PSIM

TUTORIAL

Solar Module Physical Model

July 2018

The physical model of the solar module can take into account variations of the light intensity and ambient temperature. However, it requires many parameter inputs. Some of the parameters can be obtained from manufacturer datasheets, while other parameters need to be obtained by trial-and-error.

In order to make it easier for users to define parameters for a particular solar module, a utility tool called *Solar Module* (*physical model*) is provided in the PSIM's **Utility** menu. This tutorial describes how to use this tool through examples.

The solar module physical model has the following parameters:

Number of Cells Ns:	Number of solar cells in series in a solar module
Standard Light Intensity S0:	Light intensity under standard test conditions, in W/m^2. This value is normally 1000 W/m^2.
Ref. Temperature Tref:	Temperature under standard test conditions, in ^{o}C.
Series Resistance Rs:	Series resistance of each solar cell, in Ohm.
Shunt Resistance Rsh:	Shunt resistance of each solar cell, in Ohm
Short Circuit Current Isc0:	Short circuit current of the solar module at the reference temperature, in A.
Saturation Current Is0:	Saturation current of the diode in the model, in A
Band Energy Eg:	Band energy of each solar cell, in eV.
Ideality Factor A:	Ideality factor, also called emission coefficient, of the diode in the model.
Temperature Coefficient Ct:	Temperature coefficient, in A/K.
Coefficient Ks:	Coefficient that defines how light intensity affects the solar cell temperature

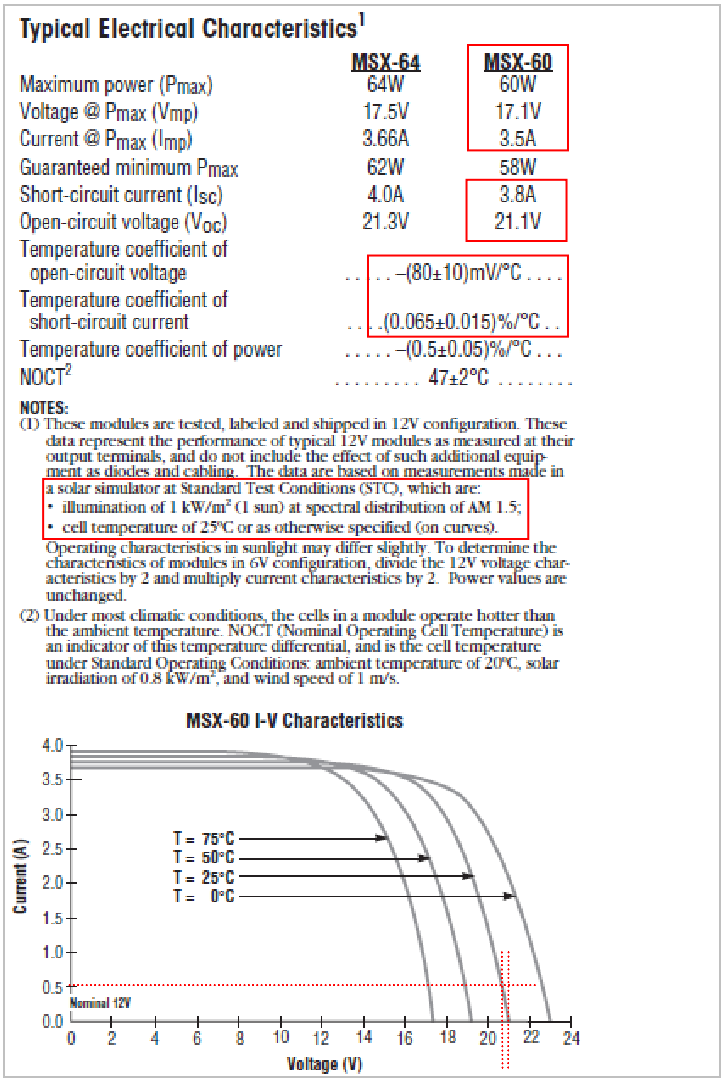
The solar module MSX-60 from BP Solar is used to illustrate how to use the utility tool to obtain the model parameters. The process involves the following steps:

- Enter the information from the datasheet;
- Make an initial guess of certain parameters;
- Obtain the I-v and P-v curves, and the maximum power point. Compare with the datasheet and experimental data for different operating conditions, and fine tune the parameters.

