High performance DC link capacitor/bus sourcing dual Infineon HybridPACK™ Drive inverters for EV applications

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Abstract

A high performance integrated capacitor / bus for the Infineon HybridPACK™ Drive was presented previously [1]. This foundation will now be used as the basis for evaluating a single DC link capacitor / bus to support two HybridPACK™ Drive inverter stages, thus enabling a significant improvement in power density, weight and cost for high performance EV applications. Detailed knowledge of the drive cycle is required along with full thermal characterization to demonstrate the required life. Transient thermal simulation results and experimental data are provided. These results are utilized to define practical topologies and power limits for one DC link feeding two HybridPACK™ Drive modules for dual motor in-board drive applications.

1. Introduction

- Low-inductance DC link allows IGBT operation at maximum working voltage and highest switching speed for optimal efficiency.
- 700A186 integrated cap/bus demonstrated previously [1] has 8nH and supports 150kW peak power using HybridPACK™ Drive.
- Now consider ONE 500V 500µF DC link feeding TWO inverters (700A243) – ideal for dual motor in-board drive applications per Figure 1.

Figure 1. Illustration of a single integrated cap / bus (SBE 700A243) sourcing two Infineon HybridPACK™ drive IGBT modules.

2. Simulation

- Full 3D transient thermal finite element analysis of 700A243 using Flux™ software [2] as shown in Figure 2.
- Thin region model for bus insulation to reduce the mesh.
- Measured material property data for capacitor windings.
- Winding losses including electrode I^2R, dielectric dissipation, and DC leakage.
- Bus losses subject to DC component and ripple current.
- Empirically validate model and apply to 700A243.

