User guide for REF-22K-GPD-INV-EASY3B

A reference design for a general purpose drive

About this document

Scope and purpose

This user guide provides an overview of the evaluation kit REF-22K-GPD-INV-EASY3B including its main features, key data, pin assignments, mechanical dimensions and corresponding control card. The reference kit REF-22K-GPD-INV-EASY3B is an industrial motor drive for three-phase 400 V AC grids and has a nominal power of 22 kW.

The REF-22K-GPD-INV-EASY3B includes the Easy3B power module FP100R12W3T7_B11, the current sensor TLI4971-A120T5, the gate driver IC 1ED3131MC12H, the 1.7 kV SiC-MOSFET IMBF170R1K0M1 and the microcontrollers XMC4800-F144F2048 and XMC4300-F100K256. The combination of these Infineon products allows the customer to evaluate these products in one design and experience the interaction between the products.

Beside the hardware, the REF-22K-GPD-INV-EASY3B offers you software for control and communication. The inverter can be controlled via a touch screen and PC-GUI.

Note: Please note that this product is not qualified according to the AEC Q100 or AEC Q101 documents of the Automotive Electronics Council.

Intended audience

This user guide is intended for all technical specialists working on industrial drives and those interested in how the latest Infineon products like IGBT7, XENSIV™ current sensors, EICE™ drivers and CoolSiC™ MOSFETs perform under application conditions.

Reference Kit

The Infineon products are embedded on this PCB with functions and form factor close to a commercial design. PCB and auxiliary circuits are optimized for the final design.

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

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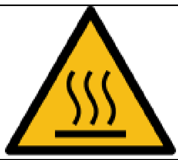
Safety precautions

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 five 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 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.*

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1 The reference board at a glance

1.1 Delivery content

The reference kit is a general purpose drive developed for applications like pumps, fans, compressors, conveyor belts. The design has the look and feel of a typical drive and includes EMI filter, pre-charge and capacitor bank, isolated power supplies, power module, controls and heat sink with fan. It can be operated directly on a three-phase grid, enabling a fast evaluation of Infineon's newest technologies like IGBT7, gate driver, current sensor and control in one system. This enables the unique opportunity to see the improvement by combining Infineon's newest technologies. You will see how the new IGBT7 modules work with the EICE™ gate driver, or test the accuracy of the current sensor.

1.2 Block diagram

The block diagram of the inverter REF-22K-GPD-INV-EASY3B is shown in Figure 1. The board consists of five boards: power board, EMI filter, high-voltage logic board, low-voltage interface board, and the DC-link board which are mounted in one housing. For more details see Section 2.2.1.

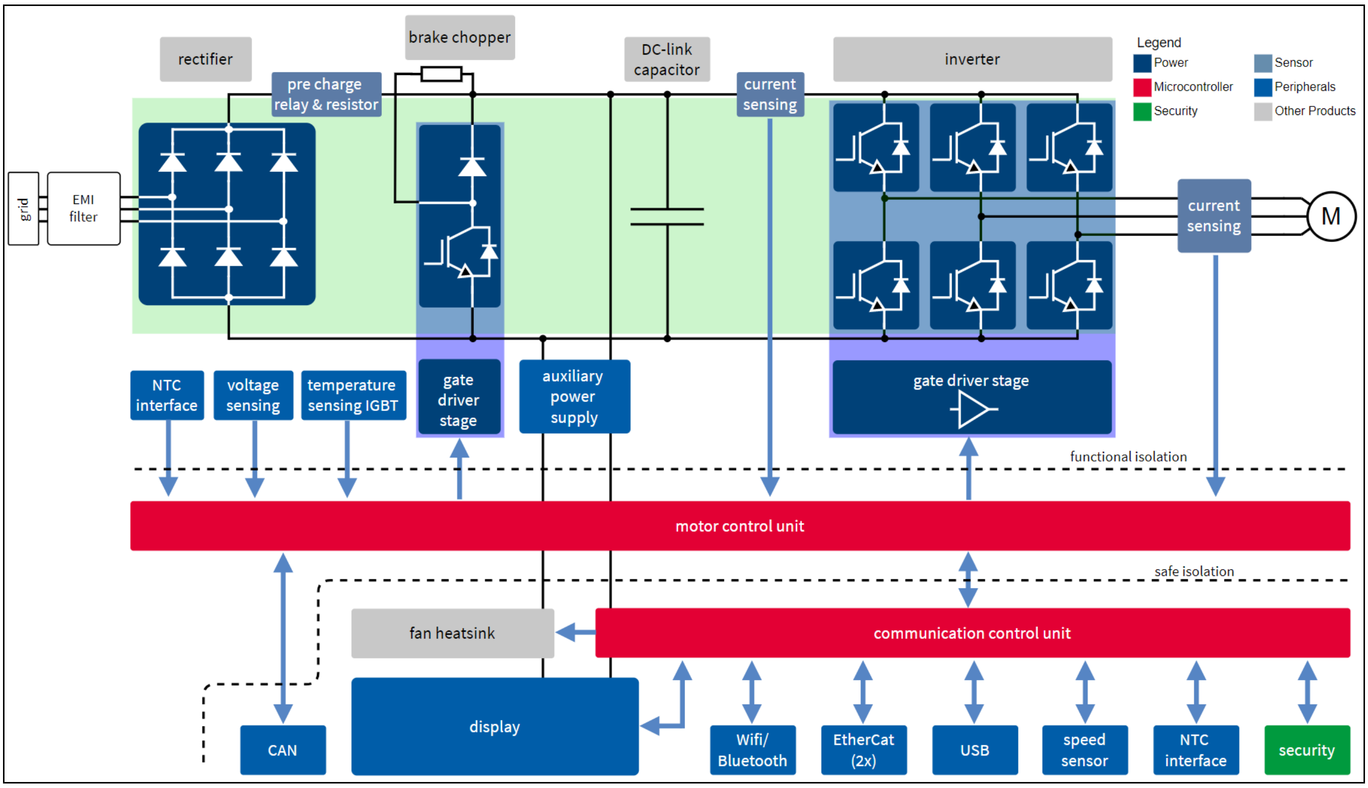

Figure 1 Block diagram of the inverter

The reference kit REF-22K-GPD-INV-EASY3B is a fully operation industrial drive inverter which can be connected to a three-phase AC input supply. The reference kit includes an input EMI-filter. The AC voltage is rectified via the uncontrolled diode full bridge. The inrush current is limited by pre-charge circuitry. The rectified AC voltage is stabilized by a DC-link capacitor bank. The IGBT six pack allows for the modulation of a three-phase output voltage/current which can be varied in terms of its amplitude and frequency. This three-phase current is used for controlling the speed and torque of the motor. During braking or deceleration of the motor, energy is transferred back into the DC-link capacitor increasing the DC bus voltage. Therefore, a brake chopper is included that absorbs this energy by switching an external brake resistor across the DC bus capacitors. The three-phase input rectifier, the six pack as well as the brake chopper are all included in one power module, the Easy3B IGBT FP100R12W3T7_B11. All IGBTs are switched using EICE™ drivers, the 1ED3131MC12H. The isolation coordination details of the unit can be found in Section 2.2.2.

The current measurement of the three-phase output current is done with TLI4971-A120T5 current sensors. The current signals are used for the motor control; additionally, these sensors are used to detect an external short circuit for the IGBT's. To protect the module against an internal short circuit, a fourth current sensor is integrated between the DC-link capacitor and the IGBT module.

The auxiliary voltage for the inverter is generated with a DC/DC switch mode power supply (SMPS) converter. The CoolSiC™-MOSFET IMBF170R1K0M1 is used in a flyback topology. More details about the flyback SMPS are listed in Section 2.2.4.

The reference inverter uses two microcontrollers; one for control and one for communication. For control the XMC4800-F144F2048 is used, for communication the XMC4300-F100K256 AA is designed in. Both microcontrollers communicate via an UART interface. The communication microcontroller allows the inverter to be controlled via a touch-screen or a PC-GUI. More details on the communication interface can be found in Section 2.2.1.

A simplified block diagram is shown in Figure 2. The block diagram shows the main components of the boards, the DC/DC SMPS converter, the low-voltage interface board (SELV board), high-voltage logic board (FELV board), the IGBT module incl. the gate driver IC, and the output phase current measurement. Also the main Infineon components used in the specific blocks are listed in the diagram.

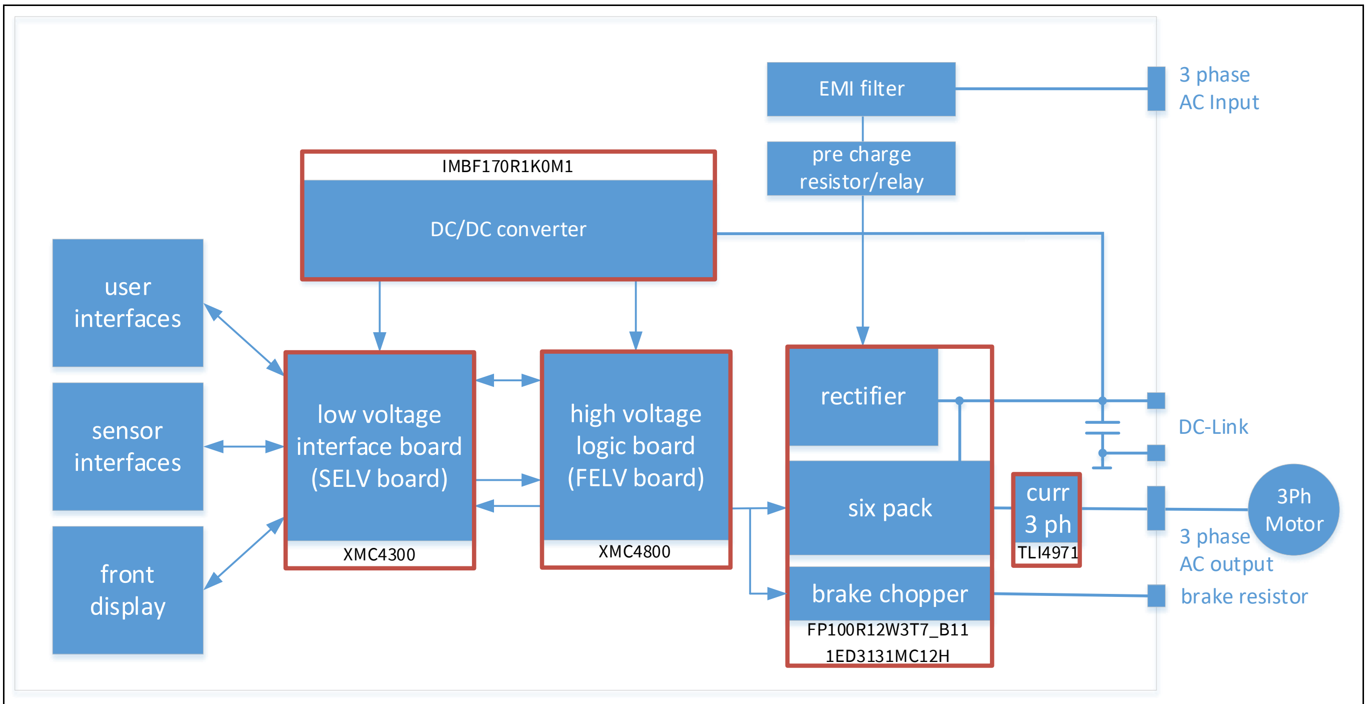

Figure 2 **Simplified block diagram of the inverter**

1.3 Main features

- FP100R12W3T7_B11: EASY3B IGBT7 module for high-current and high-power density [3]
- TLI4971-A120T5: XENSIV™ current sensor for measuring high currents with minimal power loss [4]
- 1ED3131MC12H: Gate driver for optimal EMI performance and reduced power losses [5]
- IMBF170R1K0M1: Infineon CoolSiC™ MOSFET 1700 V enables direct drive by most flyback controllers [6]
- XMC4800-F144F2048 and XMC4300-F100K256 AA: XMC microcontrollers for inverter control and communication [7]

1.4 Board parameters and technical data

The key parameters of the REF-22K-GPD-INV-EASY3B are shown in Table 2.