1. Entering Datasheet Information

The figure below shows the manufacturer datasheet image, and the region of the utility tool dialog window related to manufacturer datasheet.

All the information required by this region, except the dv/di value at Voc, can be read directly from the datasheet, as highlighted by the red rectangles. In the datasheet, the temperature coefficient of the open-circuit voltage is expressed in V/^{o}C. It needs to be converted to %/^{o}C for the utility tool as: -80mV/^{o}C = -0.08/21.1 /^{o}C = -0.38 %/^{o}C.



Typical Electrical Characteristics[1]

	MSX-64	MSX-60
Maximum power (P_{max})	64W	60W
Voltage @ P_{max} (V_{mp})	17.5V	17.1V
Current @ P_{max} (I_{mp})	3.66A	3.5A
Guaranteed minimum P_{max}	62W	58W
Short-circuit current (I_{SC})	4.0A	3.8A
Open-circuit voltage (V_{OC})	21.3V	21.1V
Temperature coefficient of open-circuit voltage	–(80±10)mV/°C	
Temperature coefficient of short-circuit current	(0.065±0.015)%/°C	
Temperature coefficient of power	–(0.5±0.05)%/°C	
NOCT[2]	47±2°C	

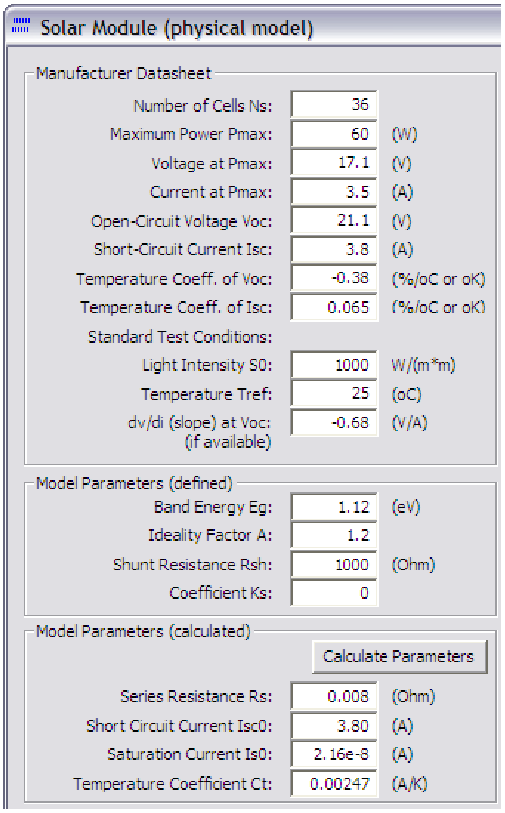
NOTES:

(1) These modules are tested, labeled and shipped in 12V configuration. These data represent the performance of typical 12V modules as measured at their output terminals, and do not include the effect of such additional equipment as diodes and cabling. The data are based on measurements made in a solar simulator at Standard Test Conditions (STC), which are:
- illumination of 1 kW/m² (1 sun) at spectral distribution of AM 1.5;
- cell temperature of 25°C or as otherwise specified (on curves).

Operating characteristics in sunlight may differ slightly. To determine the characteristics of modules in 6V configuration, divide the 12V voltage characteristics by 2 and multiply current characteristics by 2. Power values are unchanged.