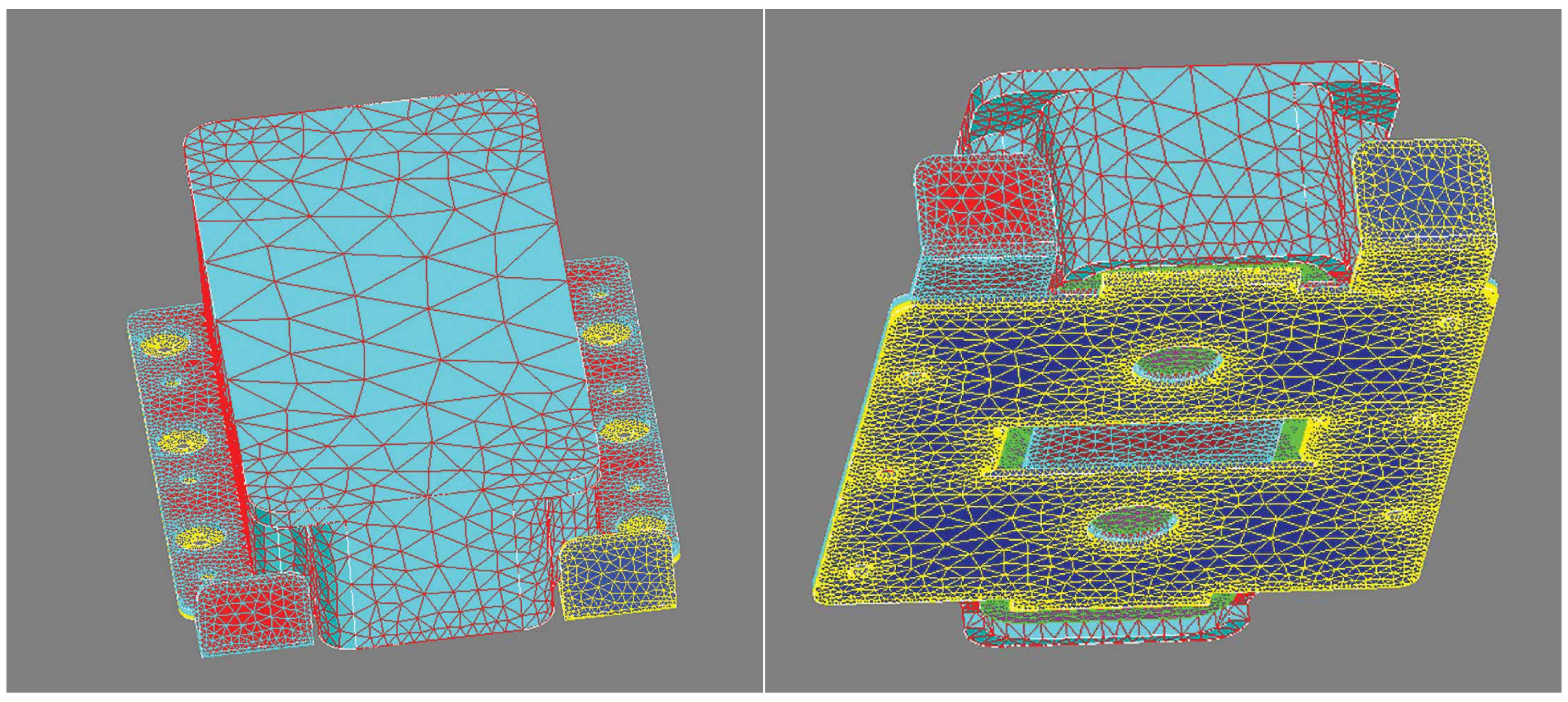

Figure 2. Finite element domain and boundary conditions for 3D simulation

3. Ripple Current Testing

- Hofer eds specified 320Arms total capacitor ripple current supplying two HybridPACK™ Drive power stage.
- Set up 700A243 prototype instrumented with thermocouples in SBE high current tester as shown in Figure 3.
- Define 65°C boundary conditions on bus and case side using water cooled aluminum plates.
- Compare to simulation results as shown in Figure 4.
- Accounting for heat loss via IGBT connections a reasonable fit is obtained.

Figure 3. SBE 700A243 500µF 500V integrated capacitor/bus installed on cooling plate and connected to ripple current source for temperature rise testing.