Table 2 Parameters of REF-22K-GPD-INV-EASY3B

Parameter	Symbol	Conditions	Value	Unit
Input line voltage	V_{in}	Three-phase AC ± 10%	380 … 480	V
Input frequency	f_{in}	± 3 Hz	50 … 60	Hz
Output voltage	V_{out}	three-phase AC	0 V … 0.95 x input voltage	V
Output frequency	f_{out}		0 … 550	Hz
Switching frequency of motor output	f_{sw}	Factory setting 4 kHz	4	kHz
Rated power	P_{rated}		22	kW
Rated current	I_{rated}		45	A
Low overload - base load power	P_{LO}	T_{amb} <= 35°C	22	kW
Low overload - base load current	I_{LO}		45	A
High overload - base load power	P_{HO}		18.5	kW
High overload - base load current	I_{HO}		38	A
Power losses	P_{loss}		< 700	W
Weight	m_{inv}		< 10	kg
Ambient temperature	T_{amb}	Relative humidity RH; 30% < RH< 80%	10 to 35	°C

1.4.1 Overload profile normal duty

The normal duty (ND) load cycle assumes a uniform base load with low requirements during short acceleration times at high torque; see Figure 3. Typical applications when designing according to normal duty include:

- Pumps, fans and compressors
- Wet or dry blasting technology
- Mills, mixers, kneaders, crushers, agitators
- Basic spindles
- Rotary kilns
- Extruders

Typical converter load cycle:

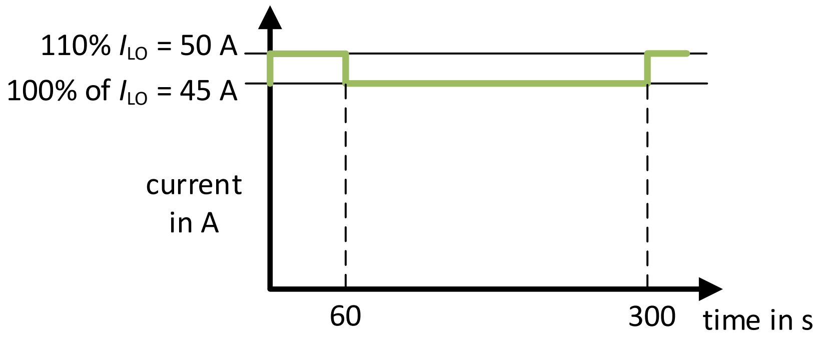

Figure 3 Overload profile normal duty

1.4.2 Heavy duty overload profile

The heavy duty (HD) load cycle permits dynamic accelerating phases at a reduced base load; see Figure 4.
Typical applications when designing according to heavy duty include:

- Horizontal and vertical conveyor technology (conveyor belts, roller conveyors, chain conveyors)
- Centrifuges
- Escalators/moving stairways
- Lifters
- Elevators
- Gantry cranes
- Storage and retrieval machines

Typical converter load cycle:

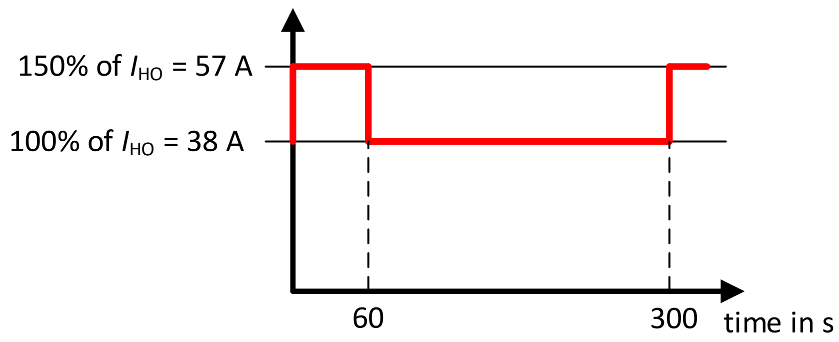

Figure 4 Overload profile heavy duty

2 System and functional description

2.1 Commissioning

The REF-22K-GPD-INV-EASY3B must be connected to a TN-S line system as shown in Figure 5. The connections to the inverter can be made only after the converter is unpacked and all packaging material has been removed.

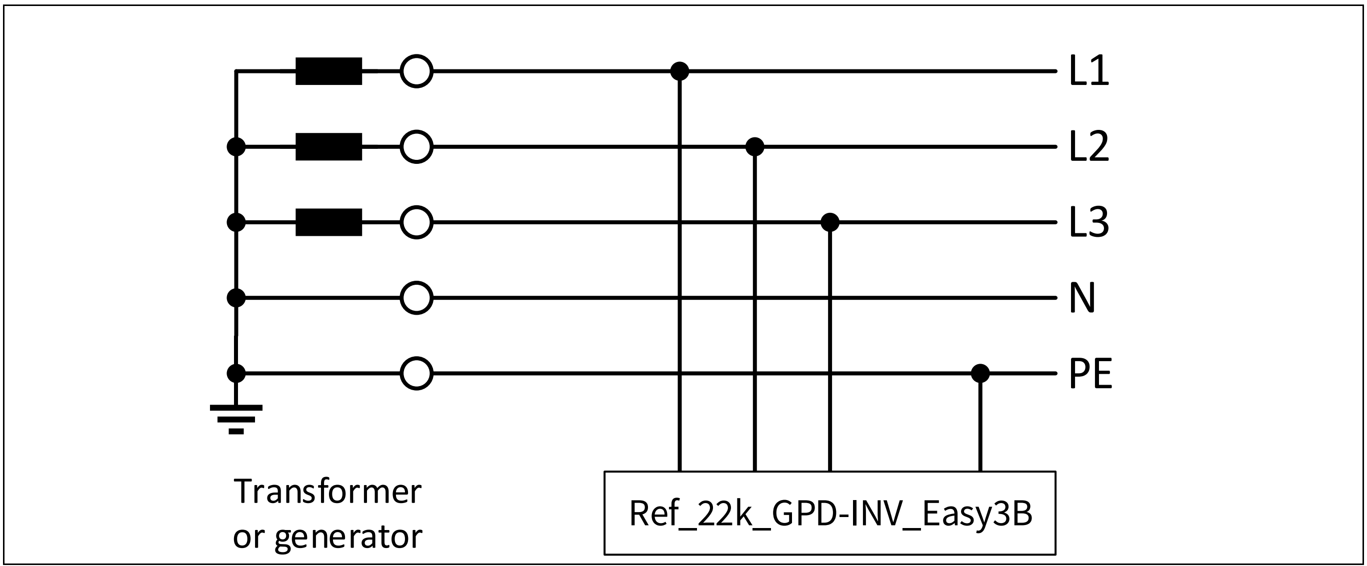

Figure 5 Connection of the inverter to TN-S line system

A TN-S system transfers the PE protective conductor to the installed plant or system using a cable. Generally, in a TN-S system, the neutral point is grounded. A TN system can transfer the neutral conductor N and the PE protective conductor either separately or combined. Also the connection to a TT system is permissible, but the connection to an IT is not permissible. The reason here is the missing or high-impedance earth connection.

The connection of the inverter is shown in Figure 6. The cross-section of the wires for the line connection, the brake chopper and the motor cable are in the range of 1.5 to 10 mm². Ensure that the inverter is in a no-voltage condition and the DC-link is discharged.

To connect the line feeder cables (L1, L2, L3 and PE), see Figure 6. To ensure correct fusing, it is recommended to make a selection according to IEC is 3NA3824 (80A). Also, connect the motor feeder cables (PE, U, V and W) to the inverter. The connection of a brake resistor is optional.

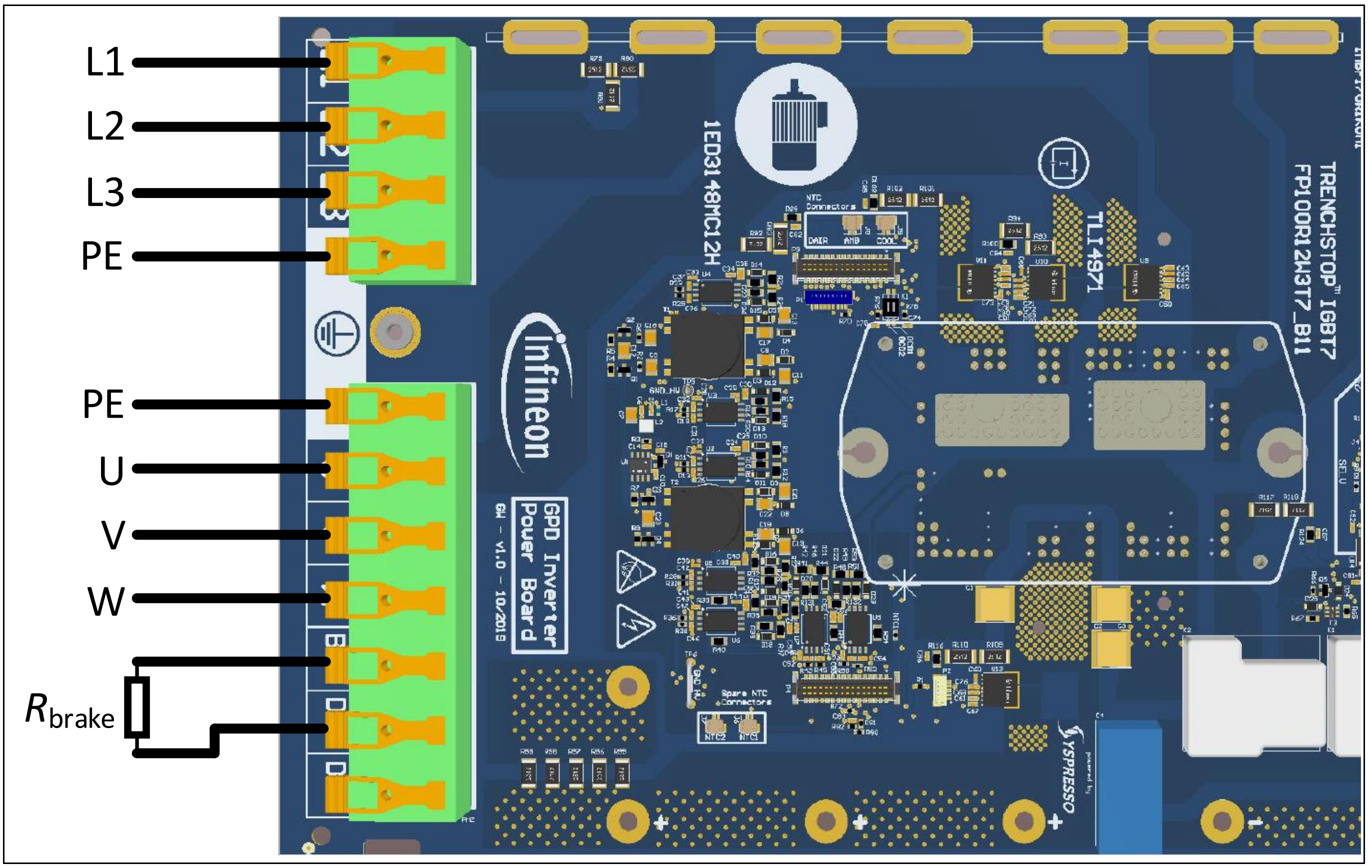

Figure 6 **Connecting of the inverter**

Also connect a USB cable to the inverter allowing for communication with the drive. The USB port is located at the front of the inverter; see Figure 7.

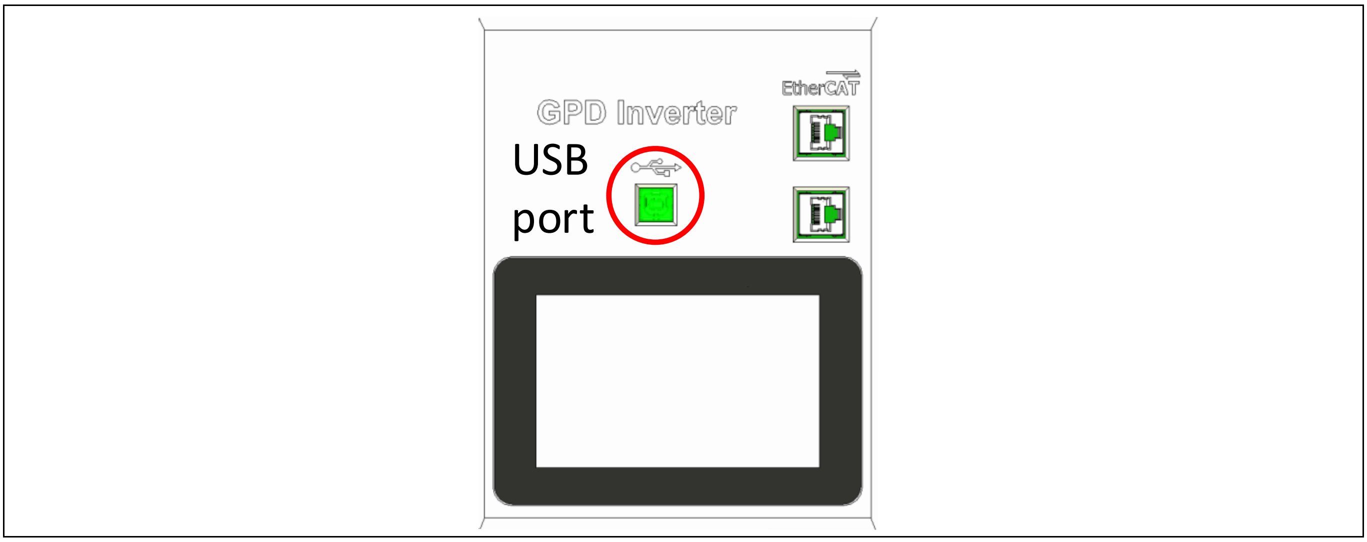

Figure 7 **USB port of the inverter**

Before you start the inverter, you need to install the XMC driver and launch the GUI. The software can be downloaded via Infineon.com. Please register your inverter to get access to the software.

