# PLECS

*DEMO MODEL*

**Boost Converter with PFC and Thermal Model**

Last updated in PLECS 4.7.1

# 1 Overview

This demonstration shows a $300\,\mathrm{W}$ switched-mode power supply. The AC input voltage may vary between $85\,V_{\mathrm{rms}}$ and $265\,V_{\mathrm{rms}}$. The controlled output voltage is $390\,\mathrm{V}$ DC.

The simulation combines the electrical power circuit, the control with a standard IC and the thermal behavior of the semiconductors.



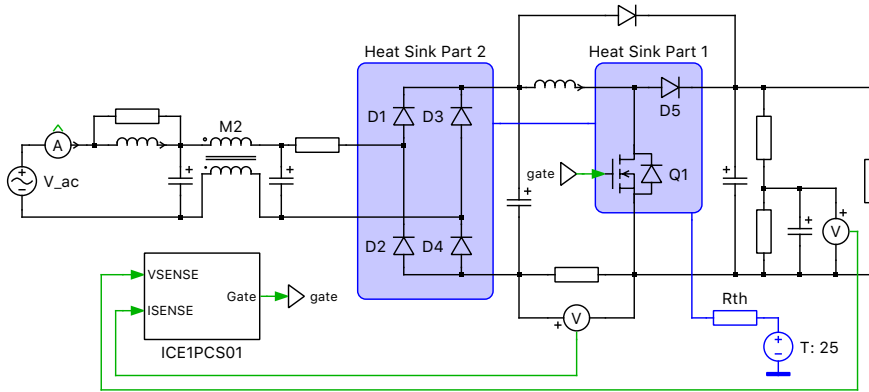**Figure 1:** $300\,\mathrm{W}$ **Switch Mode Power Supply with Power Factor Correction (PLECS Standalone)**

# 2 Model

## 2.1 Power circuit

The power supply is based on a diode rectifier and a power factor correction circuit in boost topology. After having passed the input EMI filter in CLC configuration, the single-phase line voltage is rectified by a standard diode bridge. To improve the efficiency, the boost converter is realized with an Infineon Cool-MOS power switch and a Silicon Carbide (SiC) Schottky diode.

## 2.2 Control

In PLECS Standalone the controller IC (ICE1PCS01 from Infineon [1]) and plant are modeled with functional blocks in individual subsystems. It operates in continuous conduction mode (CCM) with average current control. For PLECS Blockset the controller is implemented on the Simulink level.

The control is cascaded and consists of the inner current loop and the outer voltage loop.

- The inner current loop controls the sinusoidal profile for the average input current. It uses the dependency of the PWM duty cycle on the line input voltage to determine the corresponding input current. This means the average input current follows the input voltage as long as the device operates in CCM. Under light load condition, depending on the choke inductance, the system may enter into discontinuous conduction mode (DCM). In DCM, the average current waveform will be slightly distorted.

- The outer voltage loop controls the output bus voltage. The output voltage contains a ripple with double the frequency of the input voltage (e.g. $120\,\mathrm{Hz}$ in North America). A compensation network connected to the IC suppresses this ripple which must not be amplified by the control loop.

The mask of the controller block contains the parameters of passive components that in reality are directly connected to the IC. The switching frequency can be specified directly, although in reality it is programmed via an external resistor.

The model of the control IC supports soft start for low output voltage. However, other protection features such as over-voltage and peak current protection are not implemented.

## 2.3   Thermal model

Datasheet information for Infineon's SPP20N60C3 CoolMOS MOSFET and SDP04S60 SiC Schottky diode has been used to populate the loss look-up tables in the thermal descriptions.

A special component model is used to simulate the thermal behavior of the MOSFET. Look under the mask of this component to see the thermal equivalent circuit of the device:
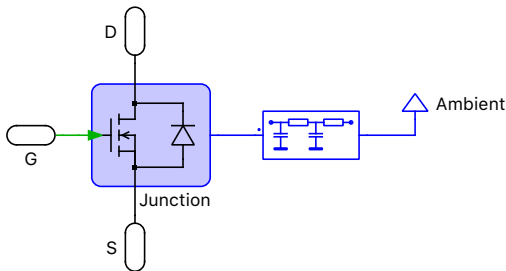


**Figure 2: MOSFET Model with body diode and thermal description**

Within the MOSFET model, the heat sink (i.e. the blue frame) represents the thermal capacitance of the chip. It collects all switching loss energy and conduction loss power from the dies of the MOSFET and the reverse diode. It also propagates its temperature back to the chip in order to receive the correct loss readings. The losses are propagated via a thermal RC chain which models the case of the component. The Ambient Temperature component at the end connects the component with an outside heat sink modeling the dissipator that the component is mounted on.

These descriptions can be viewed and edited by double-clicking on the component and selecting **Edit...** from the drop-down menu of the **Thermal description** parameter. In the SiC boost diode model, the thermal impedance of the device has been entered directly in the thermal description:



**Figure 3: Thermal impedance of SiC boost diode model**

In the main circuit it can be seen that the dissipator is split into two heat sink frames in order to comprise both the rectifier diodes and the semiconductors of the PFC stage. A thermal resistance connects the dissipator with the temperature of the ambient air.

The thermal descriptions for the MOSFET and diodes are stored in a private thermal library in the directory /buck_converter_with_pfc_and_thermal_model_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.

The "Efficiency Calculator" subsystem calculates the converter efficiency using the source power and total switch losses.