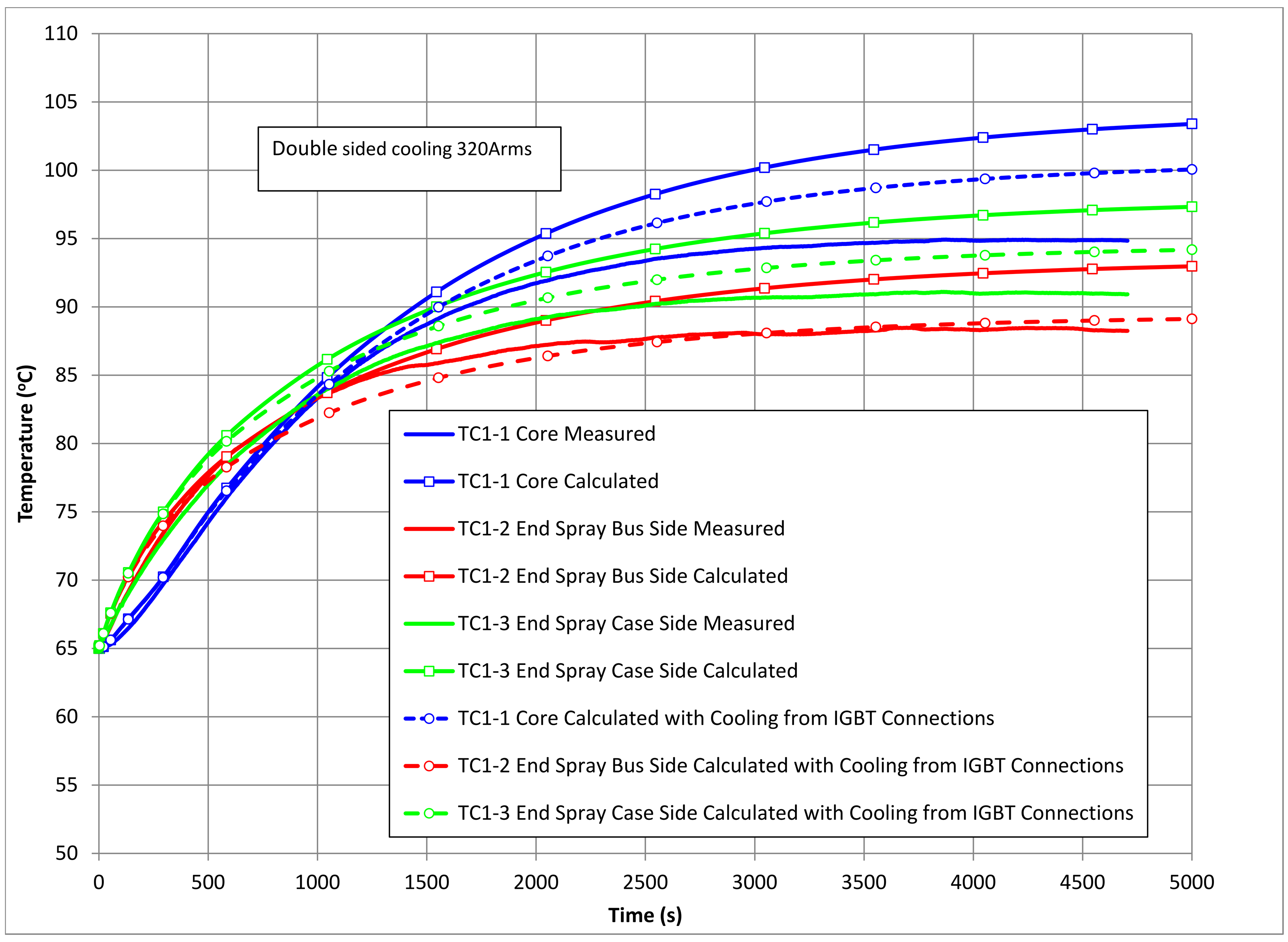

Figure 4. Calibration of the capacitor/bus transient thermal finite element analysis against measured data at 320Arms and 20kHz with 65°C cooling applied to the case and bus.

4. Drive Cycle

- Hofer eds has provided the operating conditions for continuous and peak.
- Continuous operation:
  - DC current 250A,
  - IGBT module phase current 160Arms,
  - EM phase current (current sum inside 6 phase EM) 320Arms,
  - Capacitor ripple current 192Arms.
- Peak operation (30 seconds):
  - DC current 1000A,
  - IGBT module phase current 480Arms,
  - EM phase current (current sum inside 6 phase EM) 960Arms,
  - Capacitor ripple current 580Arms.
- With interleaved PWM, capacitor ripple current can be reduced nearly up to 50% per Figure 5.