For installation, it is required to have admin rights on your computer. The software was tested with a laptop (HP EliteBook 840 G5) and Windows 10 Enterprise (Build: 10.0.17134). You have to first install the USB driver, so extract the file XMC_WinUSBDriver.zip.

To start with the installation, connect your computer with a USB cable to the inverter, and apply an appropriate voltage to the line feeder cable. The inverter will start operation in idle mode. Now you can install the USB driver: Go to “Control Panel\All Control Panel Items” then to “Device Manager.” Select the new USB device “Infineon WinUSB Device;” see Figure 8 part 1, and double click it.

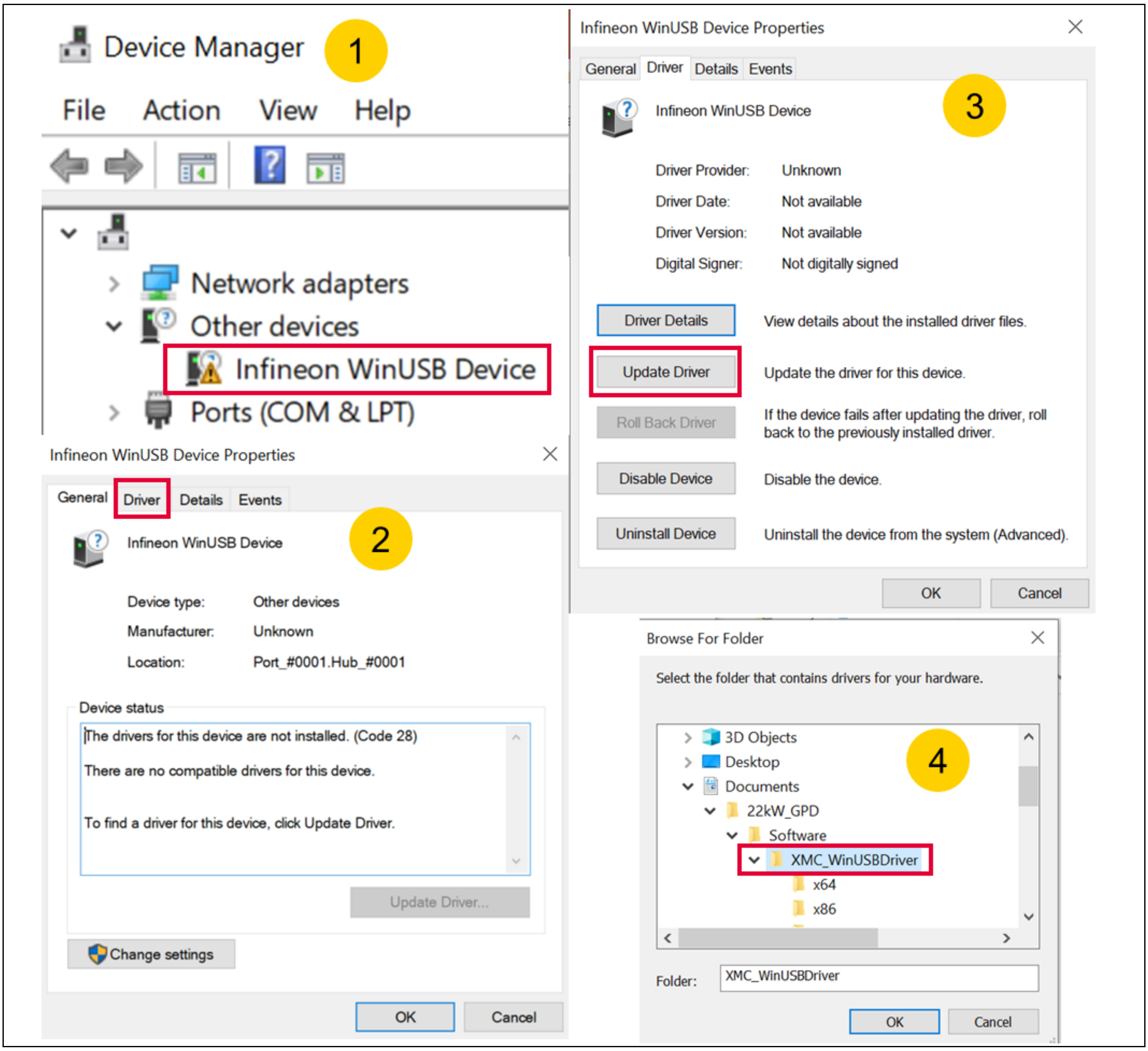

Figure 8 **USB device installation**

The window, as shown in Figure 8 part 2, will then appear. Click on the “Driver” tab, then “Update Driver” as shown in Figure 8 part 3. Now select the extracted folder “XMC_WinUSBDriver” as shown in Figure 8 part 4. Click on “OK” and close all windows you opened previously. The USB driver is now installed.

The next step is to extract the file GUI_20200819.zip; the software is available at Infineon.com. Open the folder "Debug" and double click on "GPD Inverter.exe". A window as shown in Figure 9 (left side) appears. You can connect your drive system by selecting the USB device via the drop-down menu and click on "Connect." Now your computer is communicating with the drive system.

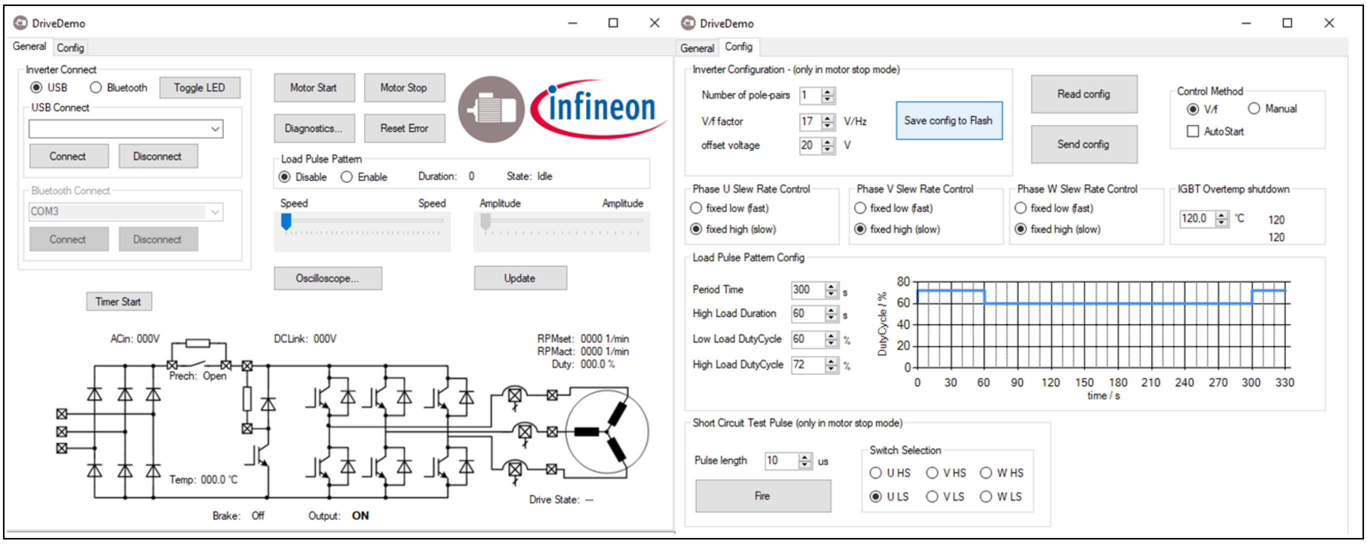

Figure 9 **Main GUI and Config tab**

Be clicking on the "Config" tab, a window will be shown as in Figure 9 (right side). You can read the Config file from your inverter by clicking on "Read config." Now you can change the settings. The "Control Method" can be selected either as "V/f" or "Manual." The parameters for the "V/f" mode can be adjusted in the "Inverter Configuration" window. In the manual mode, you can select the "Speed" value and the "Amplitude" value manually; see the "General" Tab of the GUI. In the "Config" tab you can also change the "IGBT Overtemp shutdown" value. The "Load Pulse Pattern Config" window allows you to operate the inverter in a periodic or cyclical mode. This function works only in "Manual" mode, and changes the duty-cycle value for a specific time. This approach allows for an easy implementation of an overload pattern, as shown in Figure 3 using an inductive-resistive load. In addition, a short-circuit test is also possible via the GUI; further details will be explained in Section 4.6.

Via the "General" tab, you can start the motor. You can run the motor in "V/f" mode; see section "Control Method." The speed of the motor, hence the output frequency of the inverter, can be adapted by the slider "Speed." After selecting your speed, click on "Update." You can change the "V/f" ration in the "Config" tab, as already mentioned. Via the "Manual" control mode, you can select the "Speed" and the "Amplitude" which represents the modulation index.

The current status of the inverter can be seen by clicking on "Diagnostics." A window will appear as shown in Figure 10 (left side). The voltage levels of the different power supplies will be shown, as well as any flagged faults in the inverter.

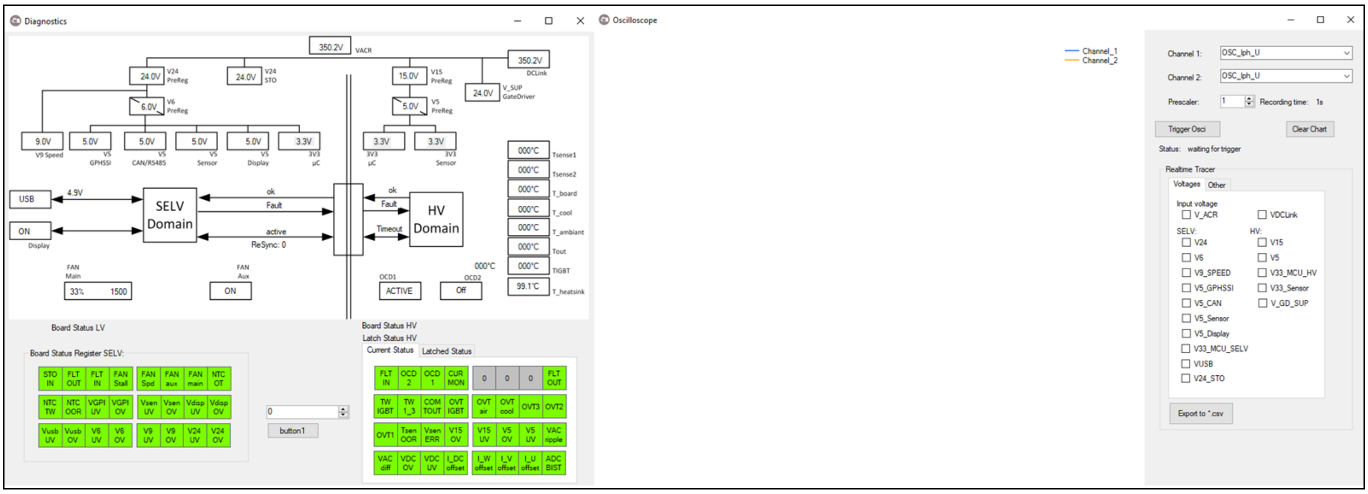

Figure 10 Diagnostics and oscilloscope of the GUI

An additional feature of the inverter GUI is the oscilloscope function, which is shown in Figure 10 (right side). The oscilloscope allows the measurement signals of the inverter to be shown, e.g. the phase output current, the DC-link voltage or the NTC-temperature of the IGBT module.