(2) Under most climatic conditions, the cells in a module operate hotter than the ambient temperature. NOCT (Nominal Operating Cell Temperature) is an indicator of this temperature differential, and is the cell temperature under Standard Operating Conditions: ambient temperature of 20°C, solar irradiation of 0.8 kW/m², and wind speed of 1 m/s.

Manufacturer datasheet



The value “dv/di (slope) at Voc” refers to the dv/di slope at the open-circuit voltage Voc of 21.1V. From the datasheet I-V characteristics, by reading the values from the graph (marked in red dotted lines), we can calculate approximately the slope as:

$$\frac{dv}{di} = \frac{\Delta V}{\Delta i} = \frac{-0.34}{0.5} = -0.68$$

If the I-V curve is not available on the datasheet, leave the dv/di value at 0.

2. Estimating Parameter Values Eg, A, Rsh, and Ks

These four parameters are normally not provided on the datasheet, and one needs to come up with a good initial guess, or obtain them from manufacturers: band energy Eg, ideality factor A, shunt resistance Rsh, and coefficient Ks.

A good initial guess of the band energy Eg is around 1.12 eV for crystalline silicon, and around 2 eV for amorphous silicon.

A good initial guess of the ideality factor A is around 2 for crystalline silicon, and is less than 2 for amorphous silicon.

A good initial guess of the shunt resistance Rsh is several thousand Ohm.

If unknown, the initial value of the coefficient Ks can be set to 0.

In this example, we set:

Eg = 1.12

A = 1.2

Rsh = 1000

Ks = 0.

3. Calculating Parameter Values Rs, Isc0, Is0, and Ct

Based on the datasheet information and the initial guess of Eg, A, Rsh, and Ks, the rest of the parameters (series resistance Rs, short circuit current Isc0, saturation current Is0, and temperature coefficient Ct) can be calculated by clicking on the **Calculate Parameters** button. The following values will be obtained:

Rs = 0.0108

Isc0 = 3.8

Is0 = 2.16e-8

Ct = 0.00247

Note that the calculation is approximate, and provides only the base values. Users should feel free to adjust these parameters to fit the calculated I-V curve to the datasheet curve or the experimental results.