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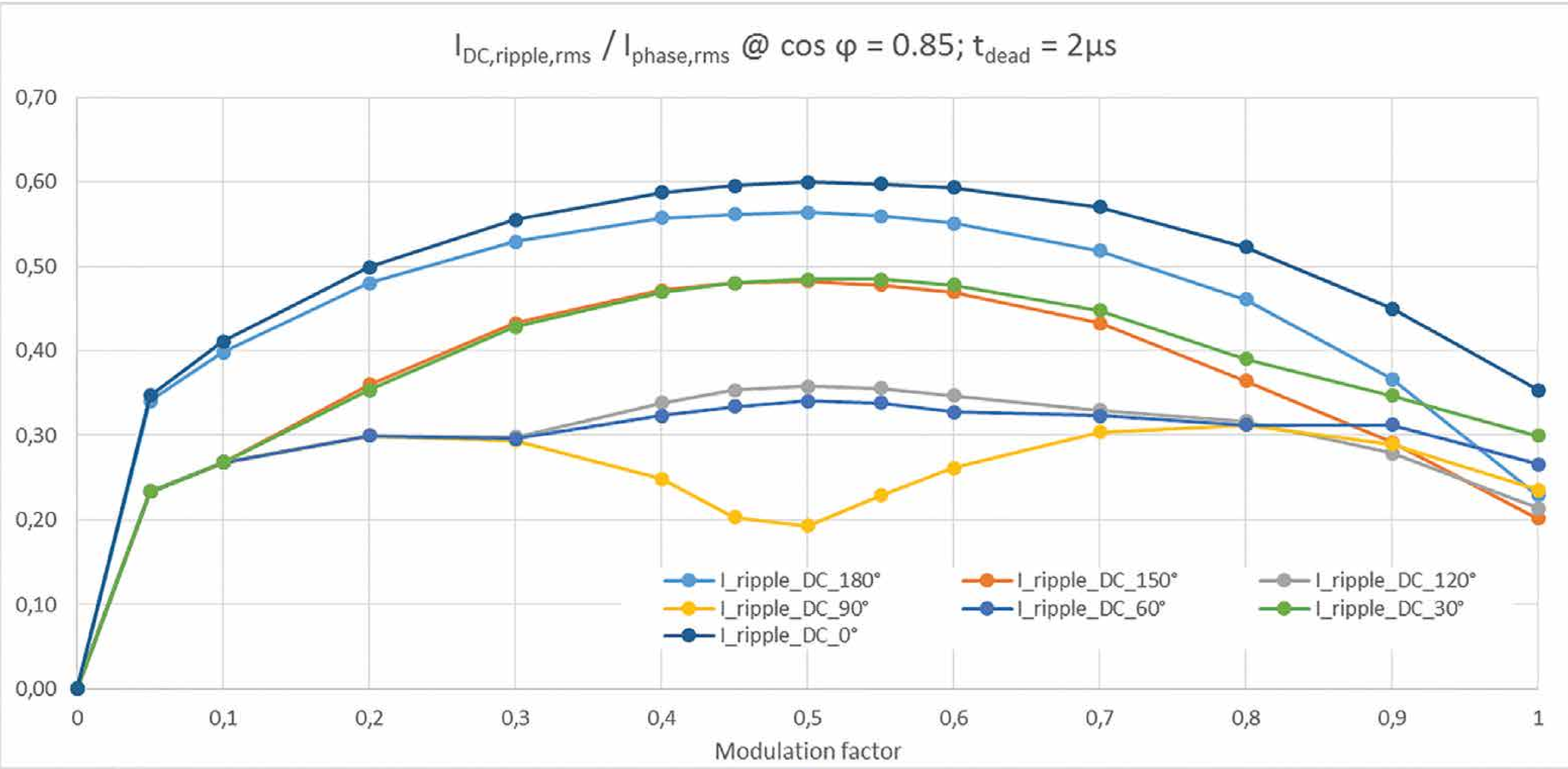

Figure 5. Capacitor ripple current normalized to phase current over modulation factor for different PWM phase-shift values

5. Capacitor/Bus Rating

- Simulation assumes heat transfer only through the bus.
- Thin gap pad to 65°C cooling plate so that bus insulation is the limit.
- Capacitor and bus losses included for all cases.
- Consider worst case no interleave continuous operation for one hour followed by 30 second peak (red curves in Figure 6) followed by an additional hour of continuous operation.
- Interleaving PWM reduces capacitor ripple by 50% leading to blue curves in Figure 6.
- Consider limits for 10,000 hour life:
  - 75°C coolant is possible with no interleave,
  - 87°C coolant is possible with interleaving.

6. Power Module Heating of the DC Link

- Thermal equivalent circuit derived as shown in Figure 7.
- Compare theory and experiment in Figure 8.
- Impact of connecting DC power tabs to actual circuit must be understood.
- Ultrasonic welded power tabs on internal ceramic substrate provide excellent thermal connection.
- Power tabs can actually cool the capacitor as shown in Figure 9.
- Consider the effect:
  - 0 to 3600 seconds (continuous): IGBT power tabs cool the capacitor,
  - 3600 to 3630 seconds (peak): The IGBT power tabs at same temperature as bus,
  - 3630 to 7200 seconds (continuous post peak): IGBT power tabs cool quickly and then cool the bus.