2.2 Description of the functional blocks

2.2.1 Hardware partitioning

The inverter hardware is partitioned into five boards:

- Power board
- EMI filter
- High-voltage logic board
- Low-voltage interface board
- DC-link board

Thanks to the separation of these individual functions, a high level of functionality can be implemented with minimum board space. Each board will be described in the following:

Power board:

The power board is used as a central connection and wiring unit between all other sub-boards. It contains the main connectors (power inlet and outlet), the power module, the main DCDC-converter and the gate driver including their power supplies. While the power board itself only contains a small DC-link capacitor, it connects to the capacitor bank which has ix (3 sets of 2 in series) electrolytic capacitors.

DC-link board:

The board has the electrolytic capacitors of the inverter. The separation of the capacitors on an additional board allows more design freedom and a more compact design of the inverter.

EMI-Filter:

The EMI input filter is used to suppress RF noise generated by the inverter operation. It is designed as three-phase CLC-topology. Due to the size and weight of the individual components, it is implemented on a separate sub-board that connects to the power board via solder connectors.

High-voltage logic board (FELV board):

All logic functions required to control the drive motor are implemented on the high-voltage (HV) logic board. It is based on a XMC4800 microcontroller as its central processing unit. The board contains the infrastructure to supply and supervise the microcontroller, diagnostic functions for the high-voltage part of the drive as well as all safety and protection functions needed to protect the inverter in case of overload or short-circuit conditions. The HV board features a direct connection the components on the power board. All control inputs for the motor control as well as the diagnostic status information are provided via a UART link to the low-voltage (SELV) interface board. Besides the UART link, the board features both a digital status input and output signal to indicate and receive information on critical error or fault conditions.

In order to minimize the number of required isolation barriers, the FELV board is referenced to the negative potential of the DC-link.

Low-voltage logic board (SELV board):

The low-voltage logic board is used to provide the user and external sensor interface functions. It features connectivity options for:

- EtherCat
- USB 2.0
- WLAN
- Bluetooth
- RS485
- High-Speed CAN

Besides the user interface function, the board also provides the capability to interface with external sensors, such as:

- High-resolution rotor speed sensor (two wire current interface)
- High-resolution rotor angle sensor (GP-HSSI Interface)
- Temperature sensor

Besides the connectivity options to remote control units, the SELV board can also be connected to a local touch pad display. This local control input allows the display of current operating conditions as well as basic user control.

The data exchange between SELV and FELV board is established via a bidirectional UART link. All relevant control commands received via the above-listed interface options or the touch display are forwarded to the FELV board via this link. For safety and redundancy reasons, the board provides two additional direct connections to the FELV board (1x input, 1x output) for error indication on the respective board. In case of a broken UART connection, critical error conditions on either board can be indicated via these redundant signals to cause the inverter to transition into a safe state.

In order to simplify the supply scheme for the multiple external user interfaces, the SELV board is supplied via a safety-isolated, low-voltage power supply. The connection to the high voltage logic board (UART, direct connection lines) is therefore established via digital isolator devices featuring reinforced isolation capability.

2.2.2 Isolation coordination

The inverter design provides three major main voltage domains:

- A mains-connected domain
- A low-voltage domain with functional isolation
- A safety-isolation domain

In Figure 11 you will find a drawing of the basic isolation coordination scheme.

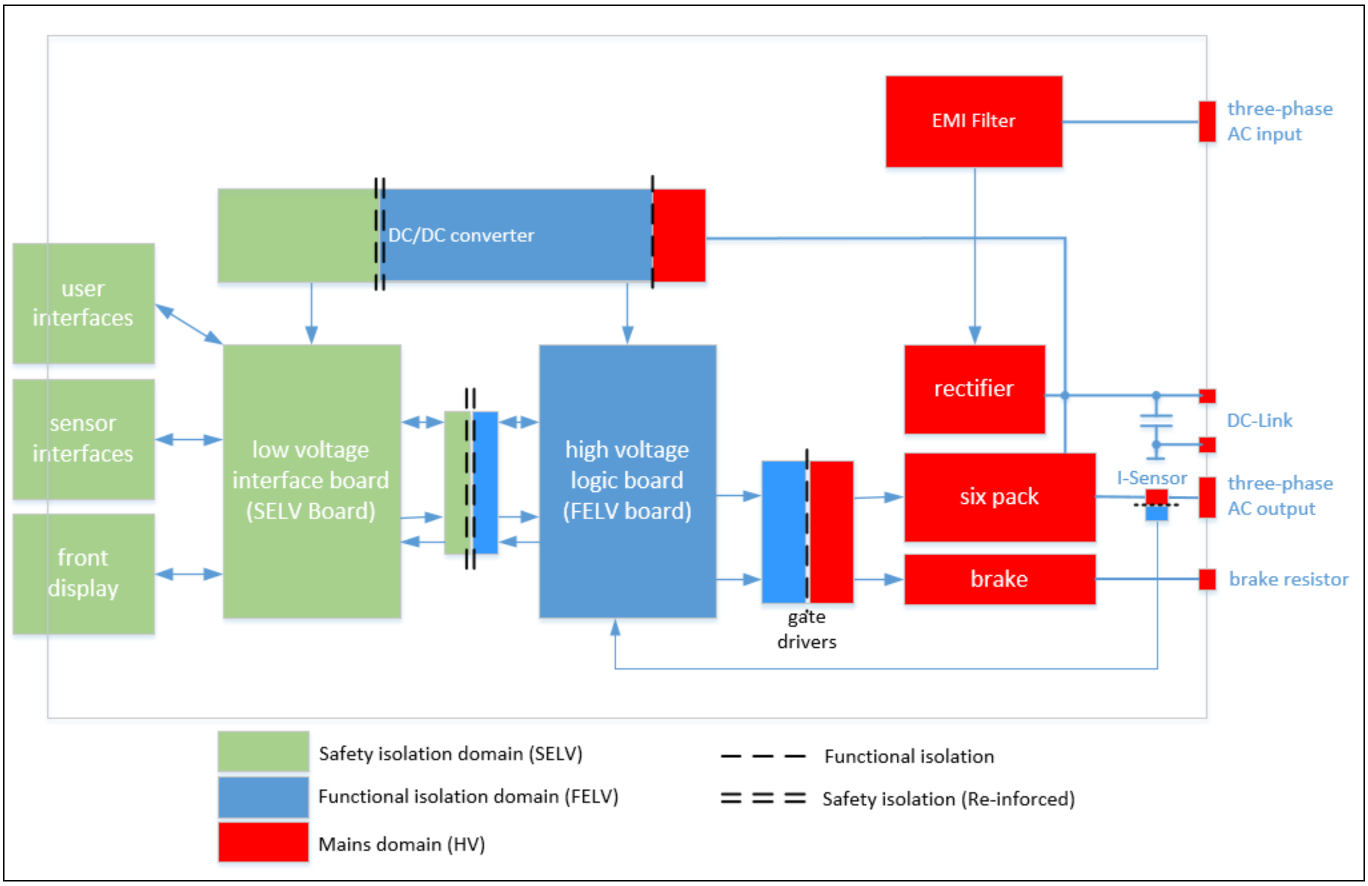

Figure 11 Basic isolation coordination scheme, the low- voltage interface board is referenced to PE and the high- voltage logic board is referenced to DC-

All power components (EMI filter, rectifier, IGBT inverter, brake switch) are directly connected to the mains supply domain. The main controller is based on a functional isolated scheme, which is connected to the DC-potential of the power domain. Thanks to this isolation scheme, all interfaces between the power domain and the main control domain only provide functional isolation. This applies in particular for the gate drivers, their power supply, the output current sensors and the voltage measurement circuits. All user interface connections are implemented on a safety-insulated domain. In order to establish a communication link between the safety-isolation domain and the functional isolation domain, a digital interface using a safety isolated data coupler is implemented. The supply for the entire board is provided by a centralized DC/DC converter which takes power from the mains supplied DC-link. The converter provides two output voltages, a functional isolated output for the functional isolation domain (FELV) and a reinforced output voltage for the user interface (SELV) domain.

2.2.3 Board interconnection schemes

The power board is used as a main platform for all sub-boards. The mains power connection is performed by power connectors on the bottom-left side of the inverter board. After passing the EMI filter board, which is connected to the left side of the power PCB, the power is routed to the power module. The rectification of the AC input power is performed in the power module; the DC-link capacitors are located on the right side of the inverter and are connected via the power PCB. Since the capacitor bank is implemented as a separate unit, the mechanical and electrical connections are made by special mounting screws. A CAD-model of the inverter is shown in Figure 12.

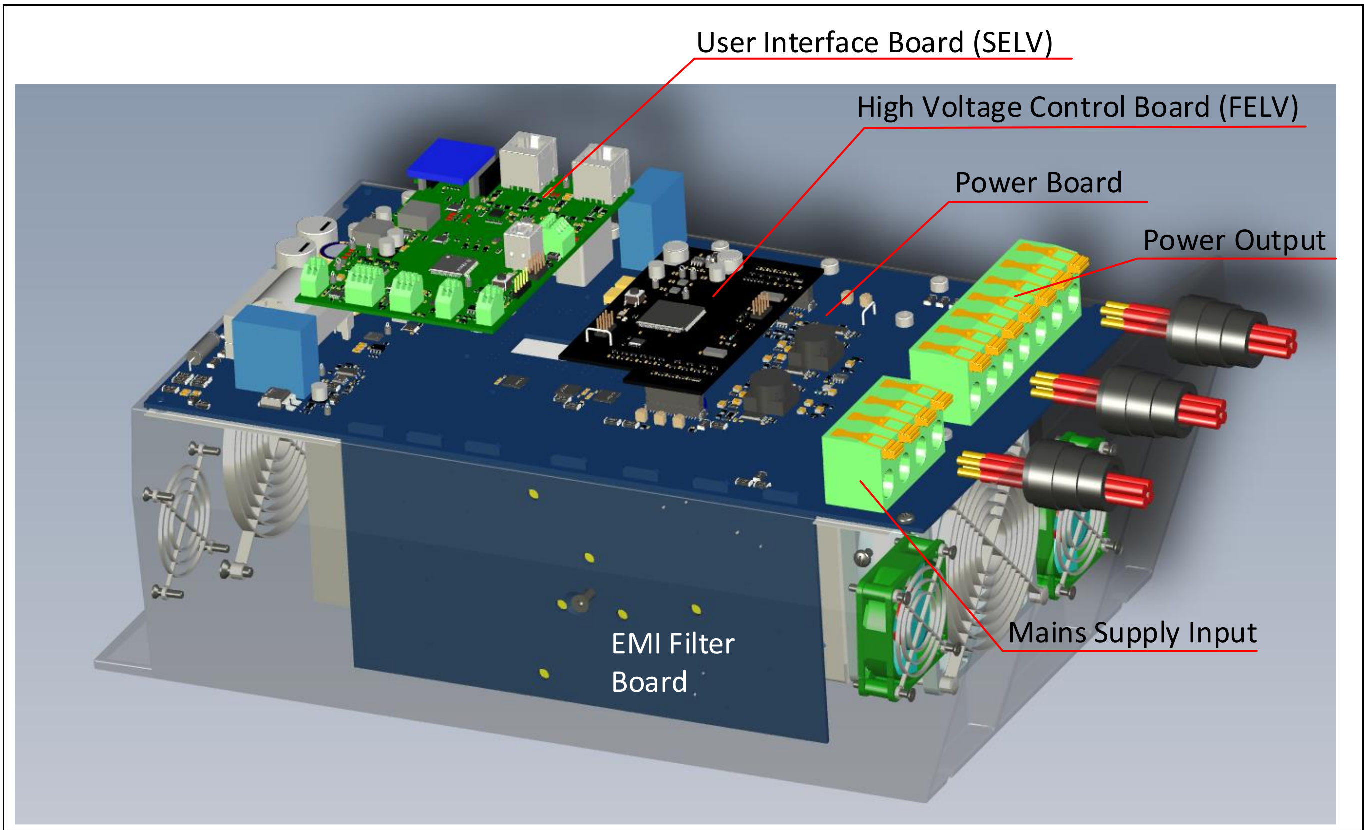

Figure 12 Inverter Construction Scheme (front-left view), Housing removed

The inverter power supply is performed by a DC/DC converter which generates galvanically isolated supply voltages for the power board, the high-voltage control board and the user interface board; see Figure 13. Both user interface boards as well as the high-voltage control board are connected the power board via pin headers. The user interface board connects to the power board on a safety-isolation island which provides the DC power for the board and the isolation stage for the digital communication link to the high-voltage control board. Connections to external sensors (e.g. rotor position sensor) or external communication buses (EtherCAT, USB, RS485, CAN) are directly provided by the user interface board. All gate-driver control signals as well as all voltage and current measurement signals are routed to the high-voltage control board via high pin-count connectors.

