90.25327880257852
400	1.04896384371	87.7528191282	0.950592277372	72.252944838	68.6772815831	95.94775489701803
200	0.699547566276	86.272319791	0.623765552708	71.9234406541	45.2949038798	98.8701999050441
100	0.349650620736	83.6697545426	0.3118539323	70.320248812	21.8777021265	95.514930580796
	0.174864389084	80.947674792	0.15588637038	67.7536864403	10.2431687988	85.44205427373092



Temperature Coefficient Calculation (Linear Regression)

# I-V Curve Test Data as Input

## Data Sources/Inputs

Manufacturer Datasheet  
IEC-61853-1 Test Matrix

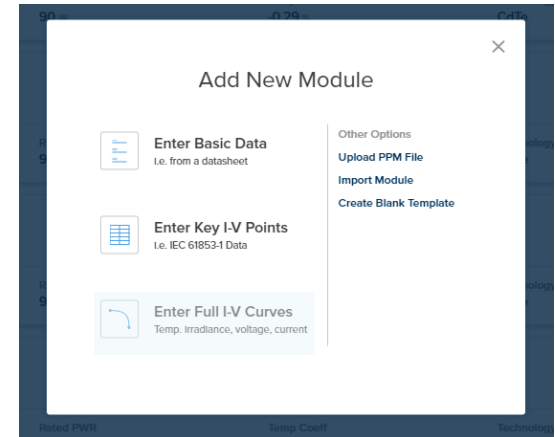
### I-V Curve Data

## Generating a Module File

Initial Calculation with Defaults  
Matching Expected Performance

*What if I only have I-V curve data?*

Temperature [deg-C]	Irradiance [W/m <sup>2</sup> ]	I [A]	V [V]
25	1000	9.43	0
25	1000	9.4279	1.271
25	1000	9.4258	2.5419
25	1000	9.4236	3.8129
25	1000	9.4215	5.0838
25	1000	9.4194	6.3548
25	1000	9.4173	7.6257
25	1000	9.4152	8.8967
25	1000	9.4131	10.1676
25	1000	9.4109	11.4386
25	1000	9.4088	12.7095
25	1000	9.4067	13.9805
25	1000	9.4046	15.2514
25	1000	9.4025	16.5224
25	1000	9.4004	17.7933
25	1000	9.3982	19.0643
25	1000	9.3961	20.3352
25	1000	9.394	21.6062
25	1000	9.3918	22.8771
25	1000	9.3897	24.1481
25	1000	9.3874	25.419
25	1000	9.385	26.69
25	1000	9.3823	27.9609
25	1000	9.3789	29.2319
25	1000	9.3748	30.5028



# I-V Curve Test Data as Input

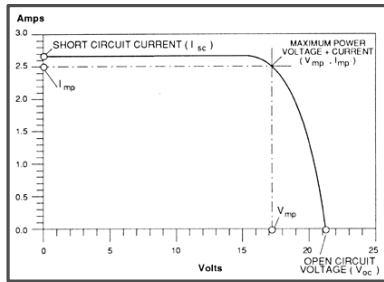
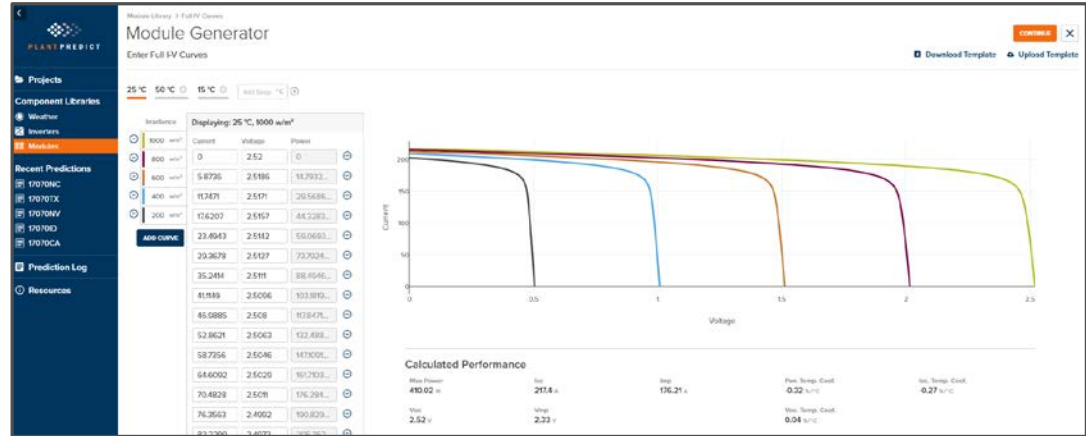
## Data Sources/Inputs