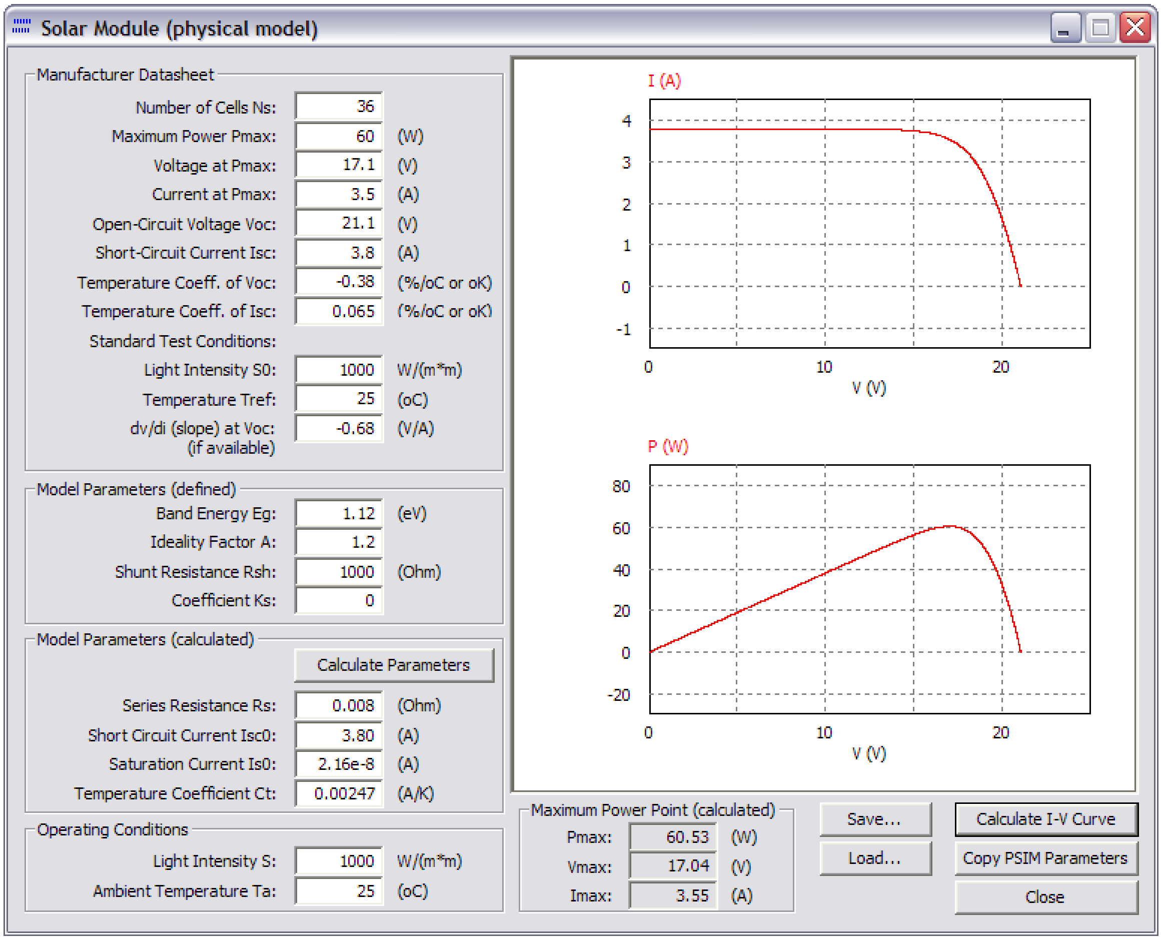
4. Fine Tuning the Parameters

Under give operating conditions of the light intensity S and the ambient temperature Ta, one can obtain the I-V and P-V curves by clicking on the **Calculate I-V Curve** button. The calculated maximum power point will also be calculated.

If we define S = 1000 W/m^2 and Ta = 25 ^oC, we can obtain the maximum power point as: Pmax = 59.27 W, Vmax = 16.73 V, and Imax = 3.54 A. Both the maximum power and the voltage at the maximum power are lower than the datasheet values of 60 W and 17.1 V. One should adjust the parameters Eg, A, Rsh, Ks, Rs, Is0, and Ct to obtain a better fit.

In this example, if we change the series resistance Rs to 0.008 Ohm, the calculated maximum power point is: Pmax = 60.54 W, Vmax = 17.04V, and Imax = 3.55 A, which is closer to the datasheet values.

The final parameter values and the I-V and P-V curves are shown below.



Many iterations and trial-and-error may be needed to obtain a good fit to the datasheet or experimental data. After the parameters are finalized, click on the **Copy PSIM Parameters** button to copy the model parameters to the PSIM schematic.

