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Review of Power Converter Temperature and Loss Simulation using Compact Device Models

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1. Introduction

Power electronic converter power densities are steadily being increased [1,2], allowing an increased range of applications to be addressed, as well as functional improvement, and a reduced cost and mass. However, if the power dissipation of the converter remains the same, the same heat must be extracted from a smaller volume, placing extra demands on the heatsinking of the converter and impacting the device reliability due to the thermal cycling [3-5]. Fast and accurate simulation must be used in any of these methods to achieve either manual or numerical optimization, for example [1,6-7]; however in reality a compromise must be made.

In this paper an alternative method is described, decoupling the fast (device electrical) time constants from the slow (thermal and converter electrical) time constants. We describe the framework developed recently [8] for converter electro-thermal modelling, integrating fast converter simulation and accurate physics-based device models. The device models are also summarized, including parameter extraction. In addition we describe an advanced compact model for the heatsink [11].

2. Converter Modelling

The key to any method of fast converter loss and temperature modelling is the decoupling of the device and converter modelling. The device switching conditions – switching frequency, supply voltage, load current, duty ratio and temperature – all remain approximately constant during any single switching cycle. Usually, it is the load current, duty ratio and temperature that vary in a power converter, but at frequencies much lower than the switching frequency.

Therefore the average power dissipation for that switching cycle may be obtained from device simulation for that combination of conditions. Hence a look-up table may be built for different combinations of conditions. Simply accessing the table in converter simulation replaces the device modelling step, making converter simulation much faster.

The steps may be summarized as follows (see also Fig. 2):

1. Compact device models generate accurate look-up tables of losses against switching conditions.
2. A fast "ideal switch" converter model, using the look-up tables and a thermal model of the heatsink and packaging to calculate device temperatures from losses very quickly.

The converter model may be implemented as a custom model such as Simulink [8], or as an ideal switch model, for example in PLECS [9].

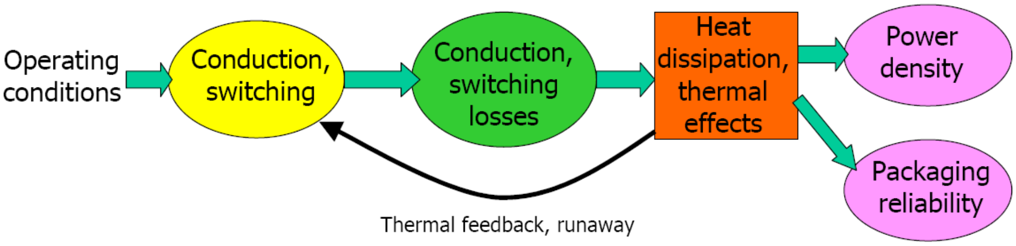

Fig. 1: Constraints on converter design from thermal issues

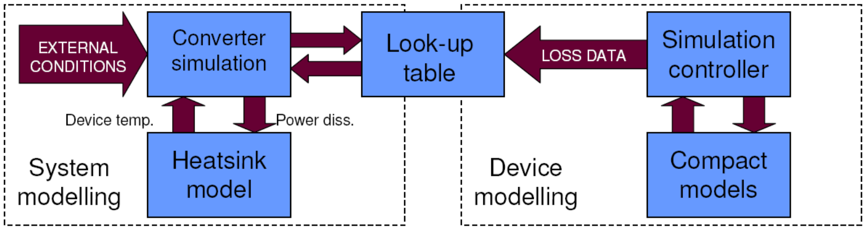

Fig. 2: Two-stage converter model

3. Experimental Validation

The electrical conditions of the inverter under test are based on those experienced inside a hypothetical hybrid-electric vehicle, subjected to the Artemis urban driving cycle [10]. To measure the chip temperatures, the test inverter used here had its cover removed. This allows infra-red camera images to be taken of the chips; suitable paint was sprayed on to the chips and surrounding area to obtain accurate estimates of the temperatures. Fig. 3 shows the comparison between the simulated and experimentally-obtained temperature profiles of upper and lower pairs of devices in the test inverter phase leg during the first minute of the load cycle. The results show a close match.

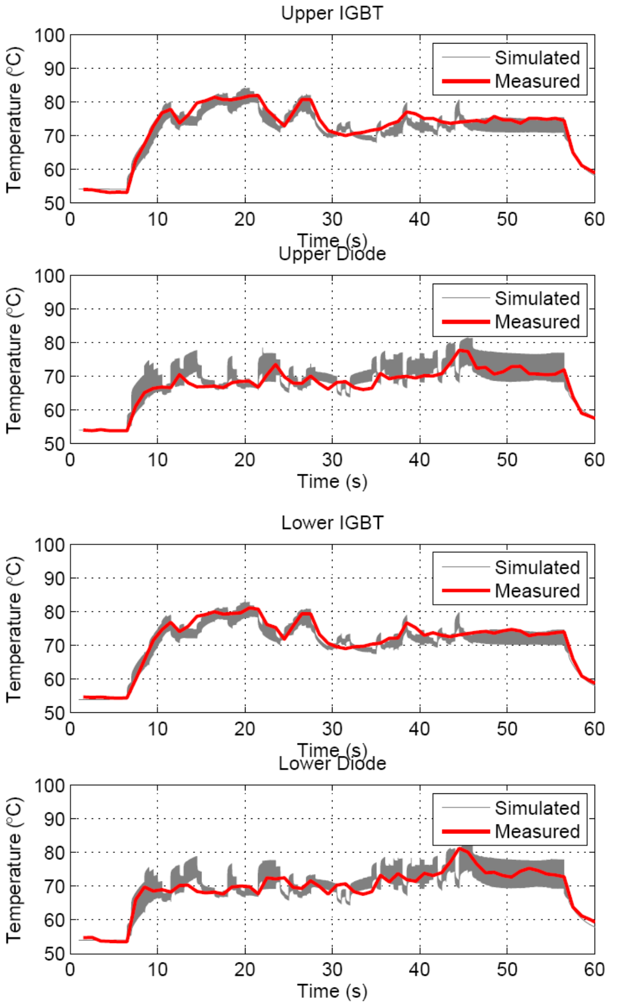

Fig. 3: Phase leg device temperatures for the load cycle [10].

The time taken for the converter simulation to run was 605 seconds; the look-up tables of device losses took an additional 119 seconds to run beforehand, giving a total of 724 seconds (approximately 12 minutes).The results in fig. 3 show that the device temperatures predicted by the fast converter model match the experimental results closely. The model has clearly captured the thermal transients during the load cycle. The validation of the fast converter model allows the use of the model in converter design and optimisation with confidence.

The resulting temperature profile can be used in at least two ways: (a) to estimate the maximum junction temperature rise in a load cycle, and (b) to estimate the packaging and device reliability. The latter is particularly important, and follows the method outlined in [9]. This gives a rather conservative estimate of the packaging lifetime, but is a useful tool to compare different converter designs.

4. Conclusions

This paper has presented a fast converter simulation method for modelling and designing power converters. The device models are valid across a wide range of conditions, including temperature. The simulated device temperatures match closely the experimental device temperatures, measured from a test inverter subjected to a load cycle (mission profile). This demonstrates the accuracy of the converter simulation method and device models. It allows the use of the method in design of converter systems and in the estimation of converter reliability.

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