Manufacturer Datasheet  
IEC-61853-1 Test Matrix  
**I-V Curve Data**

## Generating a Module File

Initial Calculation with Defaults  
Matching Expected Performance

## What if I only have I-V curve data?



1

2

Resulting dataset processed like IEC-61853-1 data to generate:

1. Electrical Characteristics @ STC
2. Temperature Coefficients
3. Relative efficiencies at low-light

For each I-V curve at a given Temperature and Irradiance,  
 $I_{sc} / V_{oc} / I_{mp} / V_{mp} / P_{mp}$  extracted via graphical methods.



# Initial Calculation with Default Assumptions

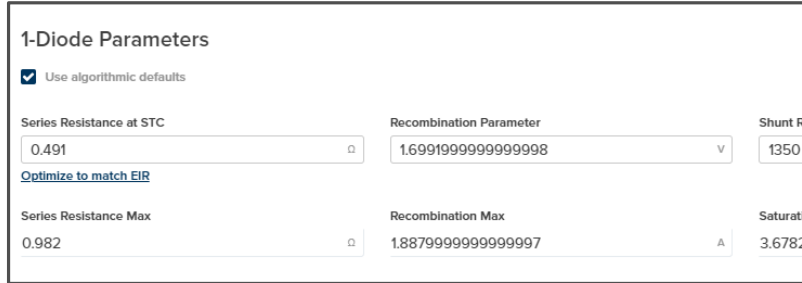
*What if I want to generate a module file as quickly as possible?*

## Data Sources/Inputs

Manufacturer Datasheet  
IEC-61853-1 Test Matrix  
I-V Curve Data

## Generating a Module File

**Initial Calculation with Defaults**  
Matching Expected Performance



1-Diode Parameters		
<input checked="" type="checkbox"/> Use algorithmic defaults		
Series Resistance at STC	Recombination Parameter	Shunt R
0.491 $\Omega$	1.6991999999999998	1350
<a href="#">Optimize to match EIR</a>		
Series Resistance Max	Recombination Max	Saturat
0.982 $\Omega$	1.8879999999999997	3.6782

Automatically calculates a set of 1-diode parameters based on technology-dependent (ie. cSi vs. CdTe) generalizations, such as:

- low-light relative efficiency at  $200 \text{ W/m}^2$  is  $\sim 97\%$  (cSi)
- Series Resistance is  $\sim 50\%$  of maximum series resistance (CdTe)
- Recombination Parameter is  $\sim 90\%$  of maximum recombination parameter (CdTe)
- etc.

# Initial Calculation with Default Assumptions

## Data Sources/Inputs

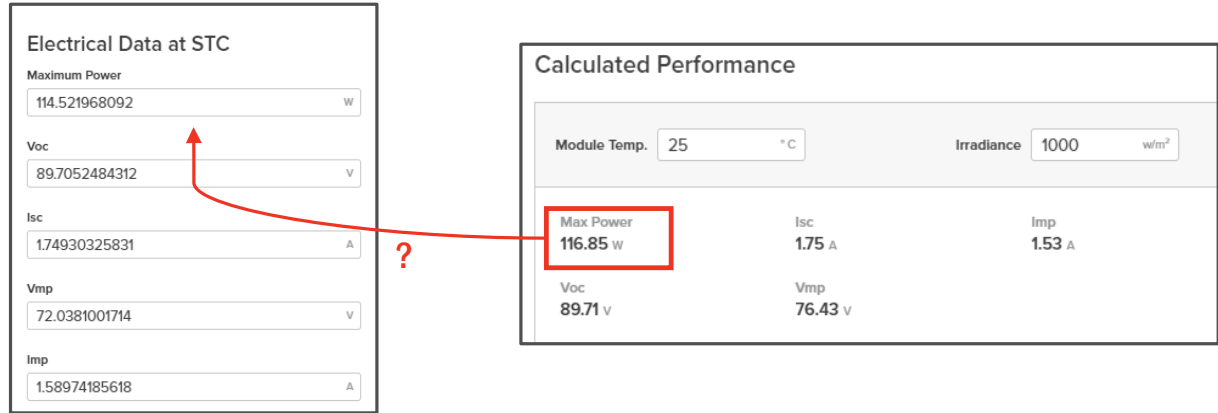
Manufacturer Datasheet  
IEC-61853-1 Test Matrix  
I-V Curve Data