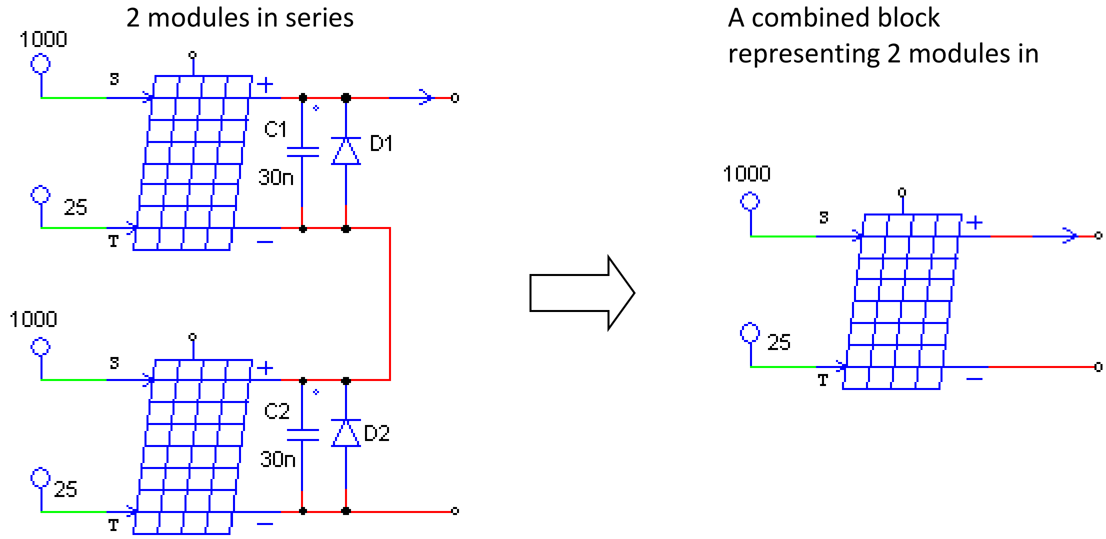
To save the datasheet and parameter values to a text file to later use, click on the **Save** button, and save it to a file (for example “Solarex MSX-60.txt”). To load the data of a specific solar module back, click on the **Load** button.

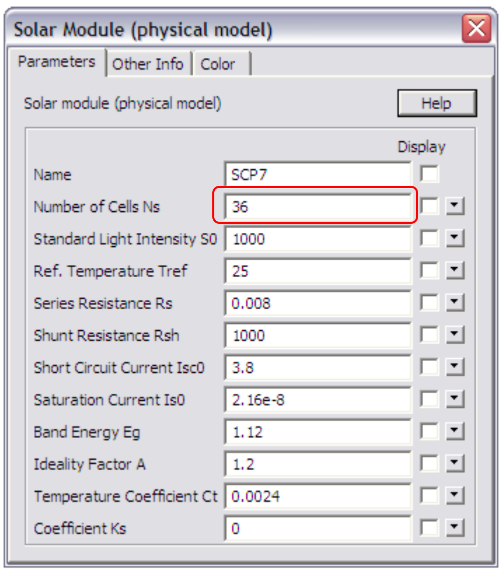
5. Multiple Modules in Series

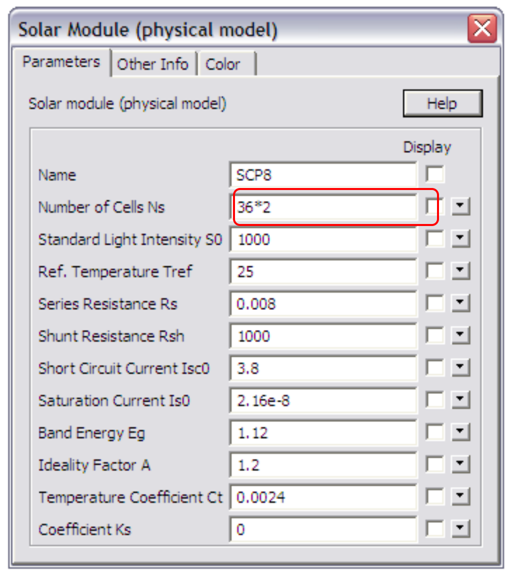
Often several identical solar modules are connected in series to form a solar array. One can use a solar module block to model the solar array.

The figure below shows 2 solar modules Solarex MSX-60 connected in series, and a combined block that models 2 modules. The model parameters of the combined block are the same as for a single solar module, except that the number of cells Ns is 2 times of the single solar module value.

Note that when multiple modules are connected in series, a bypass diode is needed across each module if the light intensity and ambient temperature inputs are different. Also, a very small capacitor (in this case 30 nF) is needed across each module for numerical convergence.





