

Modeling a Photovoltaic String using PLECS®

Dr. John Schönberger
Plexim GmbH
Technoparkstrasse 1
8005 Zürich

1 Introduction

Photovoltaic (PV) modules are often connected in series strings to increase the DC input voltage for a PV inverter. In this report, an accurate PV string model that can be included in power electronic simulations is presented. The PV model accounts for the non-linear V-I characteristic of a module, temperature and the effect of insolation, or sun strength. An example simulation model, based on a string comprising BP365 65W modules, is given. The non-linear V-I characteristic of the BP365 PV module is shown in Fig. 1.

2 PV String Model

The non-linear current characteristic of a single PV module is calculated using the Shockley diode PV model presented in [1]. The calculated current characteristic of the module is implemented in PLECS using a 3D Look-up Table component as shown in Fig. 2. To model an arbitrary number of series-connected modules, the voltage input to the lookup table is formed by dividing the output voltage by the number of modules in the string. The voltage is an internal feedback signal from the PV string model itself and the insolation is an external parameter. It should be noted that output capacitance is included in the PV string model to eliminate the state dependency of the PV current from the load current. This would otherwise create an algebraic loop.

The current surface data, shown in Fig. 3, is saved in a .mat file and contains information for the characteristic V-I curves for voltage values between 0 and 25 V, insolation values between 0 and 1 kWhr/m², and three temperatures of 0, 25, and 50 °C.

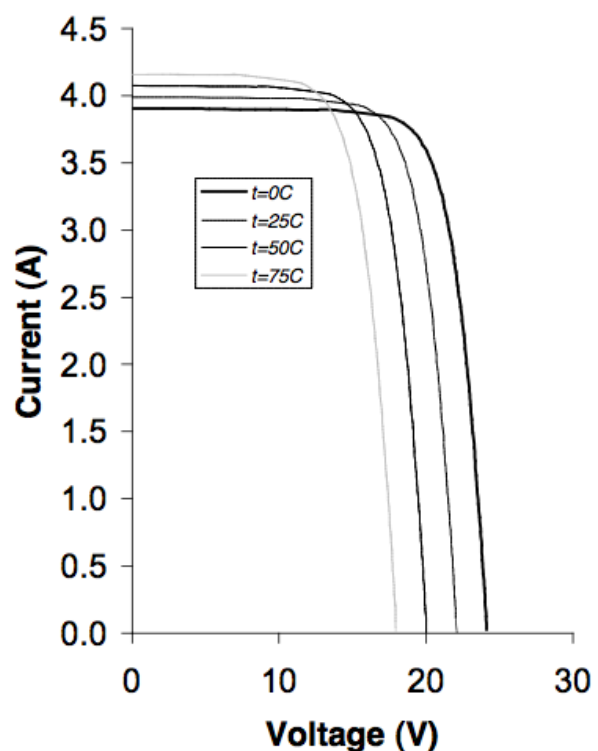


Fig. 1: V-I characteristics of BP365 65W PV module. (Source: BP Solar BP 365 data sheet, 2003).

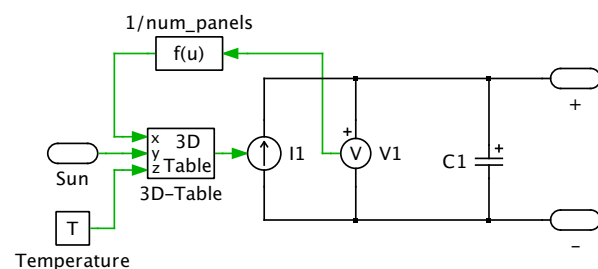


Fig. 2: PLECS implementation of PV string model as a non-linear current source that is dependent on voltage and sun insolation.

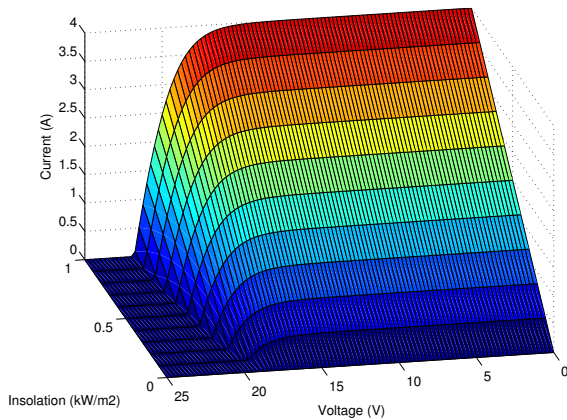


Fig. 3: Calculated non-linear current characteristic of a single BP365 65W PV array at $T = 25^{\circ}\text{C}$.