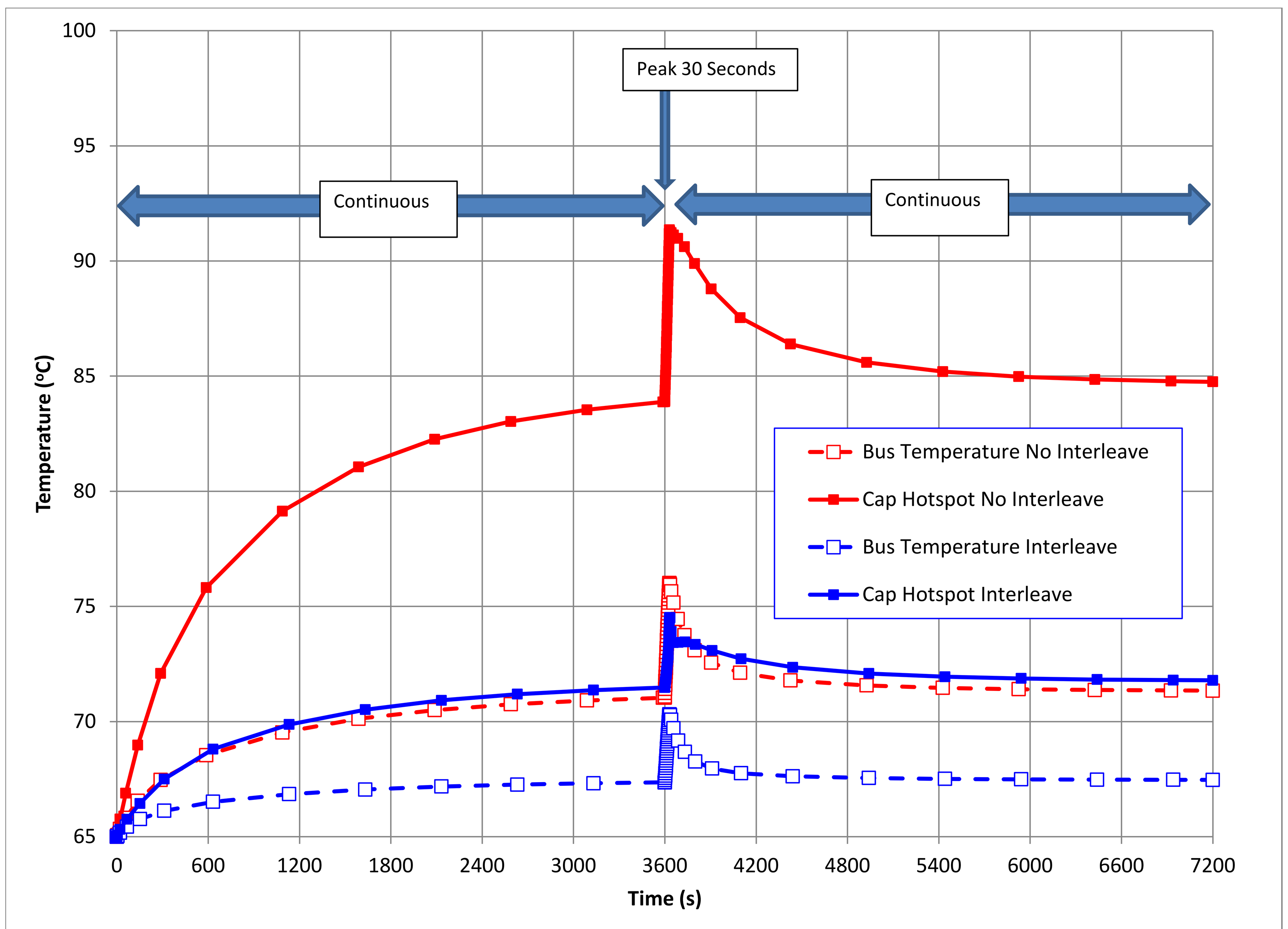

Figure 6. Maximum capacitor winding and bus temperatures predicted for one hour of continuous operation followed by a 30 second peak operating condition at 65°C with and without interleaved PWM to reduce ripple current.