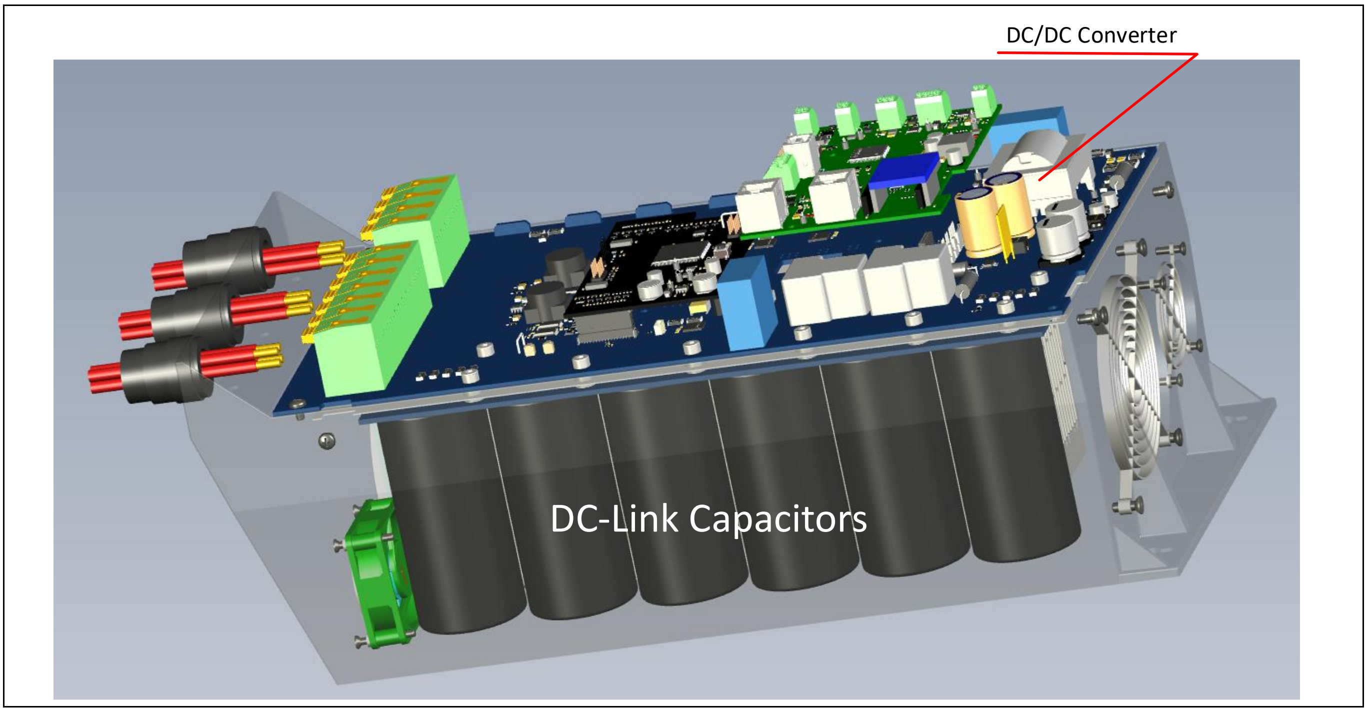

Figure 13 Inverter Construction Scheme (top-right view), Housing removed

2.2.4 Supply schemes

The three-phase AC input voltage is rectified to the DC-link supply voltage by the B6 rectifier bridge in the power module. In order to prevent high inrush currents during power-up when the three-phase supply is first connected, the DC-link capacitors are pre-charged via power resistors. After the capacitors are charged to match the line voltage, the power resistors are shorted out using power relays.

The DC-link voltage is converted to two low-voltage domains by a SiC-based flyback converter. A first output voltage (V15_HV) is used as the low-voltage supply for the functional isolated part of the inverter, supplying the gate drivers and the high-voltage logic board. The second voltage domain (V24_SELV) is used to power the low-voltage user interface board, local sensors (e.g. heat sink temperature sensor) and the cooling fans.

2.2.5 Component selection

The power module is in an EASY 3B package, part number FP100R12W3T7_B11, based on the latest IGBT7 technology allowing a compact and economic solution for an industrial drive. The FP100R12W3T7_B11 module carries all power semiconductors which are needed to control the motor current [1]. Due to the reduced VCEsat voltage compared to IGBT4 and enhanced switching controllability, the IGBT7 technology is tailored for industrial drives. For short-circuit protection of the IGBTs and for motor current control, the current sensor TLI4971-A120T5 is used. The TLI4971-A120T5 provides a fast short-circuit detection time and accurate measurement results over a wide temperature range [2]. For the gate driver IC, the EICE™ driver 1ED3131MC12H was selected. It is a single-channel isolated IGBT gate driver IC with a source and sink capability of 3 A.

The Infineon CoolSiC™ MOSFET IMBF170R1K0M1 with a blocking capability of 1700 V is used for the auxiliary power supply. By using the SiC-MOSFET, the design of the flyback inverter can be simplified.

The reference inverter uses two microcontrollers; one for control and one for communication. For control, the XMC4800-F144F2048 is used, for communication, the XMC4300-F100K256 AA is designed in. Both microcontrollers communicate via a UART interface.

3 System design

3.1 Schematics

The schematics of the design are available via Infineon.com. Keep in mind that the inverter consists of five boards, hence you will find one schematic for each board.

Table 3 Schematic overview

Board name	File name in zip folder
Power board	22kW_Inverter_Power_Board_v1.3_2021-01-11.pdf
DC-link board	U109_GPD_DCLinkCaps_v1.0_2019-10-23.pdf
EMI filter	U109_22kWGPD_EMI-filter_v2.1_2020-12-02.pdf
High voltage logic board	22kW_Inverter_Logic_v1.2_2020-09-01.pdf
Low voltage interface	22kW_Inverter_Interfaces_v1.2_2020-12-02.pdf
Connection between high voltage logic board and low voltage Interface	U109_GPD_FlexPCBConnector_v1.0_2020-12-02.pdf
Isolation sheet between power board and heat sink	U109_GPD_HeatsinkIsolation_v1.0_2020-12-02.pdf
Gasket to separate clean and dirty air	U109_GPD_Sealing_v1.0_2020-12-02.pdf

The Altium™ project files are available on request.

3.2 Layout

3.2.1 Power board

The layout of the power board is shown in Figure 14; in Table 4 you will find the names of each block.

The AC input connector (1), AC output connector (2), the brake resistor connector (3) as well as the DC-link connections (4) are located on the left hand side of the power board. The EMC filter is connected to the board in the area marked (5). The high-side gate drivers are located in the area marked (6) and the low-side gate driver are marked in section (12).

The interface to the high-voltage logic board (FELV board) is marked (7); this board has the interface connectors. The output phase current measurement is marked (8); all three-phase currents are measured, also the current between the DC-link capacitor and IGBT module is measured.

The IGBT module will be pressed in the area marked (9). The auxiliary power supply is located in the area marked (10), the SiC MOSFET is soldered to the PCB in the area (11). The DC-link board is screwed to the power board in the area marked (12).

The interface to the low-voltage interface board (SELV board) is marked (13). The safe isolation communication between the high-voltage logic board (FELV board) and low-voltage interface board (SELV board) is realized with the IC located on the PCB in area (14). The position of the pre-charge relay is shown at (16) and the pre-charge resistors are shown at (17).

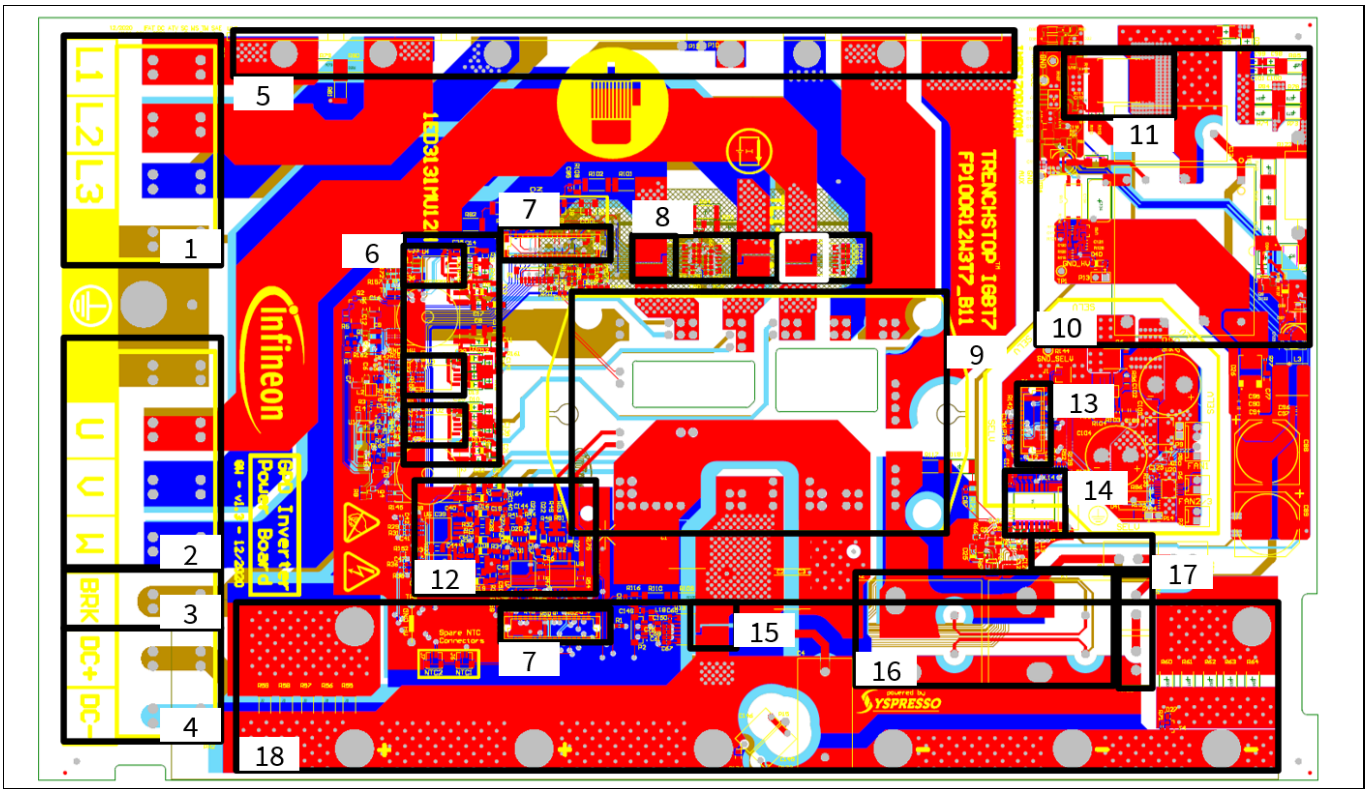

Figure 14 Layout of the power board

Table 4 Functional block - power board layout

Block number	Function
1	AC input connector
2	AC output connector
3	Brake resistor connector
4	DC-link connector
5	EMI-filter connections
6	High-side gate driver with gate driver IC 1ED3131MC12H
7	Connector for motor control board
8	Output phase current sensor measurement with TLI4971-A120T5
9	IGBT module with IGBT7 - FP100R12W3T7_B11
10	Auxiliary power supply
11	CoolSiC™ MOSFET IMBF170R1K0M1 of the auxiliary power supply
12	Low-side gate driver with gate driver IC 1ED3131MC12H
13	Connector for communication interface board
14	Isolation barrier for communication between high-voltage logic board (FELV board) and low voltage interface board (SELV board)
15	DC-link current sensor TLI4971-A120T5
16	Pre-charge relay
17	Pre-charge resistors
18	DC-Link

The gate layout of the high-side IGBT of the phase U is shown as an example in Figure 15. The traces of the emitter and gate trace are on top of each other, which minimizes any parasitic inductances.