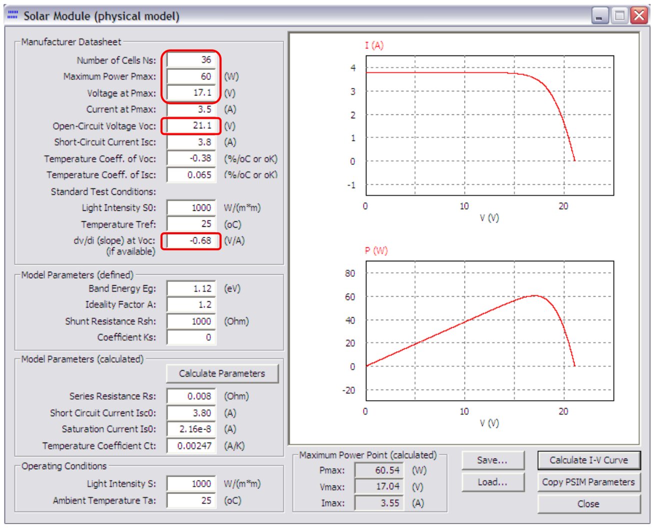


To plot the I-V curve of the combined block, change the following quantities from the single module value:

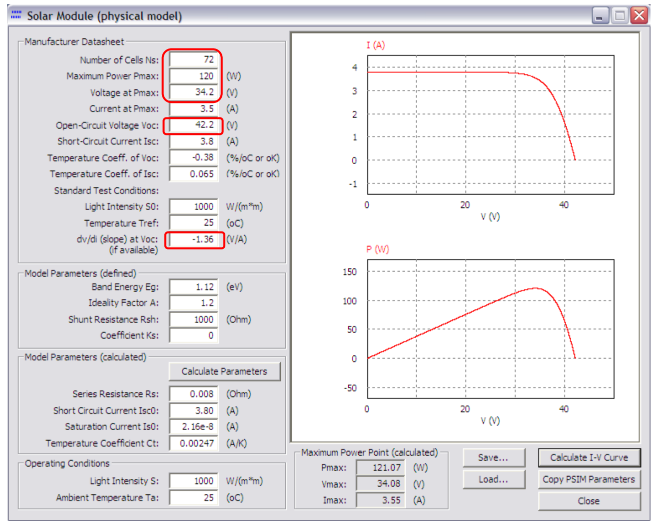
Number of Cells Ns * 2
Maximum Power Pmax * 2
Voltage at Pmax * 2
Open-Circuit Voltage Voc * 2
dv/di (slope) at Voc * 2

The figure below shows the solar module utility tool dialog for a single module and a combined block. The parameter inputs in the red boxes highlight the differences.

Data of one single solar module



Data of the combined block

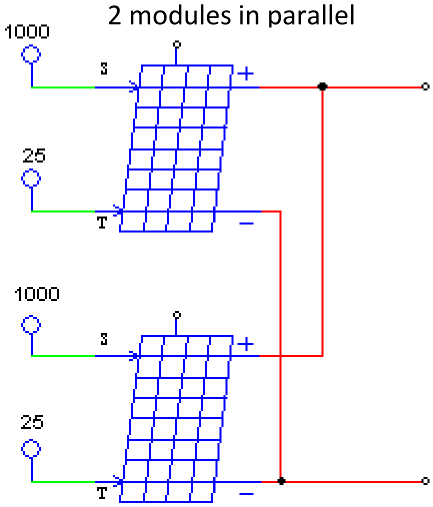


6. Multiple Modules in Parallel

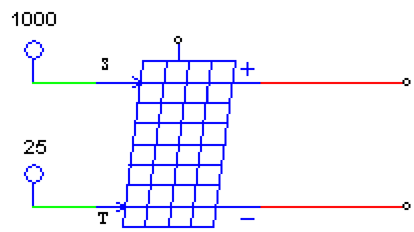
In other cases, several identical solar modules are connected in parallel to form a solar array. One can use a solar module block to model the solar array.