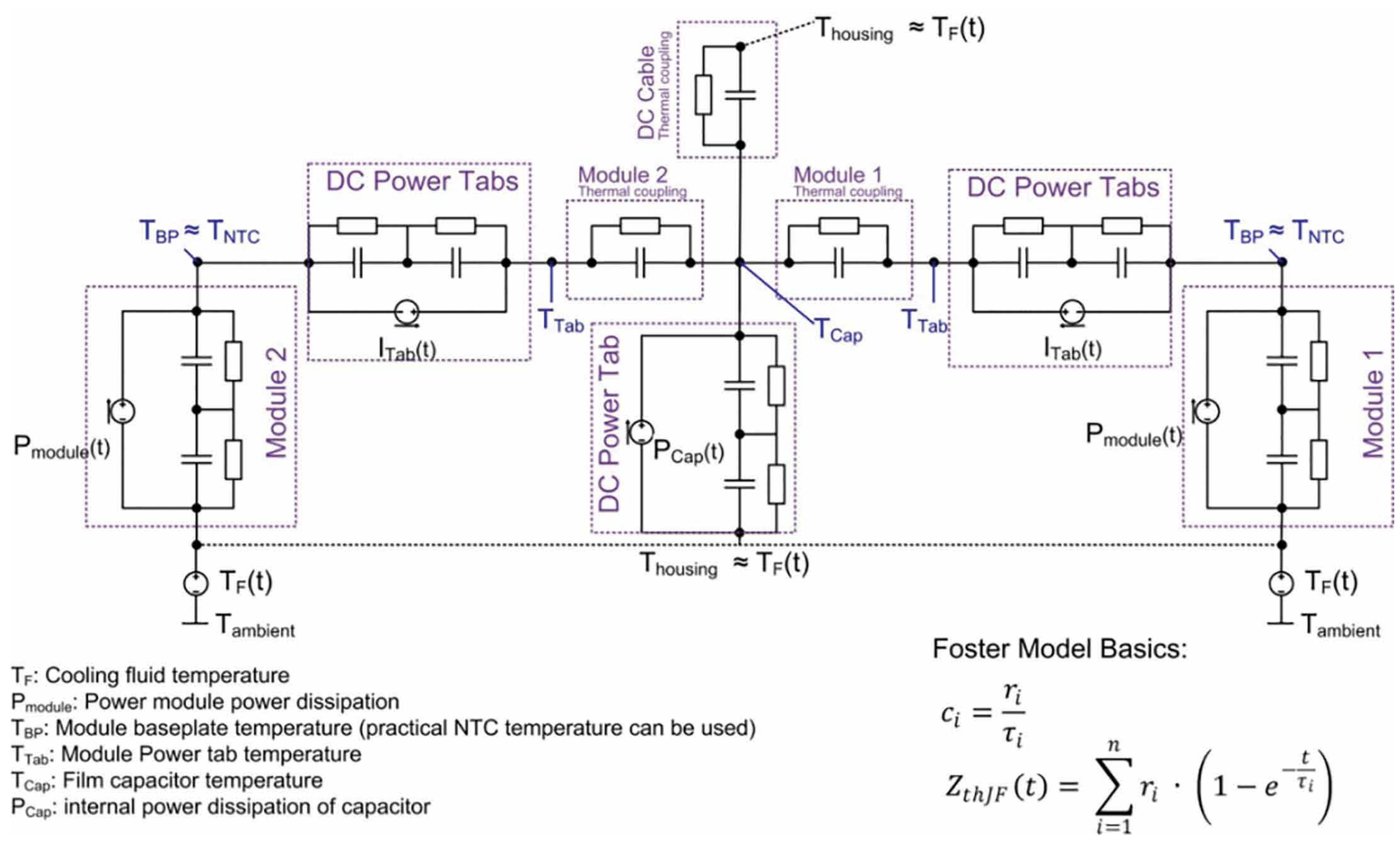

Figure 7. Behavioral thermal model for dual power module inverter and capacitor including the power tab connection and the thermal coupling paths. For single inverter applications the half side of the model can be applied.

