Doctoral Dissertation

Doctoral Program in Electrical, Electronics and Communications Engineering ($XXXIV$ cycle)

# Junction Temperature Estimation Via Plug-in System for the Design Validation of IGBT Industrial Power Converters


By

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# Abstract

In the design process of power electronics converters, the power semiconductors thermal modelling is one of the most critical tasks. Being the semiconductors overtemperature a common source of the power converters failure and the operating temperature one of the main reasons of the power module aging, several methods for the junction temperature estimation of semiconductors have been deeply discussed in literature. Despite all these methods, the temperature measurement solution able to provide the thermal models validation of power converters are still an open issue.

Therefore, this dissertation presents a straightforward method to estimate the junction temperature directly on the target converter using a plug-in measurement system. The estimation is based on the IGBT on-state voltage detection under high current and with a dedicated sensing circuitry externally connected to the converter under test (CUT). This solution is specifically designed to fulfil the requirements introduced by the prototyping and design validation processes since it allows a fast and reliable converter monitoring in all operating conditions. During the prototyping phase, the estimation of the junction temperature allows the accurate testing of the converter expected performance and the thermal model validation.

The proposed ON-state voltage measurement is a simple and reliable circuit. The input stage consists of a voltage divider that has high impedance. Therefore, it has a minimum impact on the power module operation, and the turn-on and turn-off switching transients of the IGBTs are not affected by the plug-in boards. The adopted methodology for the temperature estimation is structured as follows: (1) calibration phase, (2) data analysis phase and (3) temperature estimation phase. During the calibration phase, the IGBTs embedded in the power module under test are characterized to extract the ON-state curves at known temperature and load current (i.e., the $v_{CE} = f(i_C, T_J)$). In the data analysis phase, the calibration curves are manipulated to obtain the reverse function $T_J = f(v_{CE}, i_C)$. In the temperature

estimation phase, the reverse functions are used for the semiconductor junction temperature estimation during the actual operating conditions of the converter.

The acquisition circuitry and all the steps for the temperature estimation are validated on a 68 kVA IGBT-based industrial three-phase inverter. The experimental results prove that the proposed acquisition system can provide an accurate estimation of the IGBTs junction temperature during the converter operation. Furthermore, the converter performance for different design parameters (for instance the dc-link supply voltage and the switching frequency) can be validated directly during the operation in a fast and reliable way. A comparison between the estimated junction temperature provided by the plug-in boards with the temperature provided by a thermal simulation of the CUT shows that the simulation models may produce wrong results due to simplified thermal modelling. This results clearly demonstrates the importance of having an experimental method able to validate the converter design on the real industrial prototype.