## Generating a Module File

**Initial Calculation with Defaults**  
Matching Expected Performance

## Disadvantages of Using Default Assumptions

**Making single assumptions for ALL c-Si or ALL CdTe modules is a bad idea!**



1

Significant error between nameplate power and maximum power calculated from resulting single-diode parameters.

# Initial Calculation with Default Assumptions

## Data Sources/Inputs

Manufacturer Datasheet  
IEC-61853-1 Test Matrix  
I-V Curve Data

## Generating a Module File

**Initial Calculation with Defaults**  
Matching Expected Performance

Temperature: 25 °C  
Displaying Temperature: 25 °C

Irradiance	Rel. Efficiency
1000	100
800	100.25321159...
600	99.947754897...
400	98.878199166...
200	95.517491058...

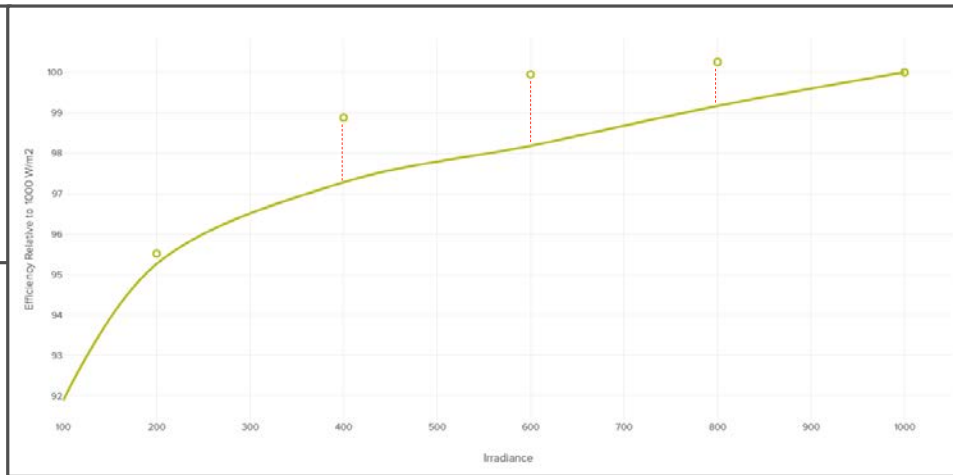
ADD CURVE

ADD POINT Clear Form Data

Effective Irradiance Response  
calculated from measured  
performance data. **This is the  
expected/target performance.**

## Disadvantages of Using Default Assumptions

**Making single assumptions for ALL c-Si or ALL CdTe modules is a bad idea!**



2

Low-light performance does not match expected performance from measured test data (IEC-61853-1).

# Matching Expected Module Performance

## Data Sources/Inputs

Manufacturer Datasheet  
IEC-61853-1 Test Matrix  
I-V Curve Data

## Generating a Module File

Initial Calculation with Defaults

**Matching Expected Performance**

*How do I “tune” the module to perform as expected?*

1

Manually adjust key single-diode parameters.

2

Use automatic series resistance optimization.

