EconoDUAL™ 3 power kit

Reference design for 250 kW traction inverters

About this document

Scope and purpose

This user guide provides an overview of the power kit REF-CAV250KMT7INV including its main features, key data, pin assignments, mechanical dimensions, and corresponding performance. The reference kit REF-CAV250KMT7INV is a traction inverter for commercial vehicles with a nominal output power of 250 kW.

REF-CAV250KMT7INV includes the EconoDUAL™ 3 module FF900R12ME7P_B11, the current sensor TLE4973, and the gate driver IC 1ED3321MC12H. The combination of these products helps customers evaluate them in one design and experience the interaction between the products.

Intended audience

This user guide is intended for all technical specialists working on high-voltage traction inverters and those interested in understanding how Infineon products such as TRENCHSTOP™ IGBT7, EiceDRIVER™, and XENSIV™ current sensors work under application conditions.

Reference kit

Infineon power modules are mounted on a heatsink with a press-in PCB and the current sensors are pre-assembled on the busbar. This compact design shows a form factor similar to a commercial design.

Note: Boards do not necessarily meet safety, EMI, and quality standards (for example UL, CE) requirements.

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Note: *Please note the following warnings regarding the hazards associated with development systems.*

Table 1 Safety precautions

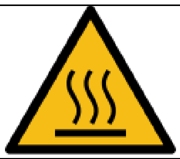
	**Warning:** *The DC link potential of this board is up to 1000 VDC. When measuring voltage waveforms by oscilloscope, high-voltage differential probes must be used. Failure to do so may result in personal injury or death.*
	**Warning**: *The evaluation or reference board contains DC bus capacitors, which take time to discharge after removal of the main supply. Before working on the drive system, wait 5 minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	**Warning:** *The evaluation or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by an oscilloscope. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	**Warning:** *Remove or disconnect power from the drive before you disconnect or reconnect wires or perform maintenance work. Wait five minutes after removing power to discharge the bus capacitors. Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.*
	**Caution:** *The heat sink and device surfaces of the evaluation or reference board may become hot during testing. Hence, necessary precautions are required while handling the board. Failure to comply may cause injury.*
	**Caution:** *Only personnel familiar with the drive, power electronics and associated machinery should plan, install, commission and subsequently service the system. Failure to comply may result in personal injury and/or equipment damage.*
	**Caution:** *The evaluation or reference board contains parts and assemblies sensitive to electrostatic discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.*
	**Caution:** *A drive that is incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the motor, supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.*
	**Caution:** *The evaluation or reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.*

Table of contents

1 The power kit at a glance

This user guide provides information about Infineon's 250 kW power kit solution for traction applications. The power kit comprises a power conversion block with TRENCHSTOP^{TM} IGBT 7 power modules, a gate driver PCB with Infineon's latest EiceDRIVER^{TM}, XENSIV^{TM} current sensors, automotive qualified DC-link capacitors, and a water cooling unit (Figure 1). Due to its assembly, it has a compact design and a power density of 27.87 kW/l.

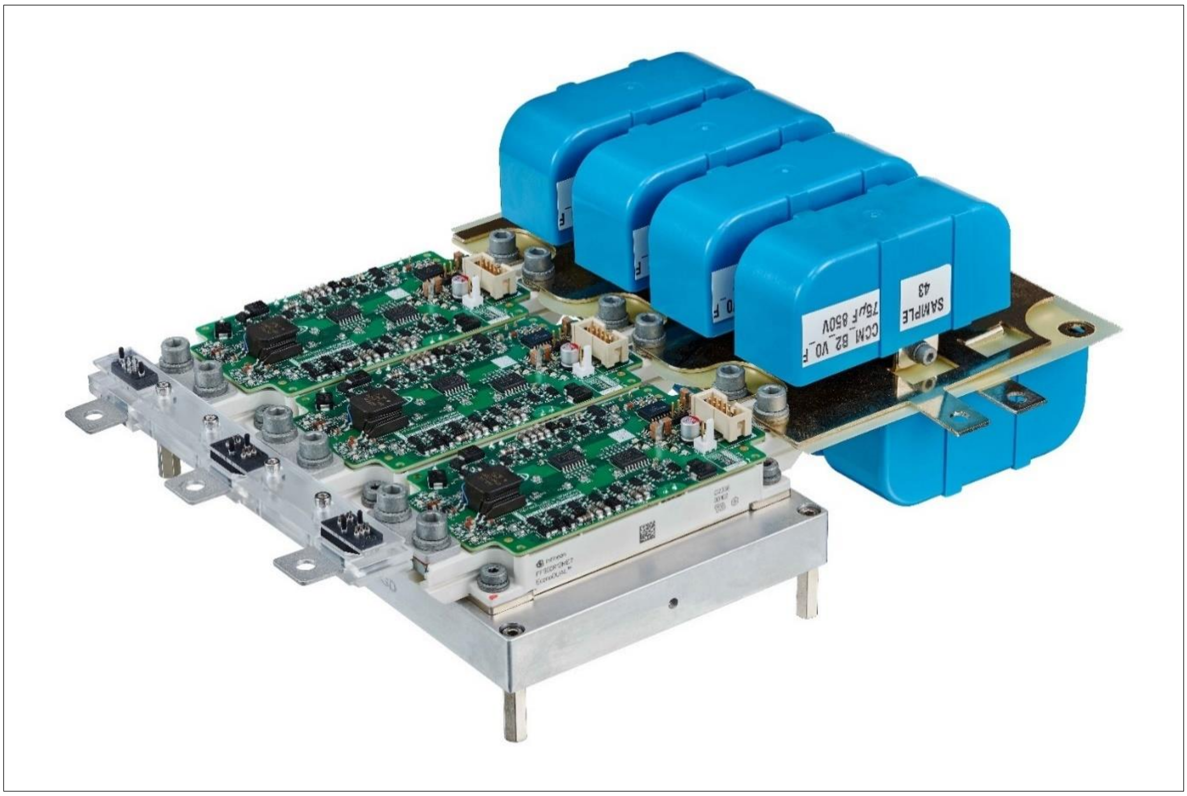


Figure 1 **EconoDUAL™ 3 power kit**

1.1 Scope of supply

- 3x EconoDUAL™ 3 modules: FF900R12ME7P_B11
- 3x Gate driver boards: EVAL-FFx00R12XE7F3DR
- 3x XENSIV^{TM} current sensors: TLE4973
- 8x DC-link capacitors mounted on a busbar
- 1x water cooling unit