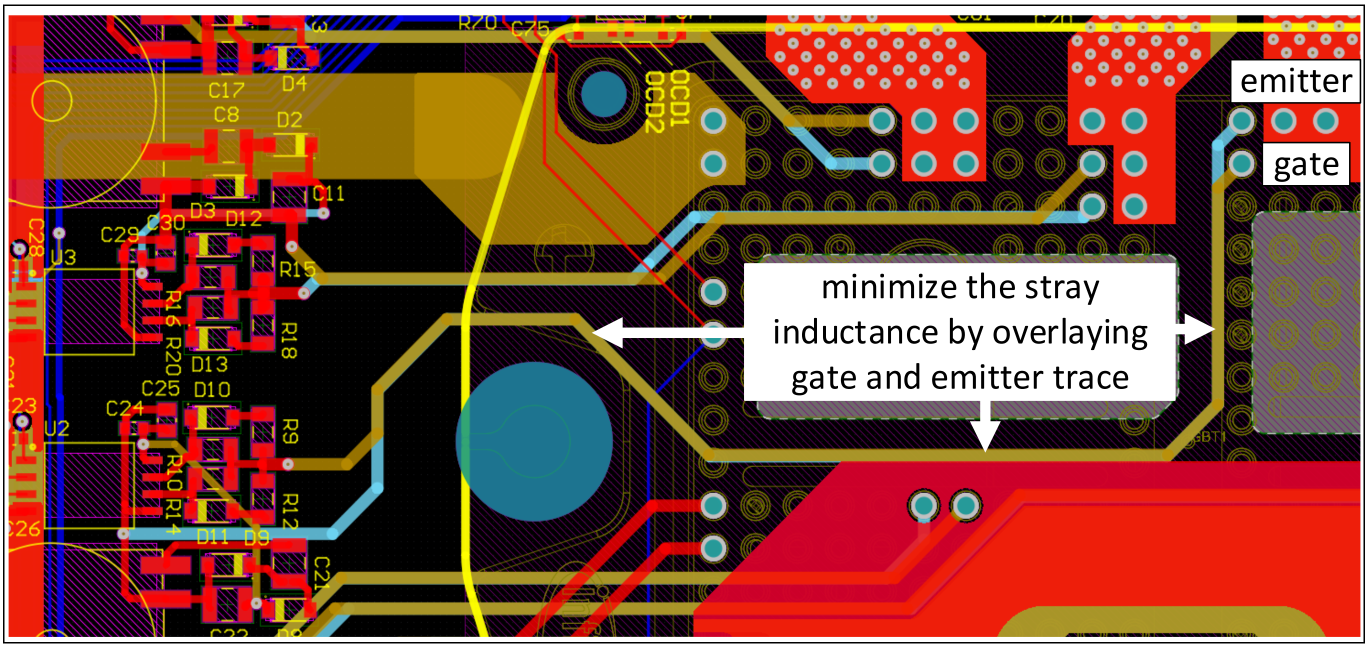

Figure 15 **Gate layout of the high-side IGBT of phase U**

3.3 Inverter cooling concept

A three-channel cooling system provides the cooling of the inverter, as seen in Figure 1 and Figure 16.
The main cooling of the IGBT is done by a heat sink and an integrated 92 mm fan with a temperature controlled flowrate of 0-270 m^3/h. The air is drawn in the bottom of the unit and blown up through the heat sink to the outlet at the top of the enclosure, assuming a normal wall mounting position.
A 52 mm auxiliary fan cools the DC-link capacitors and operates at a constant speed with a flow rate of 20m^3/h. As shown in Figure 16 the air is blown into an air channel at the bottom of the capacitor array. To provide an improved cooling over the entire surface of each capacitor the air is directed up one side and then channeled via small slits between each capacitor and then finally along the side of the heat sink to the air outlet at the top of the enclosure.
A second 52 mm fan, also operating at a constant speed, cools a third channel containing the EMI filter. The air flows beside the heat sink and over the indictors and capacitors of the EMI filter. This cooling channel has a separate air outlet at the top of the enclosure.

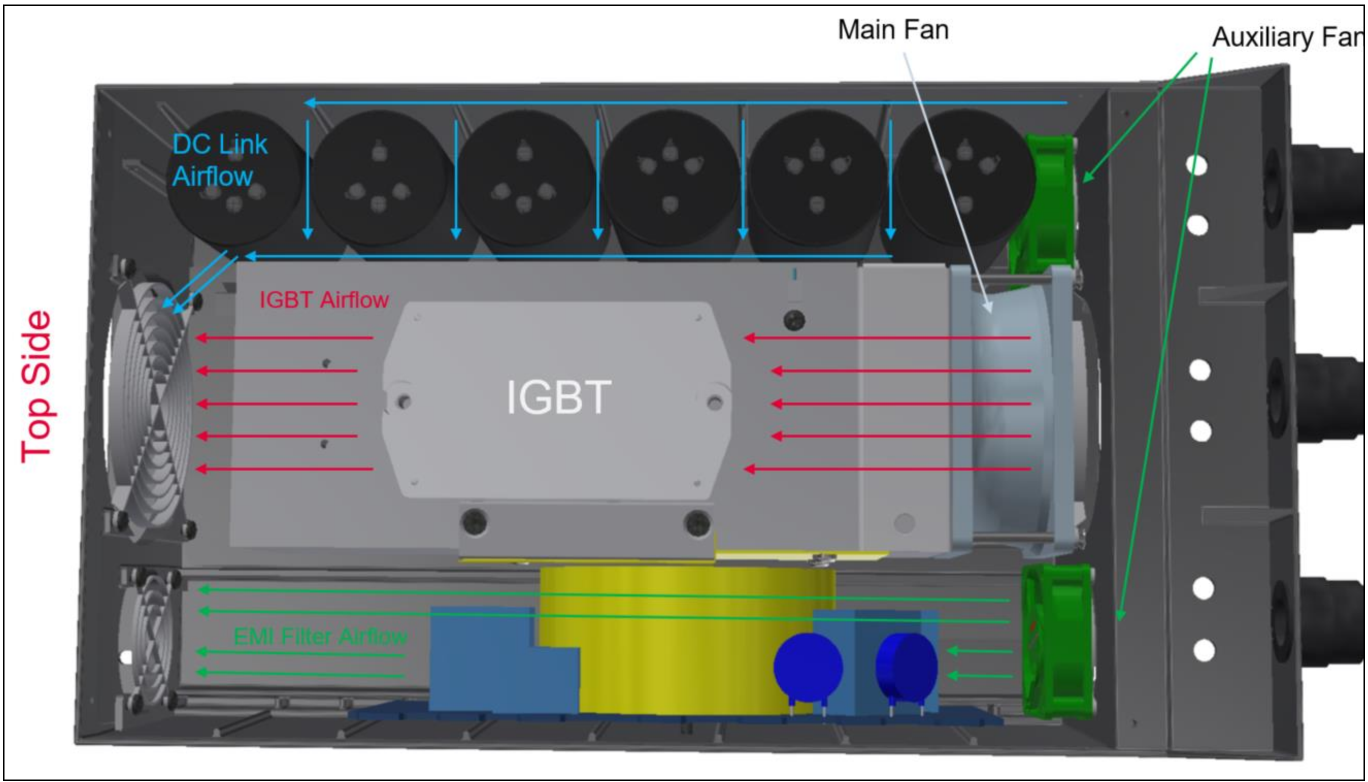

Figure 16 Airflow through the heat sink

3.4 Disassembly of the housing

The inverter enclosure consists of three separate parts that are screwed together as seen in Figure 17.

1. A low-voltage cover which acts as a frame and holder for the front panel display and protects the high power connectors and the SELV interface PCB.
2. A high-voltage cover mounted underneath the low-voltage cover protects the isolated PCB connector mounted to the power PCB below. All sensors and the display are connected there.
   In addition, the main connectors for the electric motor and the supply are available there.
3. The high-voltage cover protects all the non-isolated high voltage parts. The top side of the cover is marked with a danger sign and should only be removed by safety experts!
4. The main housing encloses all the electronic components and the cooling system, which are located there. The power electronics at the upper or front level of the main housing are separated from the main airflow over the heat sink, and potential dirt and dust, by a gasket. See Figure 17.

Figure 17 Covers of the drive system

Disassembly of the covers:

1. Low-voltage cover: remove four screws at the side of the cover; see Figure 18.

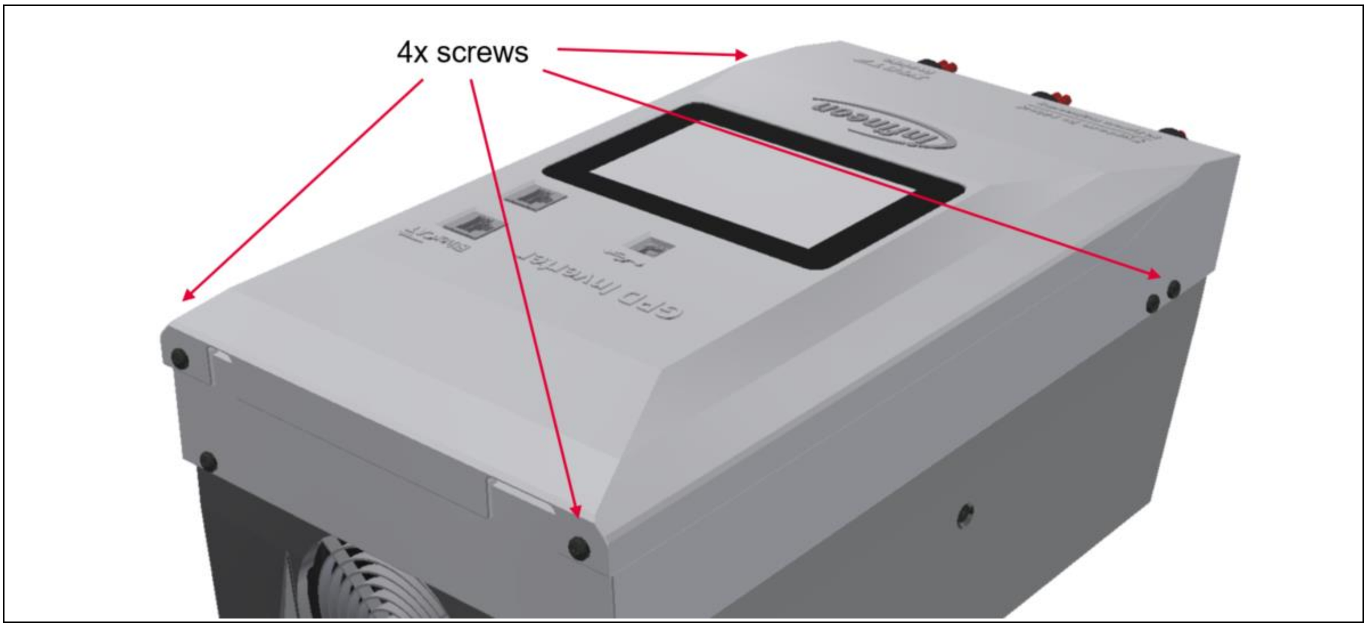

Figure 18 Disassembly of the front cover

2. High-voltage cover: remove four screws at the side of the cover; see Figure 19.
   Remove the safety screw at the center of the cover.
   Attention! This cover should only be removed by trained safety experts only!