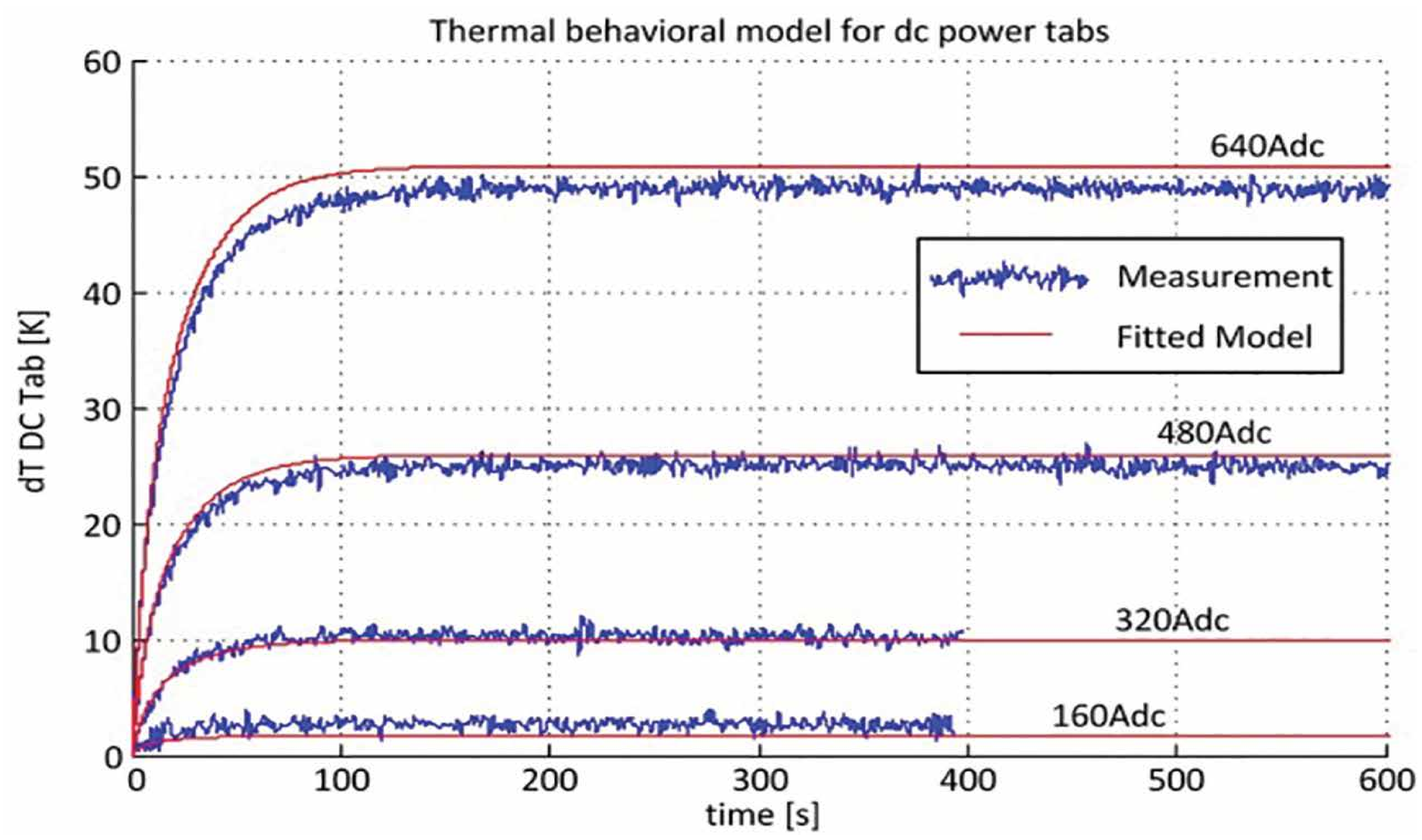

Figure 8. Comparison of behavioral thermal model with experiments. Heating of the power module power tabs in combination with the SBE 700A243 capacitor.