1.2 Block diagram

Figure 2 shows a block diagram of the components and materials. NTC, phase current measurements, and power supply for the gate driver board are isolated. The power stage including the gate driver boards can be driven with a control card/interface that does not need an isolation interface.

The power stage includes EconoDUAL™3 modules with TRENCHSTOP™ IGBT 7 technology inside. Each power module has an NTC to monitor the temperature.

Based on a DC-AC B6 inverter topology, the DC stage is connected to DC-link capacitors through low stray inductive busbars. During operation, the DC link is connected to an HV supply or to an HV battery.

The power kit is cooled with an external device and a continuous coolant flow temperature of 50°C. The flow rate is 15 l/min (see Table 1).

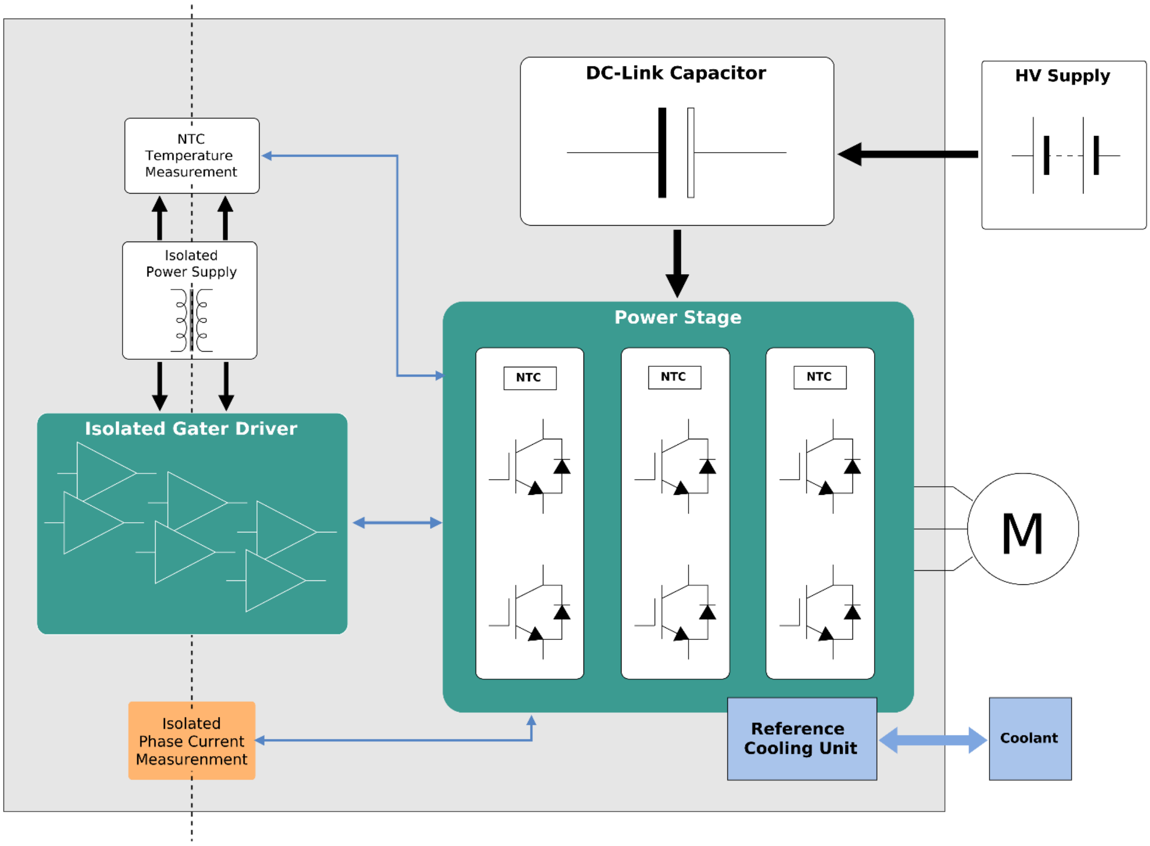


Figure 2 **Block diagram of the EconoDUAL™ power kit**

1.3 Main features

- Isolated gate driver and power supply
- Isolated phase current measurement
- Isolated NTC temperature measurement
- DESAT protection

1.4 Kit parameters and technical data

Table 1 Kit parameters

Parameter	Unit	Min. value	Nominal value	Max. value
DC-link voltage	V	600	800	850
Switching frequency	kHz	3	5	10
Inverter current at nominal switching frequency	A r.m.s	0	360	470
Output frequency	Hz	0		550
Power factor	cos(φ)	-0,95	0,85	0,95
Deadtime	µs		4	
Coolant flow temperature	°C	25	50	65
Flow rate	l/min	10	15	30

2 System design

This chapter provides information about the gate driver board, especially its schematics and mechanics. The Mechanics section describes the press-in process for the EconoDUAL™ 3 modules with press-fit pins.

Figure 3 shows the design of the evaluation board. It has a 10-pin connector and a power connector for +15 V power supply. It has different LEDs to show the status of different functionalities and the test points to measure output gate signals (low side and high side driver).