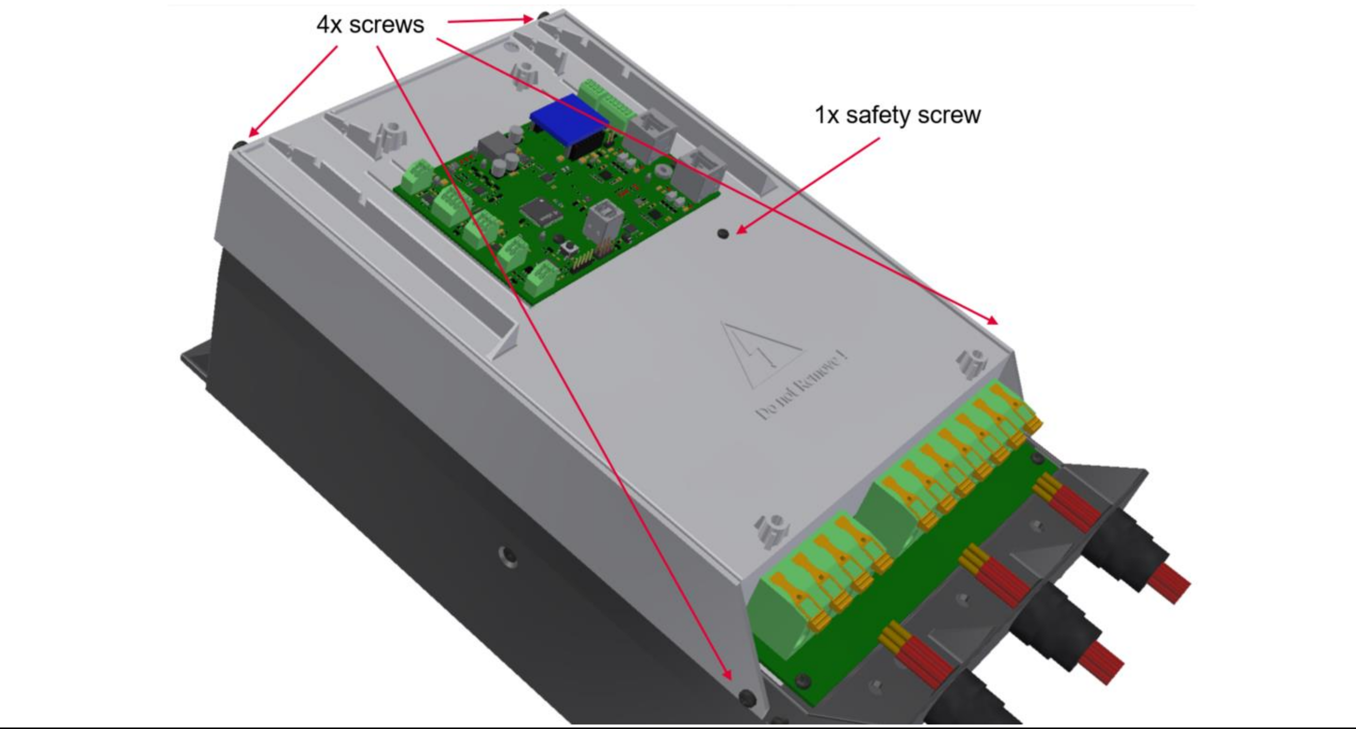

Figure 19 Disassembly of the high-voltage cover

3. If all front covers are removed, the power board PCB is visible, as shown in Figure 20.

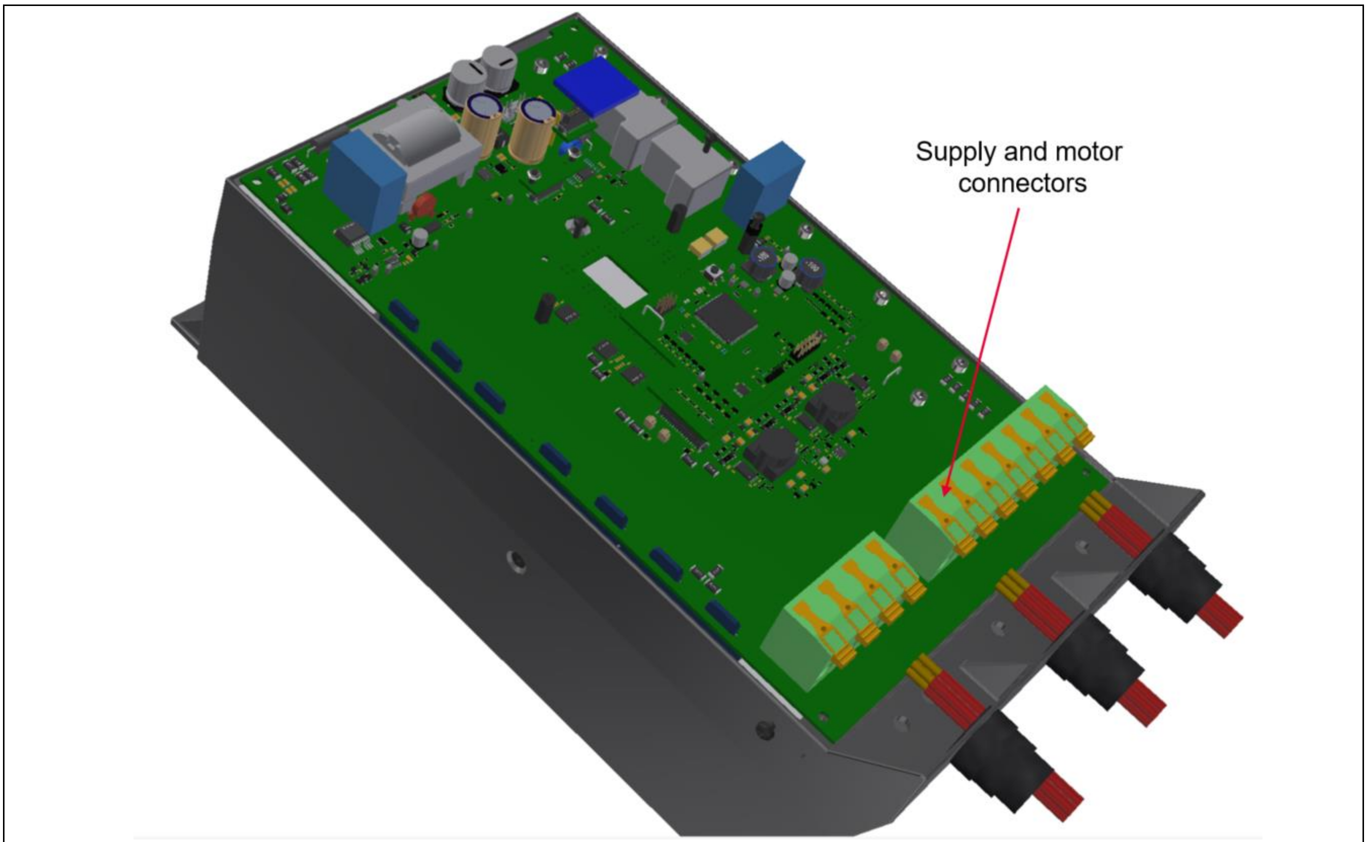

Figure 20 Inverter without front covers

3.5 Bill of material

The complete bill of material is available on the download section of the Infineon homepage. A log-in is required to download this material.

Table 5 BOM of the most important/critical parts of the evaluation or reference board (example)

Board name	File name in zip folder
Power board	BOM_22kW_Inverter_Power_Board_v1.3_2021-01-11.xlsx
DC-link board	BOM_U109_GPD_DCLinkCaps_v1.0_2019-10-21.xlsx
EMI filter	BOM_U109_22kWGPD_EMI-filter_V2_v1.0_2020-12-02.xlsx
High voltage logic board	BOM_22kW_Inverter_Logic_v1.2_2020-09-01.xlsx
Low voltage interface	BOM_U109_22kW_Inverter_Interfaces_v1.2_2020-12-02.xlsx
Connection between high voltage logic board and low voltage Interface	BOM_U109_GPD_FlexPCBConnector_v1.0_2020-12-02.xlsx

3.6 Connector details

Connectors of the power board:

Table 6 Connector PH1

PIN	Label	Function
1	Earth	Earth potential for safe operation always connect to earth
2	L3	Line feeder cable phase L3
3	L2	Line feeder cable phase L2
4	L1	Line feeder cable phase L1

Table 7 Connector PH2

PIN	Label	Function
1	Earth	Earth potential for safe operation always connect to earth
2	DC-	DC-minus voltage
3	DC+	DC-plus voltage, the brake resistor must be connected here
4	brake	The brake resistor must be connected here, it is connect between DC+ and brake
5	W	Motor feeder cable phase W
6	V	Motor feeder cable phase V
7	U	Motor feeder cable phase U

Connectors of the user interface board:

Table 8 Connector P1

PIN	Label	Function
1	SPEED_1	Input signal speed sensor
2	V9_SELV	9 V power supply

Table 9 Connector P2

PIN	Label	Function
1	Input	Input signal NTC
2	GND	Ground

Table 10 Connector P4

PIN	Label	Function
1	VCC	Supply voltage
2	D-	Data signal -
3	D+	Data signal +
4	GND	Ground

The USB port for remote control via the PC-GUI can be found at the front side of the inverter.

Table 11 Connector P14

PIN	Label	Function
1	VCC	Supply voltage
2	VCC	Supply voltage
3	GND	Ground
4	STOA	Safe torque off Channel A
5	STOB	Safe torque off Channel B
6	Chassis_GND	Chassis GND

Table 12 Connector P12

PIN	Label	Function
1	TD+	Transmission data +
2	TD-	Transmission data -
3	RD+	Receiver data +
4	N.C.	
5	N.C.	
6	RD-	Receiver data -
7	N.C.	
8	N.C.	
S1	Chassis_GND	
S2	Chassis_GND	

4 System performance

4.1 Test results inverter start-up

The inverter is supplied via an auxiliary supply which derives its energy from the DC-link capacitors, so the power supply starts when the DC-link voltage increases above a threshold voltage, approximately 100 V. In Figure 21 the inverter start-up is shown. The three-phase rectified AC voltage “Rectifier_AC_In” is shown in red, the output of phase V is shown (V_Output) in blue. In yellow the DC-link voltage, in the schematic called “Rectifier_AC” is shown and one output voltage of the auxiliary power supply “V15_HV” is shown in green.

The auxiliary power supply starts working if the voltage “Rectifier_AC” is above 100 V. The voltage “V15_HV” is moving around the set point due to the light load conditions during start-up. The reason for this is pulse skipping of the auxiliary supply under light load.

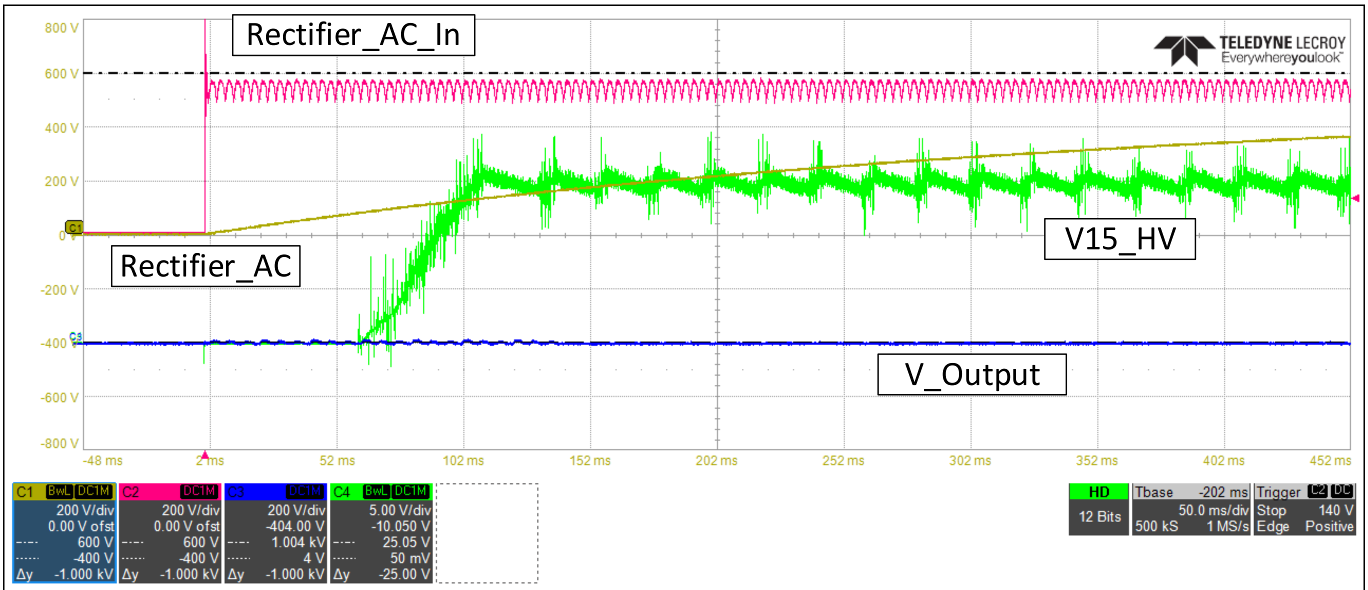

Figure 21 Inverter Start-up

If the inverter is connected to the grid, the in-rush current must be limited. Therefore, the DC-ink capacitors will be charged via the pre-charge relay and resistors. This relay will be closed after approximately 2 seconds, as shown in Figure 22. The pulse width modulation of the output phase starts approximately 200 ms after the relay closes.