**1-Diode Parameters**

Use algorithmic defaults

Series Resistance at STC	Recombination Parameter	Shunt Resistance at STC	Exp. Dep. of Shunt Resist.	Dark Shunt Resistance
0.491	1.6991999999999998	1350	5.5	16000
<b>Optimize to match EIR</b>				
Series Resistance Max	Recombination Max	Saturation Current at STC	Diode Ideality at STC	Lin. temp. Dep. of Gamma
0.982	1.8879999999999997	3.67821619420339e-11	1.3305656605886351	-0.13487692250000155

# Matching Expected Module Performance

## Data Sources/Inputs

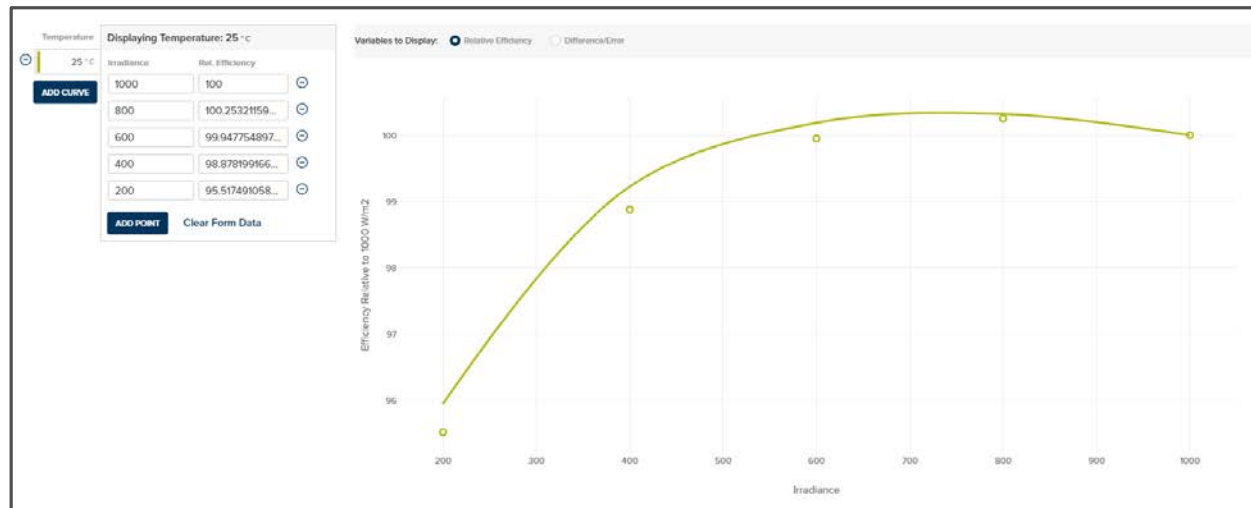
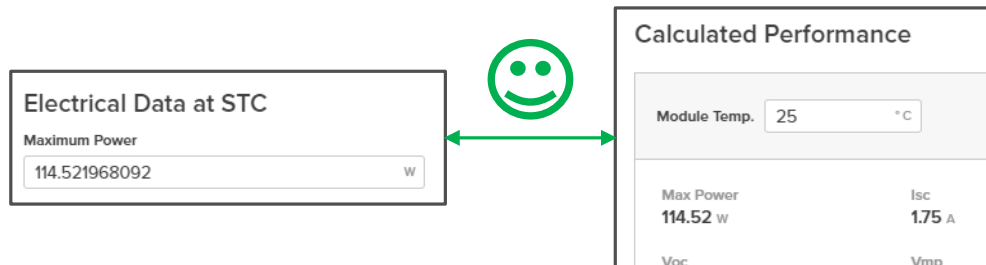
Manufacturer Datasheet  
IEC-61853-1 Test Matrix  
I-V Curve Data

## Generating a Module File

Initial Calculation with Defaults

**Matching Expected Performance**

*Module performance tuned successfully!*



# Module File Ready for Simulation

Projects > 17070NC (CFV Comparison) > 17070NC > Power Plant Builder

## Power Plant Builder

SAVE + CLOSE POWER PLANT  
Save Progress Cancel

1 BLOCK 0.5 MWdc | 0.61 MWdc    1 ARRAY 0.5 MWdc | 0.61 MWdc    A INVERTER 25 kWdc | 30.75 kWdc    1 DC FIELD 30.75 kWdc | 114.52 W | 6.15 m

### DC FIELD 1 Edit

Add Another Clone Remove

#### 17070-06 First Solar Module Files

Draft - Private Stephen Kaplan | 15 Nov 2018 CHANGE MODULE

Manufacturer	Model	Rated PWR	Temp Coeff	Technology	Facility
First Solar	FS-4115-3	114.521968092 W	-0.3176139500489223 %	CdTe	Monofacial