The gate driver IC can also detect a short circuit. Therefore, a test point has been designed to measure the DESAT signal close to the EiceDRIVER™.

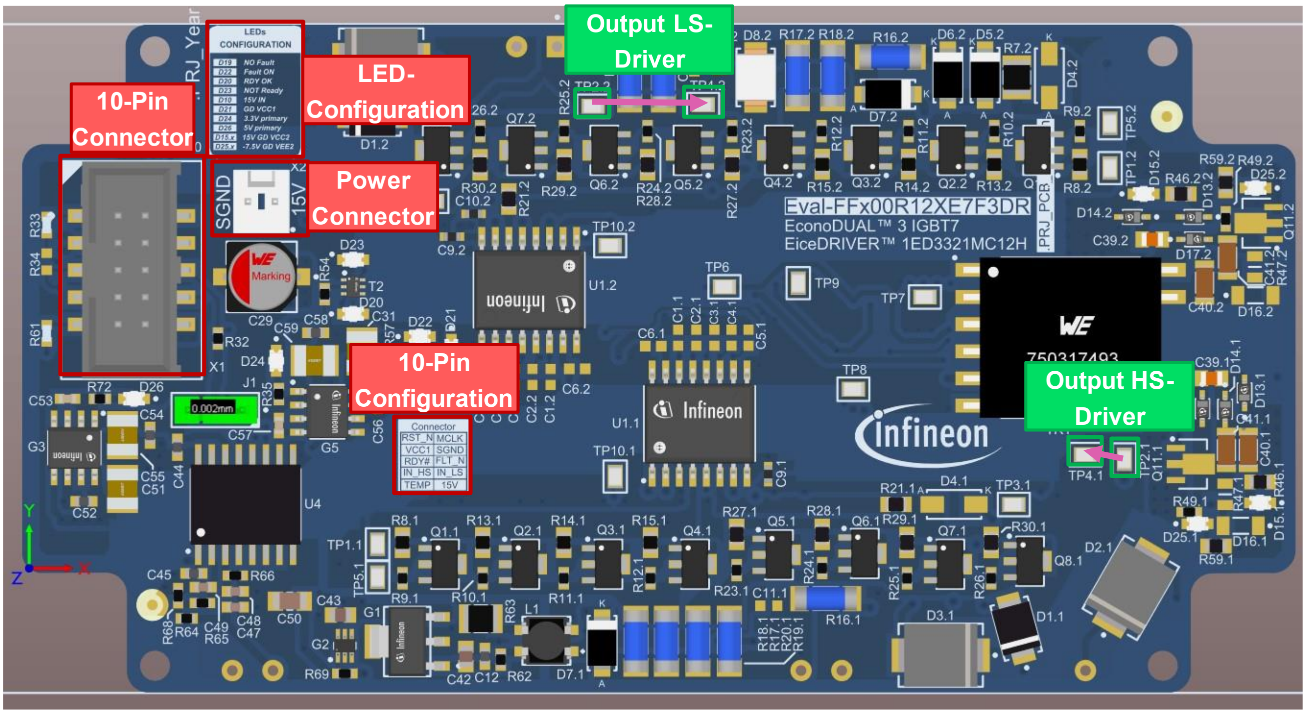


Figure 3 **FFx00R12XE7F3DR: The gate driver evaluation board**

2.1 Schematics

This section describes the schematics of the secondary side of the gate driver IC (Figure 4). Through a higher needed gate current based on an increased gate capacity, four NPN transistors designed in parallel as booster stage, to provide the needed gate current for switching on and four PNP transistors designed in parallel as booster stage for switching off the TRENCHSTOP™ IGBT 7. The results of tests carried out under these application conditions are provided in Chapter 3.

All typical test points designed for measuring gate switching characteristics are also shown in Figure 4.

