Junction Temperature Estimation Technology Update 2018

Next Generation Power Stack Technology can deliver significant benefits to the whole converter and reduce development, capital and operating costs through improved rating/efficiency and enhanced monitoring. Estimation of IGBT and diode junction temperature is a key enabling technology to deliver these benefits. Recent achievements have been made in making junction temperature estimation practical for industrial applications ahead of customer evaluation.

What is Tj Estimation?

Junction temperature (Tj) estimation uses temperature sensitive electrical parameters (TSEPs) from the IGBT and diode, *measured on the gate drive*, to estimate the on-chip junction temperature.

It is a novel approach that incorporates calculation of device temperature (Tj "simulation", i.e. loss look-up tables plus a thermal model), measurement of the module temperature sensor, e.g. NTC thermistor, and detailed electrical measurements of the power devices.

How is Tj Estimation useful?

Junction temperature estimation enables the following features in next generation "smart" converters:

- Dynamic rating control: intelligent over-rate/de-rate;
- Optimised parallel inverter stack current sharing;
- **Condition monitoring:** detection of wear-out and abnormal operation, giving predictive maintenance;
- Improved validation of inverter stack design during development and type testing;
- IGBT/diode over-temperature detection.

Resulting benefits to the converter manufacturer are optimised performance (rating or efficiency) vs cost, e.g. through reduction of margins, and to the end user (operator) the early detection of abnormal operation and potentially reduced operating costs.

Calibration & Industrialisation

Significant work has taken place to refine an **auto-calibration method** for characterising each IGBT module in a converter. This is essential for industrial deployment, because the device temperature dependence varies between module batch. For example, a typical TSEP (e.g. $V_{CE(on)}$) may have a sensitivity of 1 to 10 mV/K; with typical variations of ±100 mV or more across batches, this gives a 10-100 °C error in estimated Tj unless accurate calibration is performed.

The auto-calibration method extracts the temperature sensitivity of the devices while in operation. This provides the following benefits:

- Robustness to differences in temperature dependency between device batches/samples;
- Robustness to changes in device parasitics (electrical/thermal resistance), e.g. due to ageing;
- Robustness to drifts in measurement circuits;
- Compatibility with production test sequences, with minimum impact on converter manufacturing costs.

It is also applicable to a wide range of converter switching strategies and mission profiles, across all device voltage ratings and for all device module types. It is suitable for both Si devices (IGBTs, PiN diodes) and SiC devices (MOSFETs, schottky diodes).

Recent Results

Recent results from validation of the auto-calibration algorithm are shown in Figure 1. This shows a 5-minute training run, followed by a random mission profile. The calibration updates the temperature dependencies, showing good agreement within ±2 °C.

Temperature Comparison

Figure 1 also shows that the estimated temperatures after calibration are significantly better than either the pre-calibration temperatures – which are based on simulated junction temperature without a fully-characterised thermal model of the module and heatsink – or the baseplate temperature (shown in black). The different temperature options are summarised in the following table.

T_base	Simple external sensor Suitable for all module types Significant error (>20 °C)	✓ ✓ ×
T_NTC	Better accuracy than T_base Can detect some degradation Requires module with NTC sensor Worse accuracy than Tj_est	✓ ✓ × ×
Tj_sim	Better accuracy still: approx 5 °C Requires complex thermal model (full FEM characterization) Cannot measure degradation	✓ × ×
Tj_est	Best accuracy: <5 °C Self-calibrating with Amantys algorithm Suitable for all module types Requires baseplate or NTC sensor	✓ ✓ ✓ ✓