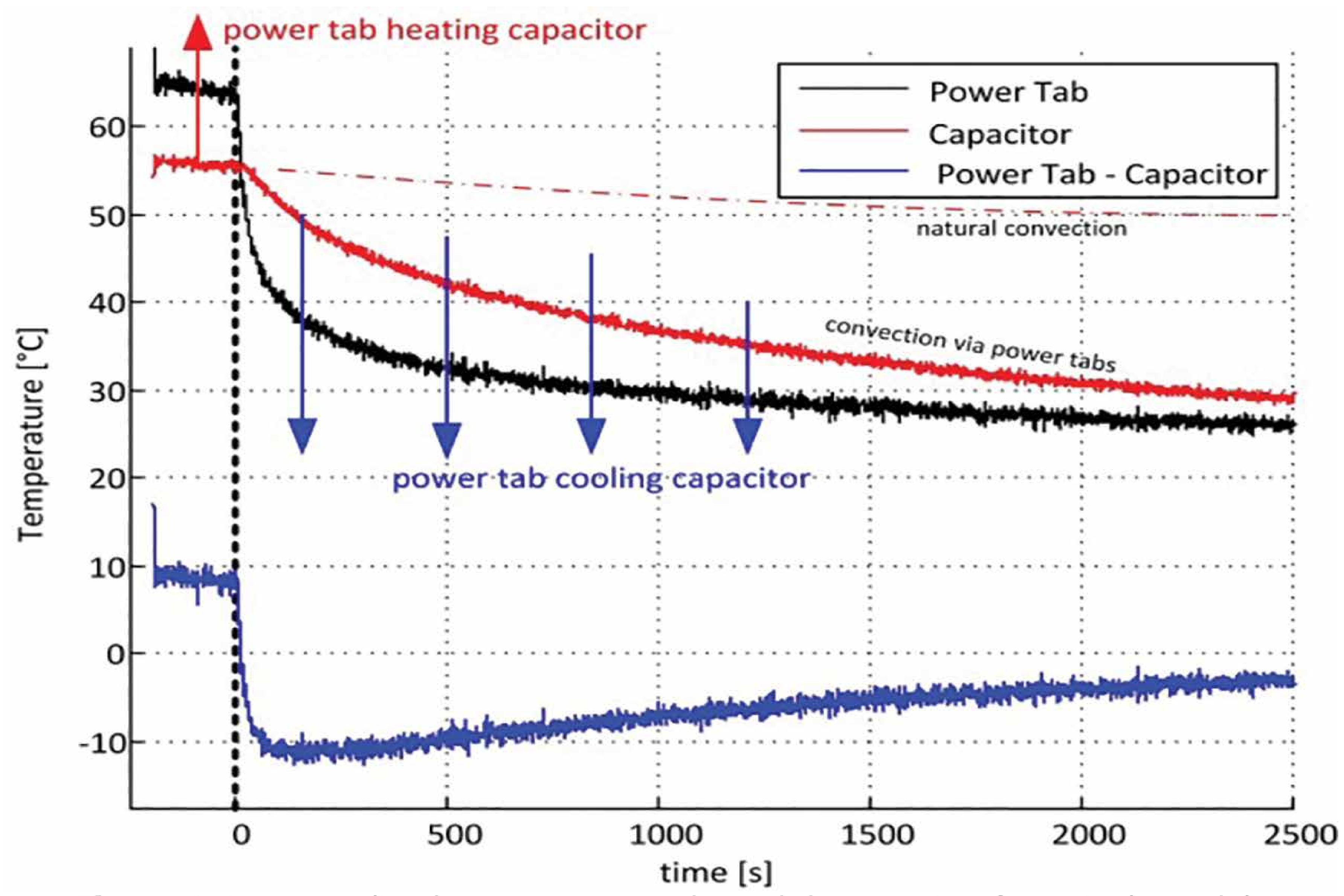

Figure 9. Heat coupling between power tabs and the capacitor for a single module connected. The power module tabs can cool the capacitor in light load conditions especially when the capacitor was heated before due to a high vehicle acceleration event.

7. Conclusion

- The use of a single 700A243 integrated cap/bus DC link with 500µF. can support operation of two parallel inverter stages of HybridPACK™ Drive modules.
- Efficient cooling of the bus is required.
- Optimized internal design of the HybridPACK™ Drive power tabs reduces IGBT heat load and actual provides cooling to the bus.
- Interleaved PWM reduces capacitor ripple current by up to 50%.
- Interleaving is simplified with the single integrated DC link (no resonance issues).
- This concept looks very promising to reduce cost and weight for dual motor in-board drive applications for high performance EV.