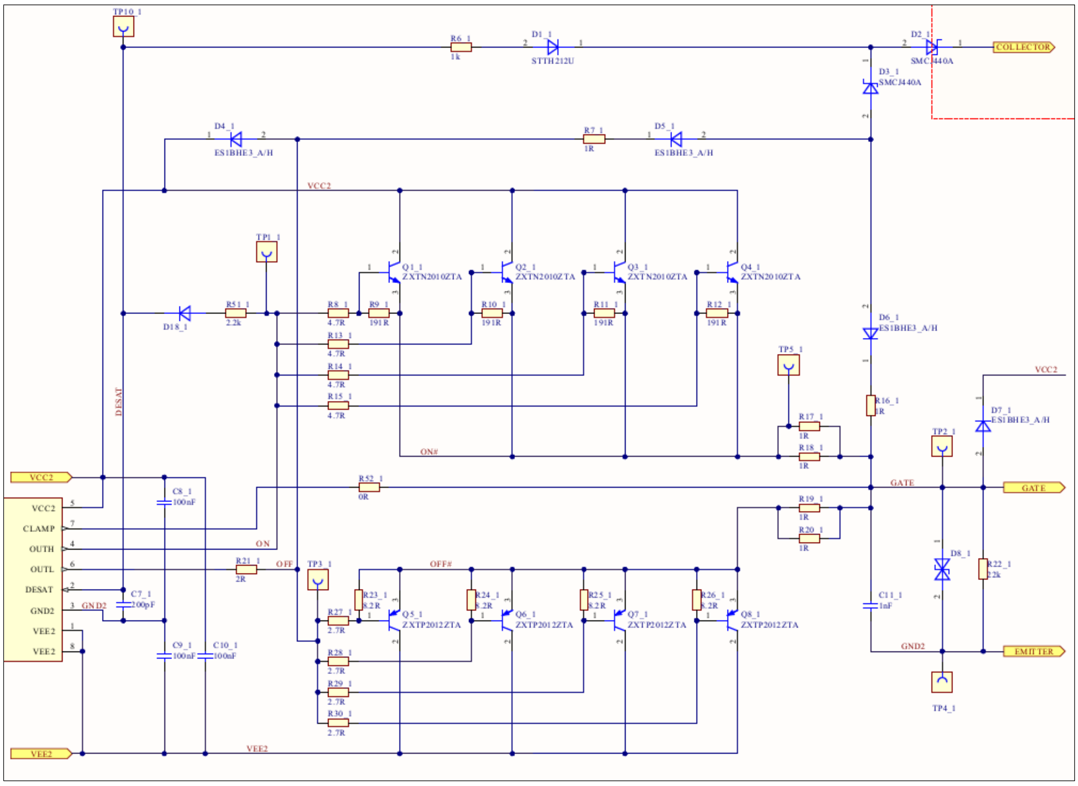


Figure 4 **Schematics of the gate driver IC**

2.2 Connector details

Table 2 Connectors

PIN	Label	Function
1	RST_N	Reset input gate driver, low active
2	MCLK	Clock
3	VCC1	Local supply voltage gate driver
4	SGND	Ground
5	RDY#	Ready output gate driver
6	FLT_N	Fault output gate driver, low active
7	IN_HS	PWM high-side switch
8	IN_LS	PWM low-side switch
9	TEMP	NTC temperature measurement
10	15 V	+ 15 V supply voltage

2.3 Mechanics

The press-in process of the PCB on the EconoDUAL™ 3 power module is covered in this section. Figure 5 shows a path/force diagram. The dot on the graph shows the frame's contact point on the PCB, approximately at 600 N. According to the application note for EconoDUAL™ 3, the curve fulfills the mechanical requirements of 770 N of force for press-fit pins. [1]

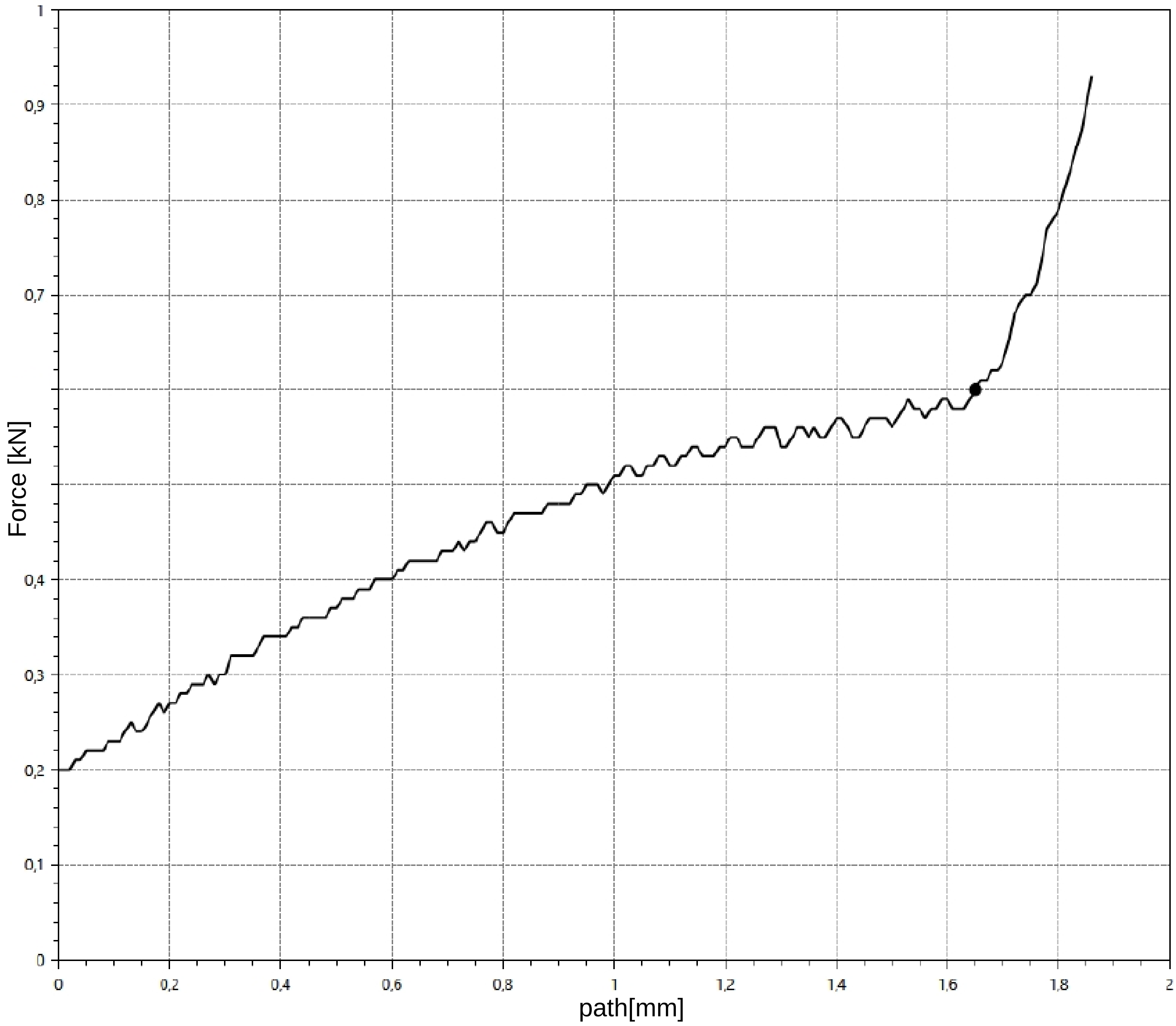


Figure 5 **The path/force diagram**

3 System and functional description

3.1 Starting the power kit

Before starting the EconoDUAL™ 3 power kit with a high-voltage supply on the DC link, checking the gate driver functionalities of each board supplied with a low voltage of +15 V is recommended (see Chapter 2).