Mounting Electrical Losses

Mounting Type:  FIXED TILT  TRACKER

Tilt Angle (degrees): 20 Seasonal Tilt:  OFF  ON

Module Orientation: Modules High

View Angles Zoom In/Out Viewer Azimuth 30° Observer Height 10°

N

# Algorithm Limitations & Potential Improvements

Limitation: *Automatic* Series Resistance Optimization currently only uses relative efficiency data at 200, 400, 600, 800 W/m<sup>2</sup> (@ 25°C)

- Potential Improvement: Implement a more sophisticated model to match measured performance at *any* temperature/irradiance condition.
- Potential Strategy: Dobos/MacAlpine method as published in “Procedure for applying IEC-61853 test data to a single diode model.” *2014 IEEE 40th Photovoltaic Specialist Conference (PVSC) (2014): 2846-2849.*

Temperature	Displaying Temperature: 25 °c		
25 °c	Irradiance	Rel. Efficiency	
<input type="button" value="ADD CURVE"/>	<input type="text" value="1000"/>	<input type="text" value="100"/>	⊖
	<input type="text" value="800"/>	<input type="text" value="100.25321159..."/>	⊖
	<input type="text" value="600"/>	<input type="text" value="99.947754897..."/>	⊖
	<input type="text" value="400"/>	<input type="text" value="98.878199166..."/>	⊖
	<input type="text" value="200"/>	<input type="text" value="95.517491058..."/>	⊖
<input type="button" value="ADD POINT"/>	<input type="button" value="Clear Form Data"/>		

Limited Performance Tuning Target (Current)

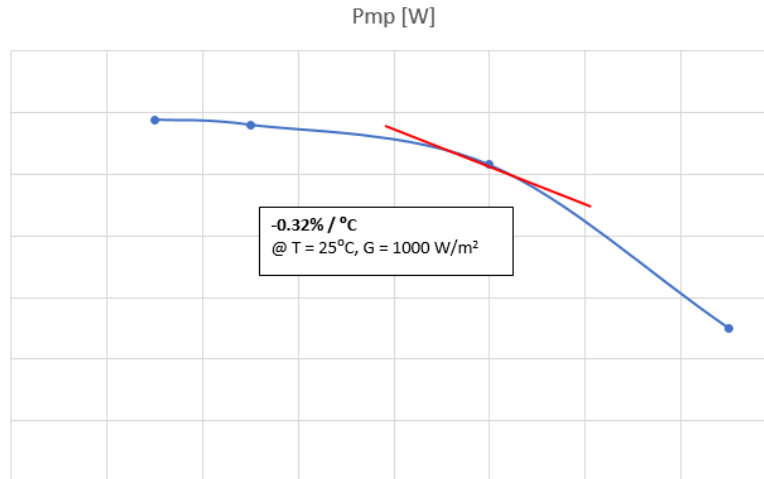
Temperature	Displaying Temperature: 15 °c		
15 °c	Irradiance	Rel. Efficiency	
<input type="button" value="ADD CURVE"/>	<input type="text" value="1000"/>	<input type="text" value="100"/>	⊖
	<input type="text" value="800"/>	<input type="text" value="100.39469224..."/>	⊖
	<input type="text" value="600"/>	<input type="text" value="100.191435182..."/>	⊖
	<input type="text" value="400"/>	<input type="text" value="99.24429057..."/>	⊖
	<input type="text" value="200"/>	<input type="text" value="95.89096902..."/>	⊖
	<input type="text" value="100"/>	<input type="text" value="89.76599205..."/>	⊖
<input type="button" value="ADD POINT"/>	<input type="button" value="Clear Form Data"/>		

Comprehensive Performance Tuning Targets (Future)

# Algorithm Limitations & Potential Improvements

Related Limitation: Algorithm assumes a linear temperature coefficient of power, calculated via linear regression. Therefore, the resulting model's performance does not match measured data at non-STC conditions.

- Potential Improvement: Treat temperature dependence as non-linear. The nameplate (datasheet) “linear” temperature coefficient should be interpreted as the **derivative** of the measured non-linear trend at STC.





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SUSTAINABLE ENERGY FUTURE

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