



PLECS

*DEMO MODEL*

## Three-Phase Grid-Connected PV Inverter

Last updated in PLECS 4.7.1

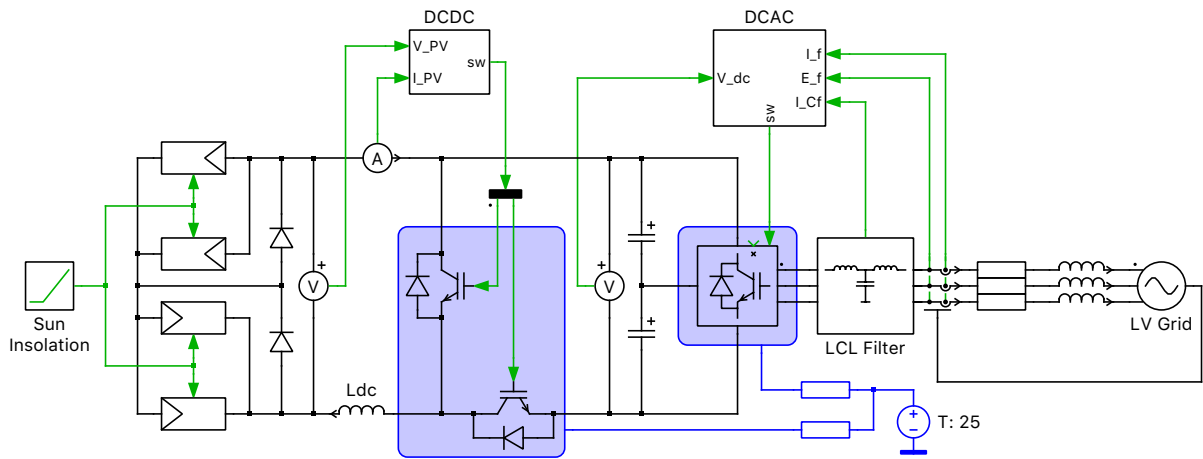
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# 1 Overview

Three-phase PV inverters are generally used for off-grid industrial use or can be designed to produce utility frequency AC for connection to the electrical grid. This PLECS application example model demonstrates a three-phase, two-stage grid-connected solar inverter. The PV system includes an accurate PV string model that has a peak output power of 3 kW and the strings can be series-parallel connected to scale to a desired array output power. The simulation combines the electrical power circuit, the DC/DC and DC/AC control schemes, and the thermal behavior of the semiconductors.

## 2 Model



**Figure 1: Inverter system.**

The power generation system is comprised of a solar array that provides a steady-state output of 700 VDC, a three-level inverter that has improved waveform quality as compared to a two-level inverter, and an LCL output filter connected to a low voltage 230 V<sub>rms</sub>, 50 Hz grid system. The topology employed is a neutral-point-clamped converter (NPC) with a boost converter stage that increases the voltage from the panels to the DC-link (from  $\sim 700$  V to 800 V). An output LCL-type filter is used to smooth the current ripple caused by the PWM modulation of the grid-side inverter.

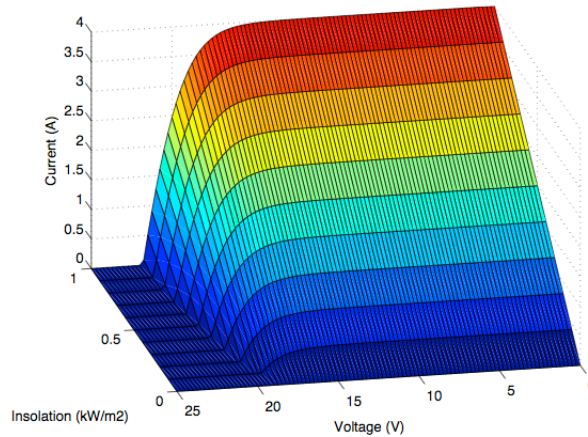
### 2.1 PV String Model

The PV string component is based on a non-linear current source that accurately models the IV characteristic with variable insolation (sun intensity). Further, it can be connected in various series and parallel configurations and used as a DC source for both offline and grid-connected systems. The model is based on the Shockley diode equations for accuracy and can be used to study the interactions between a PV inverter and the supply modules. The typical output current characteristic of the PV model is shown in Fig. 2.

In this example, insolation-dependent data has been mapped for a BP365 65 W solar module, and 4 parallel arrays, each comprising 2 parallel strings of 20 series modules. The current surface data, is saved in a .mat file and contains information for the characteristic IV curves for an insolation range of 0 to 1 kWh/m<sup>2</sup>, voltage values between 0 and 25 V, and a fixed temperature of 25 °C.