3.2 Functionalities of the gate driver board

The undervoltage lockout (UVLO) function was verified under test conditions. Figure 6 shows the output signal of a gate driver, the related supply voltage, and the RDY (ready) signal as feedback. When the supply voltage reaches a value over 12.6 V, the output stage is cycling. When the voltage falls below 11.4 V. The gate driver shuts down and the ready signal as feedback is low.

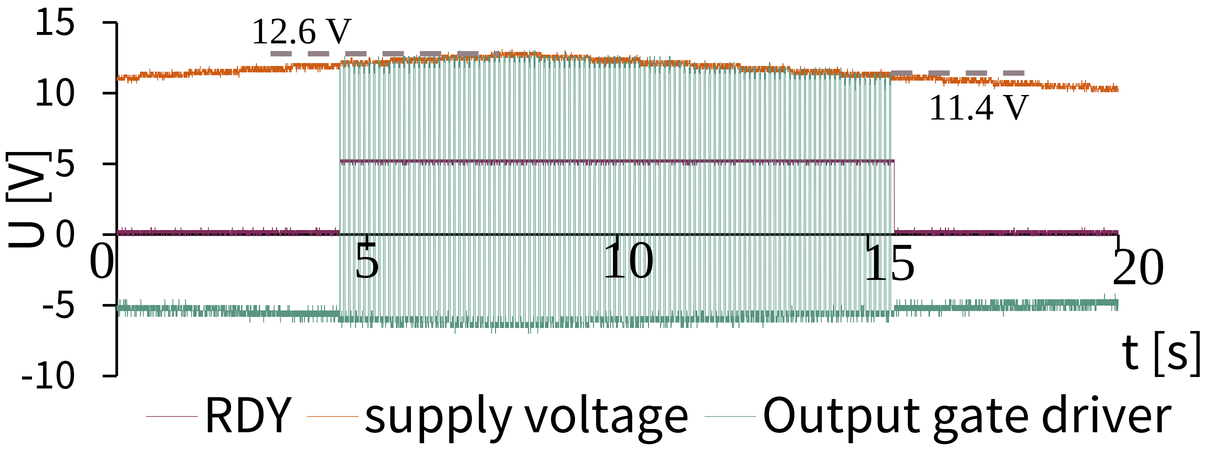


Figure 6 **Undervoltage lockout (UVLO) measurement**

Figure 7 shows the DESAT functionality of the gate driver board. The board has been tested for short circuit configuration. As image shows the collector-emitter voltage (V_{CE}), the gate-emitter voltage (V_{GE}), the fault signal (V_{FLT}), and for scaling reason collector current (I_C) is multiplied by a factor of 10.

When a short circuit event occurs, the collector current increases up to 3300 A and the collector-emitter voltage of the IGBT starts desaturating. After approximately 5 µs, the gate driver shuts down the short circuit event with a soft turn-off. Due to this functionality, the high di/dt combined with the stray inductance of the system does not become critical and does not lead to overvoltage based on the switching-off event.

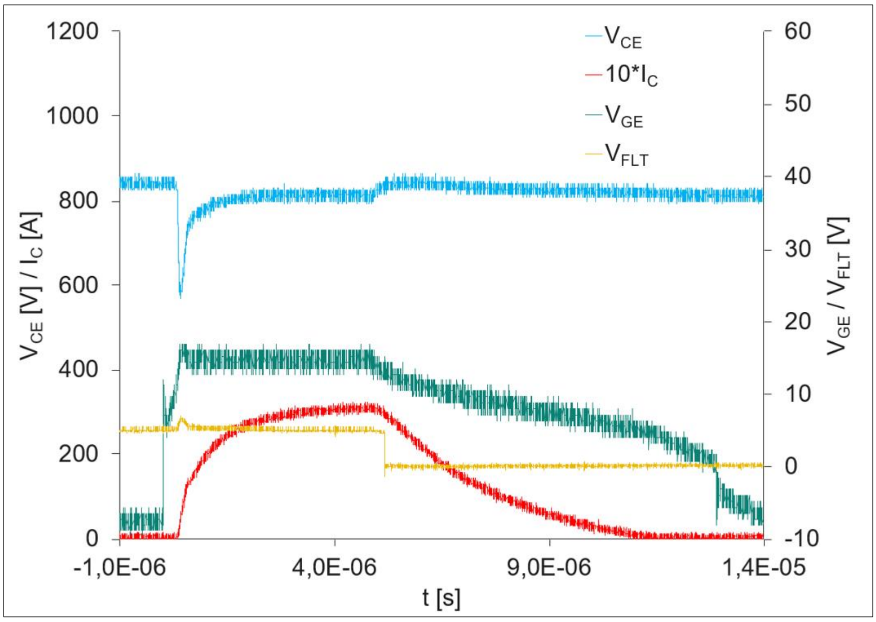


Figure 7 **DESAT protection functionality**

Finally, a gate current measurement based on the booster stage is shown in Figure 8. The results are based on the schematic described in Section 2.1. The gate of the TRENCHSTOP™ IGBT 7 shows a significant gate charge. Due to this, a gate current of 15 A is needed. The booster stage is designed considering the gate charge requirements and for continuous operation at 20 A gate current. [2]