2.1 Parameters

The PV string component is implemented in PLECS as a masked subsystem. The mask parameters box for the subsystem model is shown in Fig. 4. The parameters are described as follows:

- **Number of PV modules in string:** The number of series-connected panels in the string. Valid numbers are floats greater than zero. Increasing this parameter increases the total output voltage.
- **Number of strings in parallel:** The number of PV strings connected in parallel. Valid numbers are floats greater than zero. Increasing this parameter increases the total output current.
- **Output capacitance (F):** Output capacitance connected across the PV string.
- **Initial output voltage (V):** Initial voltage across the output capacitance.
- **Temperature (C):** Operating temperature of the PV string. Valid numbers for this particular set of data are 0, 25, and 50.

2.2 Probe Signals

The available probe signals for the PV string component are output voltage, current and power.

3 System Simulation

The PV string component can be connected in various series and parallel configurations and used as

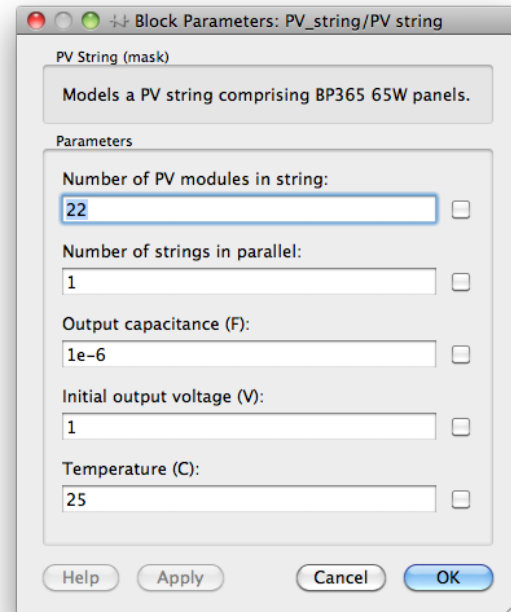


Fig. 4: PV string block parameters box.

a DC source for both offline and grid-connected systems. Stand-alone PV inverters are operated without a connection to the mains, or are off-grid. The application and size of these can vary from residential systems to remote buildings, spacecraft, or military sites. In many cases when the load requirements are independent of the generated power, batteries or supercapacitors are used for onsite storage and a charge controller may be added. A model of a stand-alone PV inverter integrating the PV string source is included with this report. The voltage source inverter doesn't have a storage stage, and is controlled using a basic sinusoidal modulation scheme with natural sampling.

This simple system can be extended in many ways, such as employing a maximum power point tracking controller to obtain maximum power during variations in the total resistance, insolation, and temperature. For a residential system, PV strings each connected to a DC-DC boost converter, can then be connected in parallel to a common DC bus before the inverter stage. Using a space vector modulation technique, for example, a more complex model of an online three-phase inverter can be designed to produce utility frequency AC for connection to the electrical grid.

Appendices

A Simulation Files - PLECS Blockset

Example files for simulating a PV string and the use of the PV string in an example inverter system using PLECS Blockset accompany this application note:

- *PV_string_model.mdl*: A model of a PV string comprising 22 series-connected BP365 modules.
- *PV_string_inverter.mdl*: A model of a single-phase voltage source inverter powered by the above PV string.
- *I_surface_BP365.mat*: The current matrix containing the data for the PV model that is automatically loaded into each model.
- *plot_Isurf.m*: A function for visualizing the 3D current matrix as a surface for a given temperature.

B Simulation Files - PLECS Standalone

Example files for simulating a PV string and the use of the PV string in an example inverter system using PLECS Standalone accompany this application note:

- *PV_string_model.plecs*: A model of a PV string comprising 22 series-connected BP365 modules.
- *PV_string_inverter.plecs*: A model of a single-phase voltage source inverter powered by the above PV string.
- *I_surface_BP365.mat*: The current matrix containing the data for the PV model that is automatically loaded into each model.

References

- [1] G. Walker, "Evaluating MPPT converter topologies using a Matlab PV model," *Journal of Electrical & Electronics Engineering, Australia*, vol. 21, no. 1, pp. 49–56, 2001.