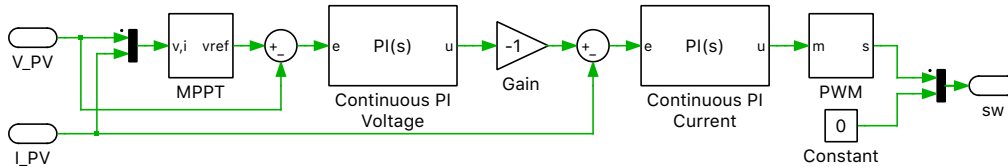
### 2.2 Control

The DC/DC control system comprises three control loops: a maximum power point (MPP) controller, a voltage controller and a current controller. The outer control loop is a MPP controller that ensures max-



**Figure 2: Typical output current characteristic of the BP365 PV module model at 25 °C.**

imum power is extracted from the PV string for a given insolation level. To do this, it calculates the optimal PV terminal voltage using a MPP algorithm known as  $dP/dV$  control. The voltage control loop employs a PI controller and regulates the PV voltage to this optimal level by controlling the level of current that is injected into the boost stage. The innermost control loop, the current controller, sets the modulation index of the IGBT such that the desired current is injected into the DC-link. The current controller is also based on a PI control scheme.



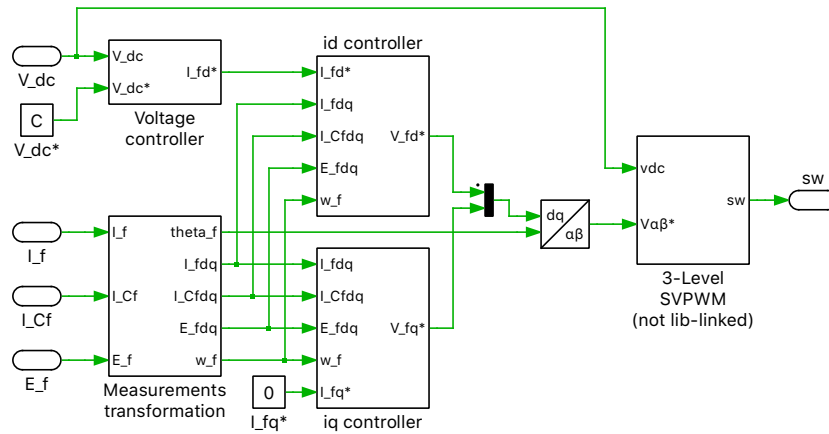
**Figure 3: DC/DC converter controller.**

The DC/AC control system regulates the current to the grid. The grid-side converter transfers the power from the DC-link into the grid through an LCL filter, and maintains the DC-link voltage at 800 VDC. The control scheme for the grid-side inverter comprises a two-loop configuration with an outer loop for voltage control and an inner loop for current control. The voltage loop provides the reference signal for the d-axis current control and employs a PI controller. The current control loop is implemented in the dq frame and is synchronized with the grid voltage, where the orientation reference is provided by a phase-locked loop (PLL). The decomposed d- and q-axis current controllers are based on PI control schemes. The methods of active damping, feed forward as well as integrator anti-windup are adopted for the PI controllers.

The inverter operates using space vector PWM (SVPWM) modulation. Note that the 3-Level SVPWM block used in this demo is a non-library-linked component. It features an extra Alternating zero vector modulation strategy apart from the Symmetrical option. In Alternating zero vector method, the zero vector is alternated in each switching sector to minimize the number of switching transitions thus lower switching losses, but results in higher THD content in modulated voltages. On the other side, for Symmetrical modulation both zero vectors are applied during a single switching sequence — one is split into both the start and the end of the switching cycle and the other is applied at the middle of the switching cycle. This method results in higher switching losses but lower THD.

## 2.3 Thermal

A thermal model has been added to the boost converter and voltage source inverter switches using Infineon F3L30R06W1E3\_B11 600 V, 30 A IGBTs. These descriptions can be viewed and edited by double-



**Figure 4: DC/AC converter controller.**

clicking on the component and selecting **Edit...** from the drop-down menu of the **Thermal description** parameter. The conduction loss and switching loss of a single IGBT, as well as the temperature of the device's junction can be readily observed, and the user can also probe the same information for the clamping diodes of the three-level converter. Additionally the user can design a cooling system for either converter.

The thermal descriptions for the MOSFETs are stored in a private thermal library in the directory /dual\_active\_bridge\_converter\_plecs.

The average switching, conduction and total losses of the semiconductor devices can be calculated easily using the “Switch Loss Calculator” component. Select the switch components of interest in the schematic editor and drag them onto the probed components list of the “Switch Loss Calculator” block. For more details, browse the **Help** section of this block.

For more information on thermal modeling and the calculation of device losses and efficiency, see the demo model “Buck Converter with Thermal Model” in the PLECS demo models library.

### 3 Simulation

As the simulation starts up the sun insolation level is  $0.5 \text{ kW/m}^2$ . The maximum power output per PV string is  $\sim 1,250 \text{ W}$  and the inverter outputs  $\sim 9.9 \text{ A}$  into the grid. At  $t = 3 \text{ s}$  the insolation level begins to ramp up to a final value of full sun conditions at  $1 \text{ kW/m}^2$ . The PV string eventually has a maximum power output of  $\sim 2,600 \text{ W}$  and the inverter outputs  $\sim 19.2 \text{ A}$  into the grid.

## Revision History:

PLECS 4.3.1	First release
PLECS 4.4.2	Update PI controller component
PLECS 4.7.1	Updated the model with the Switch Loss Calculator

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