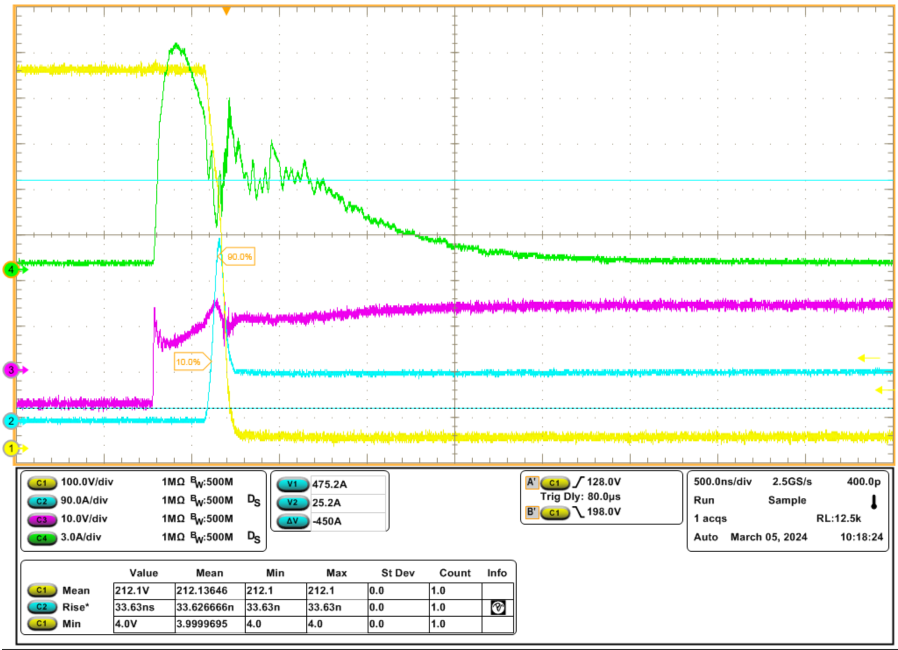


Figure 8 **Gate current measurement based on the booster stage**

4 System performance

This chapter describes system performance measurements and validations for the operating conditions. The test setup is described along with the performance curves of the junction temperature (T_J) versus those of the output current (I_A). Finally, the measurement results have been compared with the results from simulations that were carried out using PLECS.

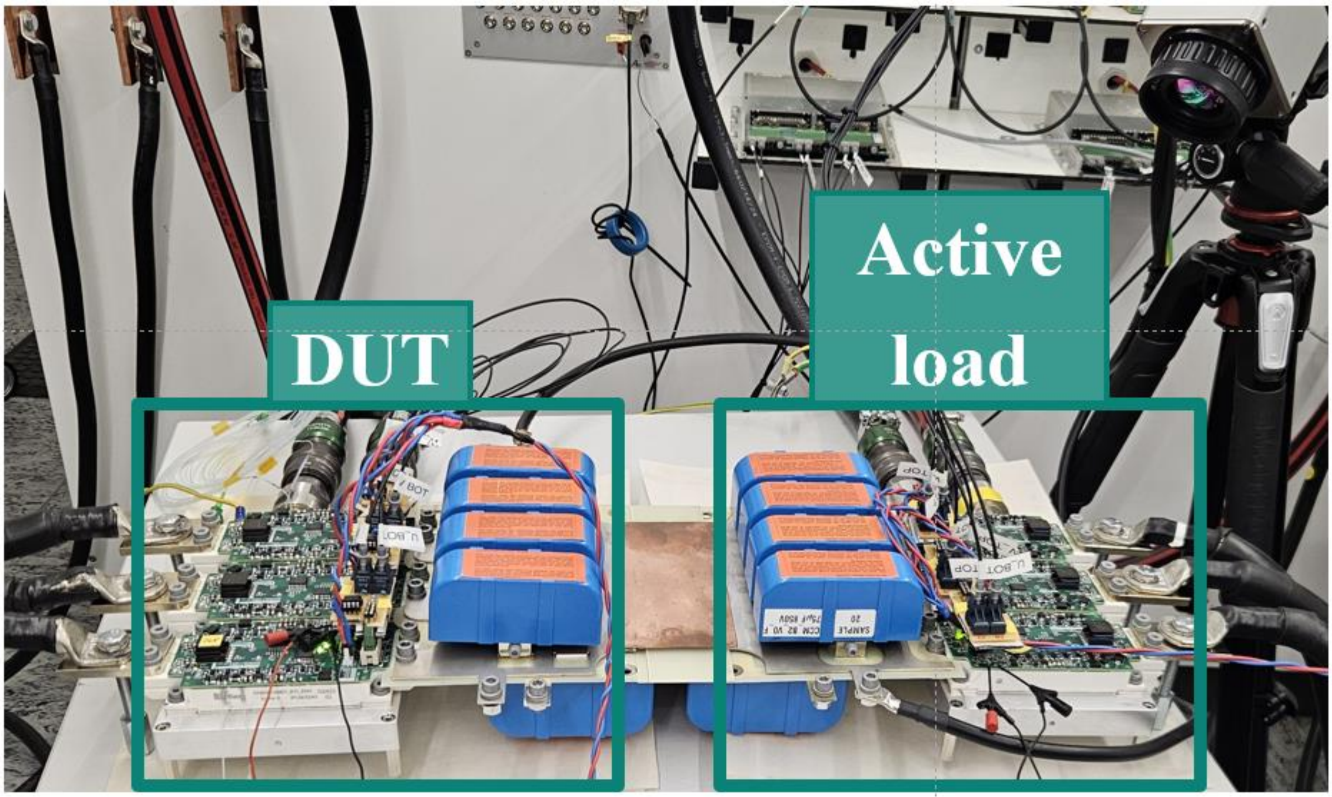


Figure 9 **System setup**

Figure 9 shows the system setup, where one EconoDUAL™ 3 power kit is used as a device under test (DUT) and the second is connected as an active load. Both DC links are coupled with a low inductive busbar and the output stages relate to a 3-phase inductor. This setup is handled as a back-to-back operation. The advantage of this setup is that only power losses needed to be supplied because the energy flows in a close system.

