Loss Calculation and Thermal Model in a Buck Converter

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General

From a 300 volts DC source, a 12-kW buck converter supplies, through a 3-mH choke, a 125 VDC to the load. The initial switching frequency is set to 10 kHz and the duty cycle to 0.42.

The buck converter is implemented using a half-bridge IGBT model with loss calculation. Based on the thermal characteristics of the IGBT module selected for the simulation, both switching and conduction losses are calculated and injected into a thermal network. Thermal blocks of the Simscape foundation library are then used to build an external thermal network simulating heat dissipated by the heat sink.

The simulation illustrates the impact of switching frequency and load on the total losses of the buck converter. The circuit is simulated using a variable-step solver (ode23tb) and the SimPowerSystems (SPS) simulation type is set to "Continuous - *Enable use of ideal switching devices*".

Half-bridge IGBT Model Description

If you go inside the model (using *Edit/Look under mask* from the main menu), you will see four sections:

1) Power

The buck converter is built using standard SPS power electronics elements (IGBT/Diode block). The upper IGBT/Diode block is pulsed from the external pulse generator. In this buck topology, there is no need to pulse the lower IGBT block (only the diode will be turned-on).

2) Loss Calculation

One Simulink subsystem is used to calculate the IGBT losses and another one for the diode losses. The losses are calculated as follows:

For the IGBTs:

- Turn-on loss: Pre-switching value of the voltage across the device, post-switching value of the current flowing into the device, and the junction temperature are used to determine the energy losses with the help of a 3-D lookup table. This energy is converted into a power pulse which is injected into the thermal network.
- Turn-off loss: Pre-switching value of the current flowing into the device, post-switching value of the voltage across the device, and the junction temperature are used to determine the energy losses with the help of a 3-D lookup table. This energy is converted into a power pulse which is injected into the thermal network.
- Conduction loss: Value of the current (Ic) flowing in the device and its junction temperature determine what would be the saturation voltage (Vce) across the IGBT using a 2-D look-up table. This Vce is then multiplied by Ic to obtain the losses which are injected into the thermal network.

For the diodes:

- Reverse recovery loss: Pre-switching value of the current flowing into the device, post-switching value of the voltage across the device, and the junction temperature are used to determine the energy losses with the help of a 3-D lookup table. This energy is converted into a power pulse which is injected into the thermal network.

- Conduction loss: Value of the current (If) flowing in the device and its junction temperature determine what would be the on-state voltage (Vf) across the diode using a 2-D look-up table. This Vf is then multiplied by If to obtain the losses which are injected into the thermal network.

3) Thermal model

A Simulink state-space block is used to build a one-cell Cauer network modeling the thermal capacitance of the device junction as well as its junction-to-case thermal resistance. A Simscape physical modeling connection port is built using an "*Ideal Heat Flow Source*" block.

4) Measurements

A bus creator is used to output all relevant signals to a Simulink outport.

Note:

The loss calculation is based on the specifications found on the manufacturer's data sheets. In our demonstration, we provide a choice of 3 different commercial components. Using the "IGBT type" and "Diode type" pop-up menus of the mask, you can choose among these three IGBT modules. (The thermal specifications are saved on two ".mat" files). However, you could create your own thermal library by modifying the 2 following ".m" files: *LossSpec_IGBT_LibCreate* and *LossSpec_Diode_LibCreate*.

Simscape Thermal Model Description

This Simscape subsystem contains a two-cell Cauer network based on the thermal capacitances (case and heat sink) and resistances (case-to-sink and sink-to-ambient) specified in the mask menu. If you go inside the model, you will see various Simscape blocks (from the thermal foundation library) used to build the thermal network. Of course, a far more complex thermal representation can be done with Simscape. For the sake of simplicity, we have used this two-cell Cauer network with arbitrary values for the thermal capacitances in order to reduce the time required to simulate the thermal phenomena.

Demonstration

Using the "*Half-Bridge IGBT*" pop-up menu, select "*Fuji: Half-bridge IGBT 600V/150A*" as IGBT and Diode type. Run the simulation for 4 seconds and observe the following sequence of events on the various scopes and displays:

- From t=0 sec to t= 2 sec, the buck converter supplies a 125 volts DC to a 12-kW load using a switching frequency of 10 kHz. In steady-state, the converter total losses are 235 W and the diode junction temperature reaches 122 degrees Celsius.

- At t=2 sec, an extra load of 2.5 kW is switched-on. We can observe a significant increase in the converter losses and the diode junction temperature reaches a critical temperature of 144 degrees Celsius.

- At t=2.5 sec, the switching frequency of the converter is reduced to 2.5 kHz. In steady-state, the converter total losses go down to 212 W and the diode junction temperature is reduced to 125 degrees Celsius.

Select the "*ABB: Half-bridge IGBT 3300V/250A*" as IGBT and Diode type and re-run the simulation. At around 1 sec, the junction temperature of the IGBT will exceed 150 degrees Celsius. The simulation will stop and you should then hear something…