Medium voltage motor drives


Locomotive traction & marine drives


Wind turbine & solar inverters


High voltage DC infrastructure

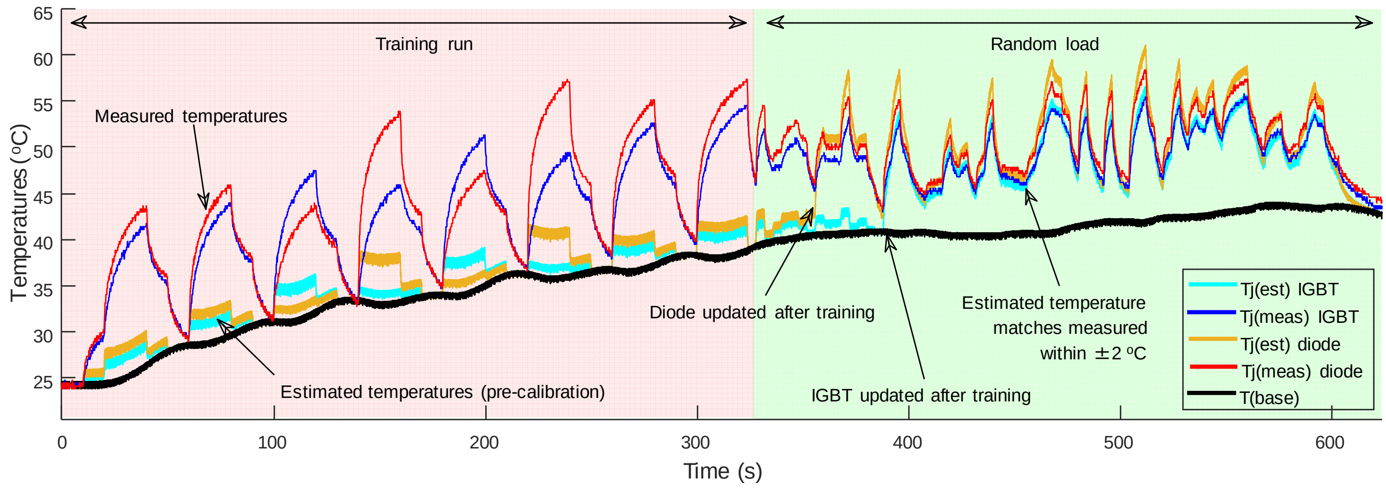

Fig. 1: Comparison of estimated junction temperatures and measured junction temperatures, showing the training run and a random mission profile. (Note that the calibration does *not* require knowledge of the measured junction temperature.)

T_base and T_NTC are less accurate because these measurement points are a significant distance from the device chips, as shown in Figure 2. Tj_est performs best because it is using TSEPs – i.e. the temperature dependencies of the devices themselves – to estimate the temperature.

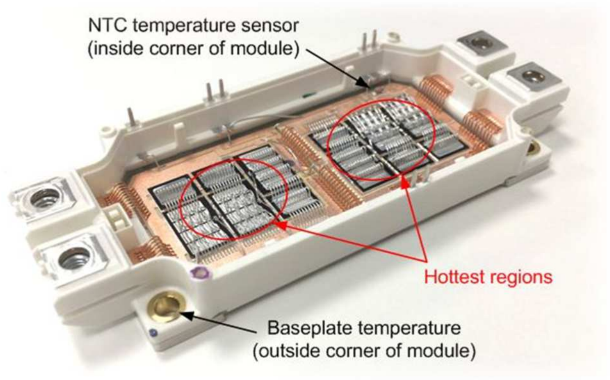

Fig. 2: Location of different temperatures in a typical half-bridge IGBT module

Technology Evaluation

Amantys will be releasing a Tj Estimation Evaluation Kit later in 2018. This will allow customers to evaluate the technology in test inverter stacks, or in converters in the field. It can work with any gate drive, and can take detailed measurements of device operation within a phase leg (half-bridge). It is compatible with all device modules up to and including 3300 V rating.

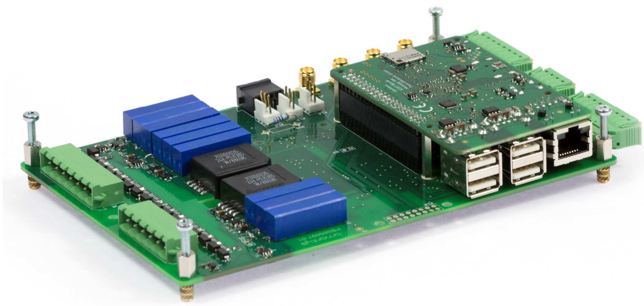

Fig. 3: Tj Estimation Evaluation Kit

System Integration

A number of possible options exist for commercial deployment, including licensing and customised driver development. System integration in a customer's inverter stack will also be assisted by **Amantys Power Insight** technology, giving two-way communication between the converter controller and the gate drive.

Amantys would be delighted to discuss your requirements.

Want to know more…?

For more information, please contact us at info@amantys.co.uk.

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