The DUT was prepared with fiber optical temperature sensors. These sensors help in measuring the chip temperature in an inverter operation without any EMI or isolation issues. The heatsink was connected with Y-caps to DC+ and DC- to catch the interference currents based on parasitic capacitance. Due to this no EMI problem occurred during the inverter operation. The Y-caps are not shipped with the EconoDUAL™ 3 power kit and customers have to obtain their own.

For both the inverter stages, water-cooled heatsinks were used with 15 l/min flow rate (see Section 1.4).

4.1 Test results

Figure 10 shows the chip temperature measured against the output current. The operating conditions are listed in Section 1.4. The test was conducted with up to 150°C chip temperature continuously at 470 A r.m.s. At nominal inverter output current ($I_{NOM(Inverter)}$), T_J was up to 121°C.

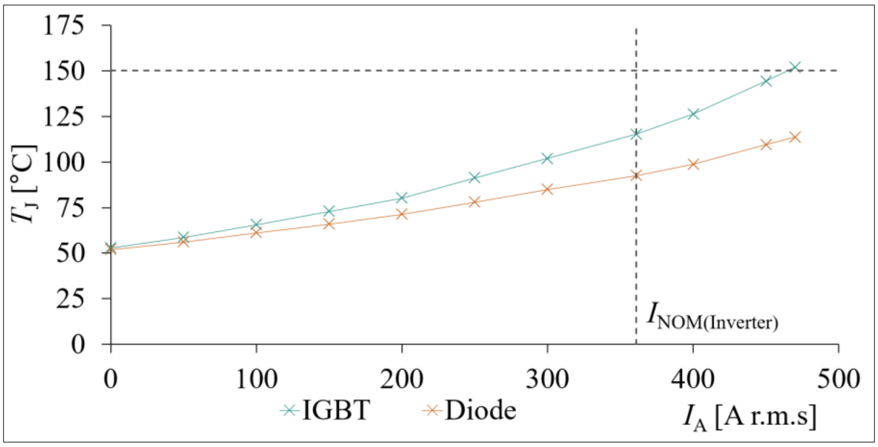


Figure 10 **The chip temperature, T_J, versus the output current, I_A [A r.m.s]**

Figure 11 shows the maximum achievable output current combined with a fixed junction temperature of 150°C as a de-rating curve against the switching frequency.

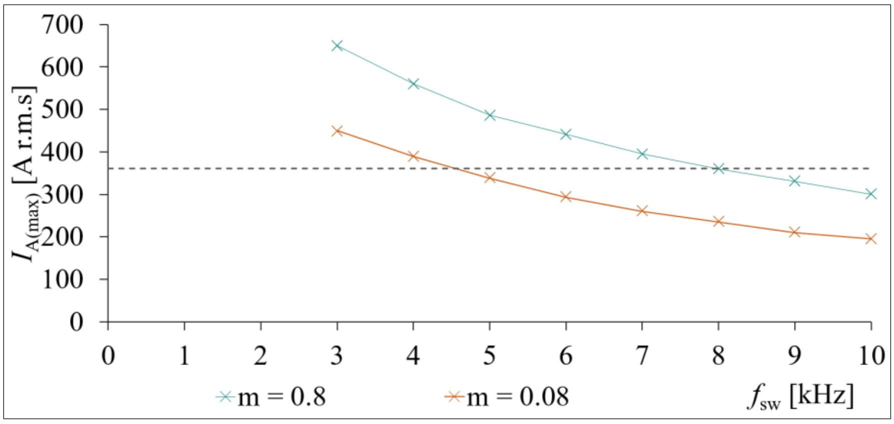


Figure 11 **The output current, $I_{A(max)}$ [A r.m.s] versus the switching frequency, f_{sw}**

4.2 Measuring dV/dt in an inverter operation

High output-voltage slew rates can damage the motor of an electric vehicle due to the interference currents and resulting bearing damage. Therefore, the dV/dt of a traction inverter is limited to a certain value. In this design, the limits were set at -15 and +15 V/ns. The slew rates were measured in the inverter operation, phase-to-phase, at 10% nominal inverter current and nominal switching frequency.