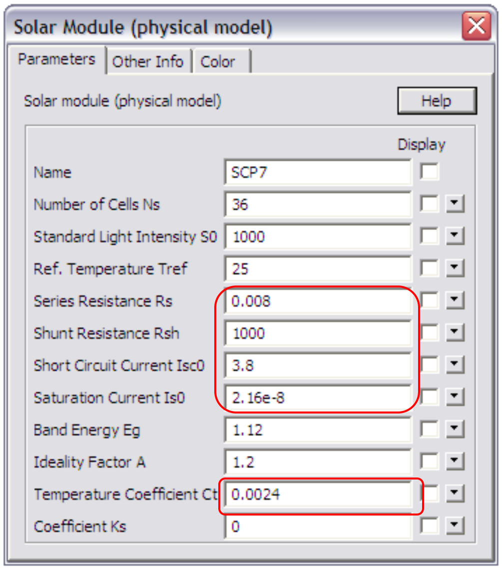
The figure below shows 2 solar modules Solarex MSX-60 connected in parallel, and a combined block that models 2 modules. Some of the parameters of the combined block are different as compared to the parameters of a single solar module, as highlighted in the red boxes below.

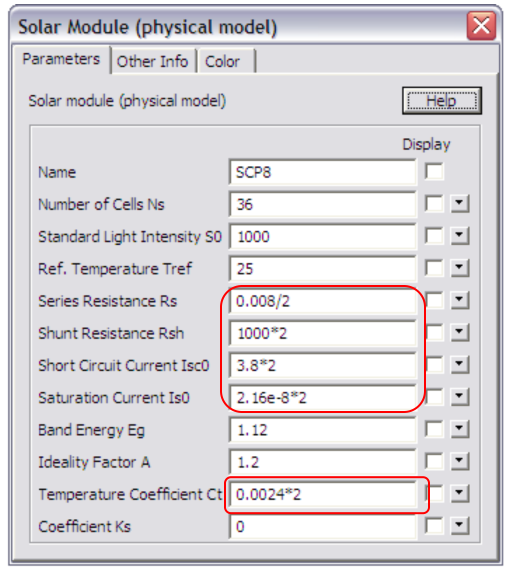
2 modules in parallel



A combined block representing 2 modules in parallel





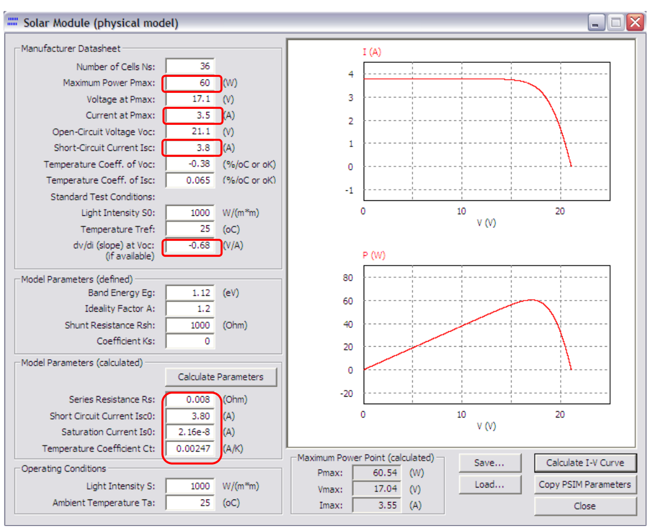


To plot the I-V curve of the combined block, change the following quantities from the single module values:

- Maximum Power Pmax * 2
- Current at Pmax * 2
- Short-Circuit Current Isc * 2
- dv/di (slope) at Voc * 0.5
- Series Resistance Rs * 0.5
- Short Circuit Current Isc0 * 2
- Saturation Current Is0 * 2
- Temperature Coefficient Ct * 2

The figure below shows the solar module utility tool dialog for a single module and a combined block. The parameter inputs in the red boxes highlight the differences.

Data of one single solar module



Data of the combined block