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

The simulation shows a start-up of the power supply under constant load. Fig. 4 with the electrical quantities shows the sinusoidal mains current and the ramp-up of the output voltage. A $120\,\mathrm{Hz}$ ripple in the output voltage can be observed. Fig. 5 shows the junction temperature of the MOSFET (green) and
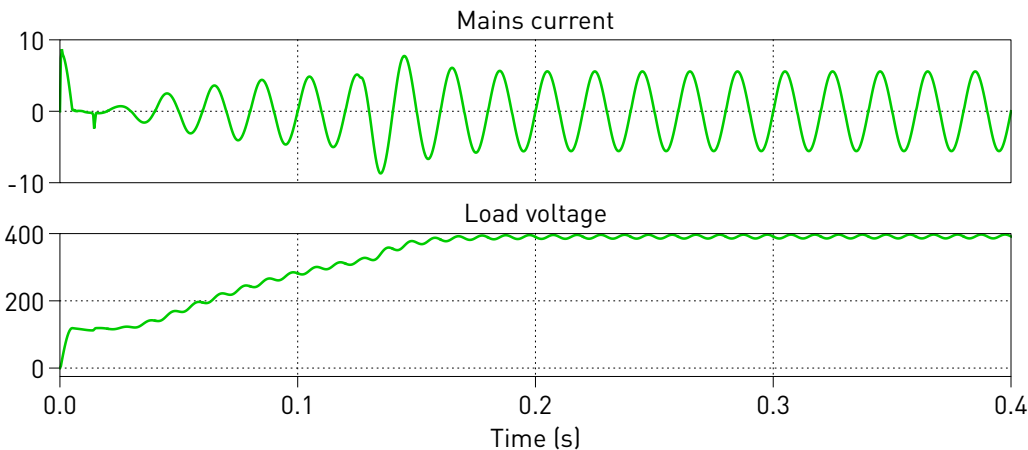


**Figure 4: Electrical behavior during start-up of the power supply under constant load**

the boost diode (red). The temperature of the external heat sink is rising very slowly in the time frame of the simulation.

## 3.1 Steady-state operation

It is not practical to determine the stationary temperature levels of the dissipator and the semiconductors by running a simulation until the thermal transients have settled. Due to the large thermal time constants such a simulation would take several hours.

Instead, you can perform a Steady-State Analysis that is pre-configured in the model. For PLECS Standalone or Blockset (in Simulink) execute the following steps:

- *Standalone:* From the **Simulation** menu choose **Analysis tools...**. This opens a dialog, in which the analysis has already been pre-configured. To start the analysis, click on the **Start analysis** button. You can display the progress of the analysis by clicking on the **Show log** button.
- *Blockset:* Double-click on the Steady-State Analysis block to open the dialog and click on the **Start analysis** button. The progress of the analysis is displayed in the MATLAB Command Window.
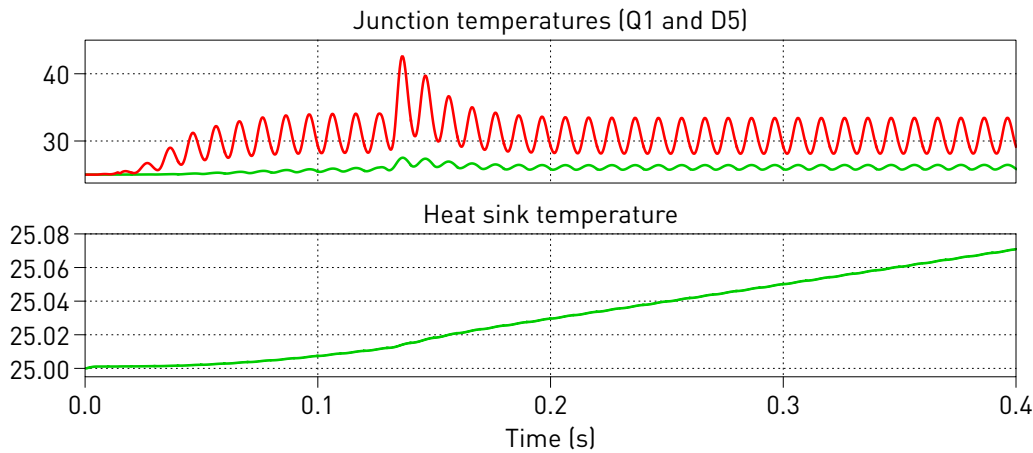
**Figure 5: Thermal behavior during start-up of the power supply under constant load**

When the analysis has finished a simulation of five steady-state cycles is displayed for all waveforms preconfigured in the Scopes.

# 4  Conclusion

This demo model shows a grid-connected boost converter with PFC and thermal modeling. The system is controlled by an IC from Infineon, which is modeled with functional blocks in a separate subsystem. The control is cascaded and consists of the inner current loop and the outer voltage loop. To describe the thermal behavior of the MOSFET and the boost diode, thermal descriptions were added in the component parameters. Due to the large thermal time constants a transient simulation would take several hours to reach steady-state. Instead, you can perform the *Steady-State Analysis* on the circuit, which finds the steady-state within seconds. For further information regarding the control IC, the circuit and the power semiconductors please refer to: http://www.infineon.com/pfc.

# References

[1] Standalone Power Factor Correction (PFC) Controller in Continuous Conduction Mode (CCM) Click to access online: ICE1PCS01 Control IC from Infineon.

**Revision History:**

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| PLECS 4.3.1 | First release |
| PLECS 4.7.1 | Updated the model with the Switch Loss Calculator |

**How to Contact Plexim:**

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