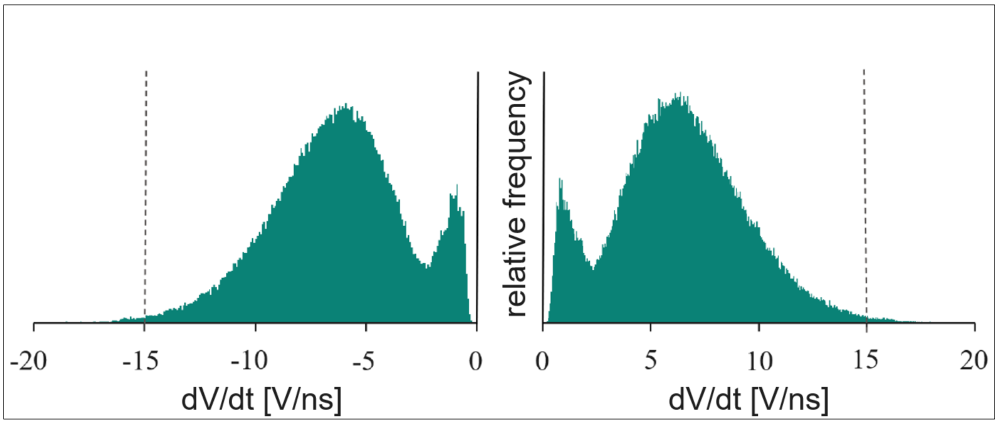


Figure 12 **dV/dt measurement**

4.3 Simulation

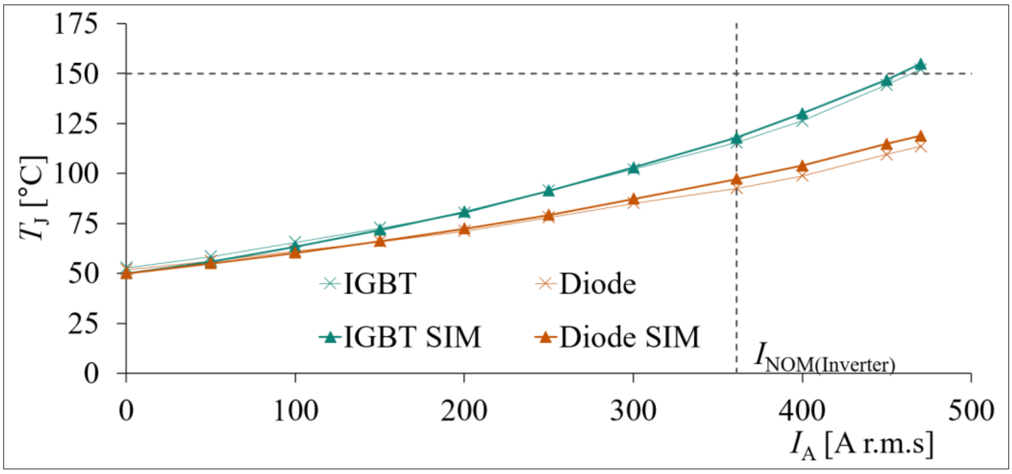


Figure 13 **Simulation versus the measured chip temperature**

In Figure 13, the previously discussed data curves from the inverter operation are compared to the simulated data. It can be seen that the simulated and measured data have a variation less than 2%.

Results from another simulation can be seen in Figure 14. Not all inverter operations could be tested properly on the test bench. Especially, it was not possible to test the locked rotor or 0 Hz output frequency called as "DC operation". However, through a well-validated PLECS model, with a variation less than 2%, it was possible to reproduce the locked rotor test.

Table 3 locked rotor test condition

Parameter	Unit	Nominal value
DC-link voltage	V	800
Switching frequency	kHz	3
Inverter current at nominal switching frequency	A r.m.s	560
Output frequency	Hz	0
Coolant flow temperature	°C	50
Flow rate	l/min	15

The locked rotor test was done at 0 Hz output frequency (see Table 3). Also, the switching frequency was de-rated to 3 kHz. The following figure shows the IGBT and diode temperatures of the more loaded device and the passive heated component. As can be seen, the temperature of the loaded diode increased up to 145°C and that of the IGBT went up to 135°C. The low side IGBT and high side diode were heated by thermocoupling effects.

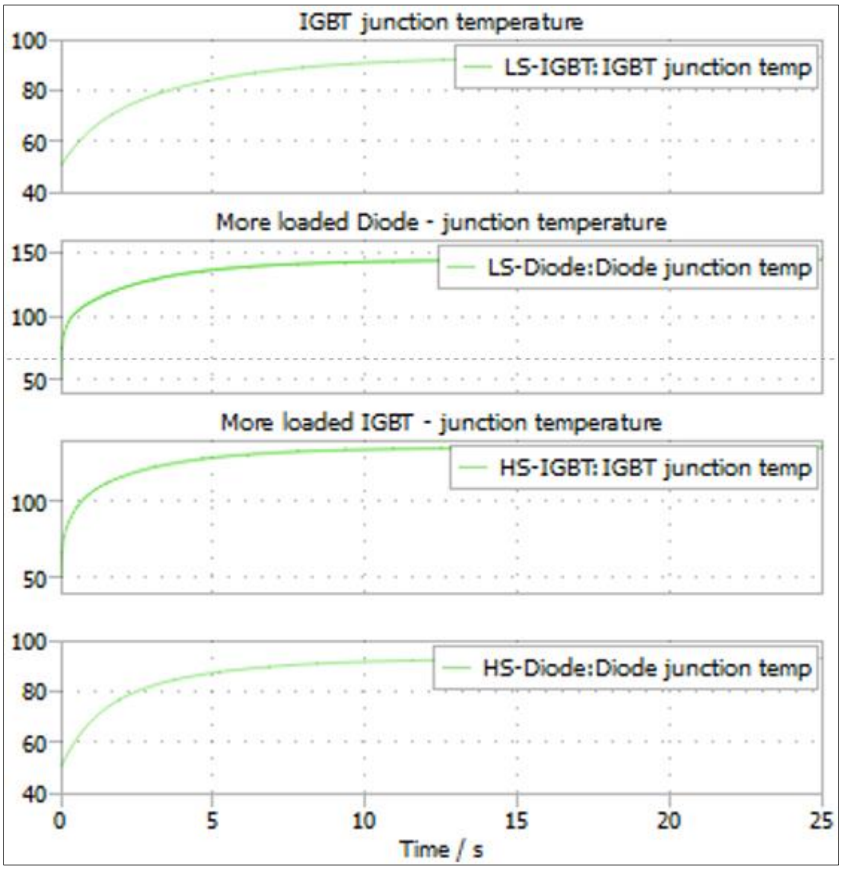


Figure 14 **Simulated chip temperature from the locked rotor test**

References

[1] Infineon Technologies AG, AppNote 2006-05: Mounting Instructions of EconoDUAL™ 3 Modules, V1.02 www.infineon.com

[2] Diodes Incorporated, Datasheet ZXTN2010Z: 60V NPN LOW SATURATION MEDIUM POWER TRANSISTOR IN SOT89

Revision history

Document revision	Date	Description of changes
1.0	2024-09-30	Initial version

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