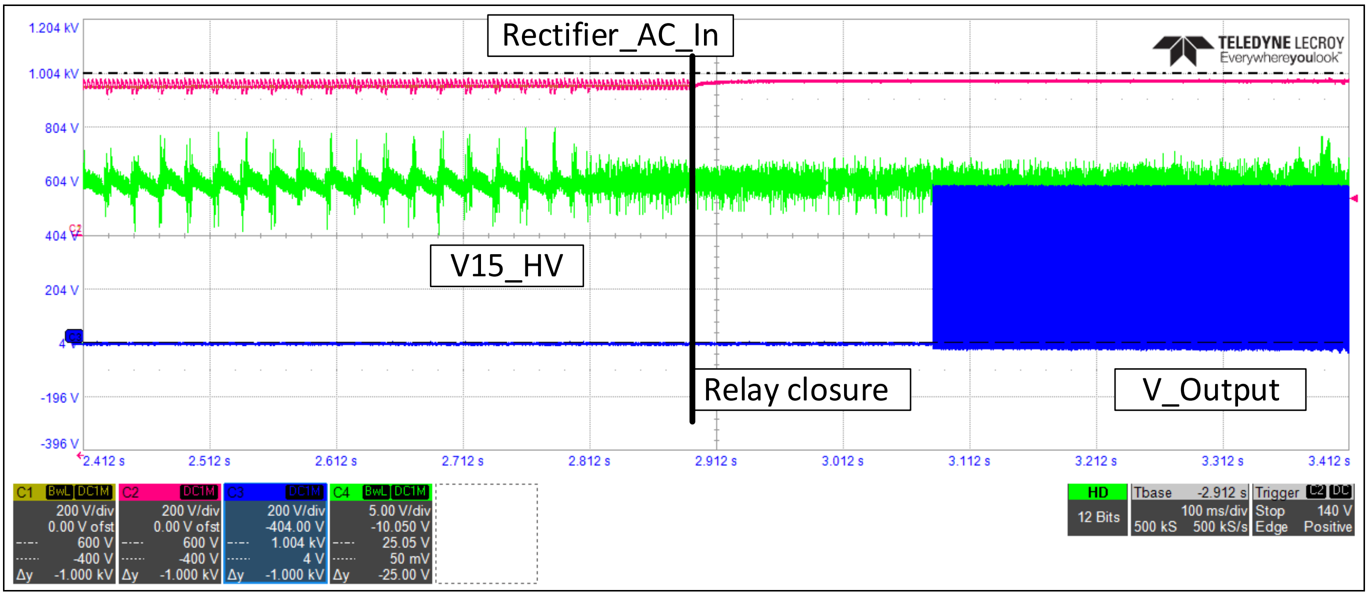

Figure 22 Relay closure

4.2 Operation under rated conditions

The following chapter shows the nominal operation conditions. The inverter is supplied by a 400 VAC grid and can be connected at the output to a symmetrical RL-passive load for test purposes rather than a motor load, as illustrated in Figure 23.

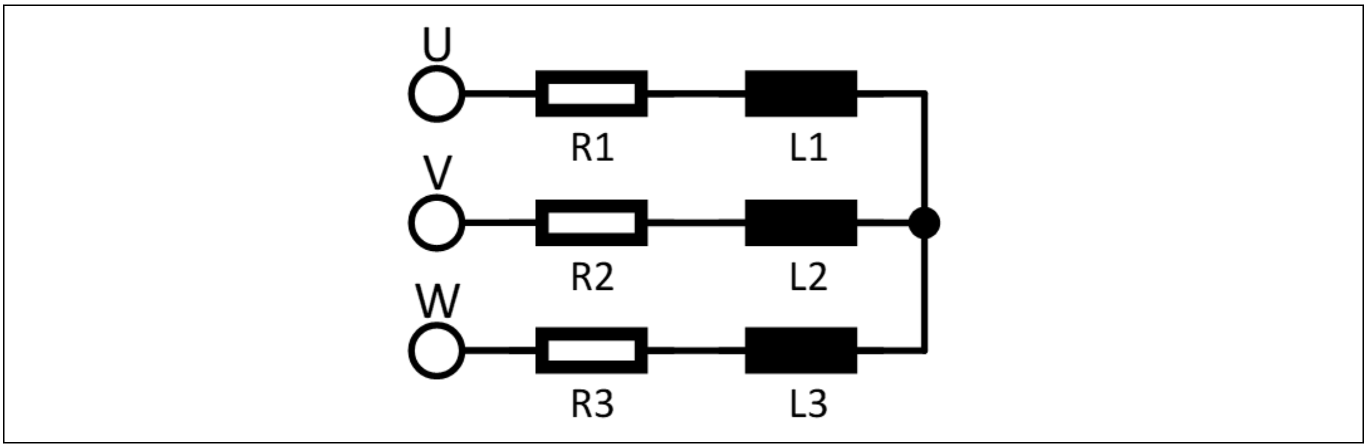

Figure 23 Passive load

The value of the inductor L1, L2 and L3 is 8 mH; the value of the resistor is 3.4 Ω. The sinusoidal output frequency is set to 50 Hz and output current to 45 $A_{RMS.}$ The switching frequency was set to 4 kHz. The measurement results are shown in Figure 24.

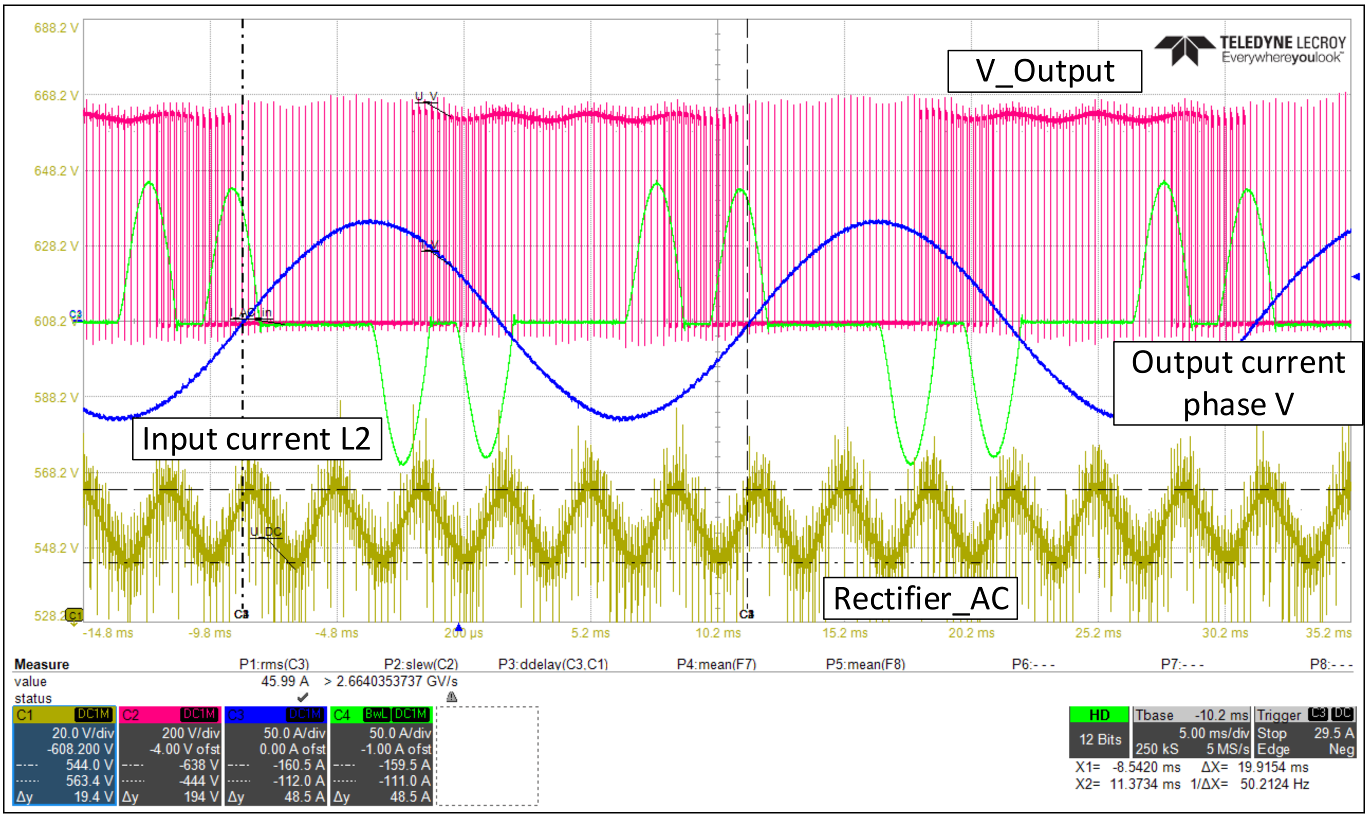

Figure 24 **Inverter under nominal operation conditions**

The output phase current (green) and the resistor voltage (red) are almost sinusoidal, whereas the input line current (blue) shows the typical waveform of a capacitor charging current. The yellow signal shows the rectified DC-bus voltage of about 562 V.

4.3 Switching behavior of the IGBT turn-on

The following diagram shows the turn-on behavior of the lower V phase IGBT, marked as IGBT #4, “V_BOT”. The value for R35 was set to 6.8 Ω and R39 to 4.7 Ω. The RMS current of the inverter was 57.5 A. In the top part of Figure 25, the “persistence” function of the oscilloscope was used to show the changing dv/dt levels at turn-on. In the diagram at the bottom, a histogram is shown tabulating the dv/dt slope of 1,000 measured periods. The histogram shows a spectrum of the dv/dt in the range between 0.5 V/ns and 4.5 V/ns with the average being around 2 V/ns.

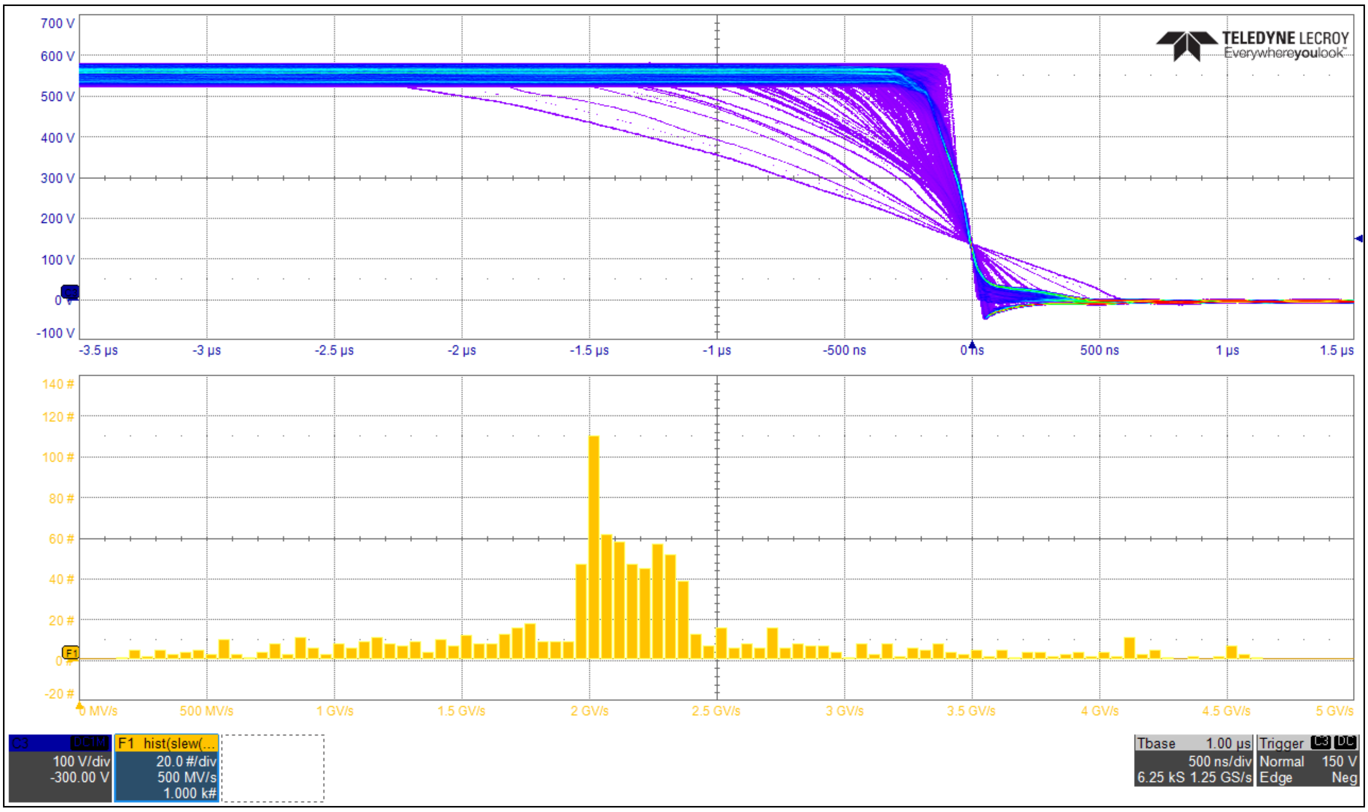

Figure 25 V_{CE} voltage slope and dv/dt histogram during turn-on

4.4 Switching behavior of the IGBT – turn-off

The following diagram shows the turn-off behavior of lower phase V IGBT marked as IGBT #4, “V_BOT”. The value for R35 was set to 6.8 Ω and R39 to 4.7 Ω. The RMS current of the inverter was set to 57.5 A. In the top part of Figure 26 the “persistence” function of the oscilloscope was used to show the changing dv/dt levels at turn-on. In the diagram at the bottom, a histogram is shown tabulating the dv/dt slope of 1,000 measured periods. The histogram shows a spectrum of the dv/dt in the range between 0.5 V/ns and 4 V/ns with an average around 2.4 V/ns.

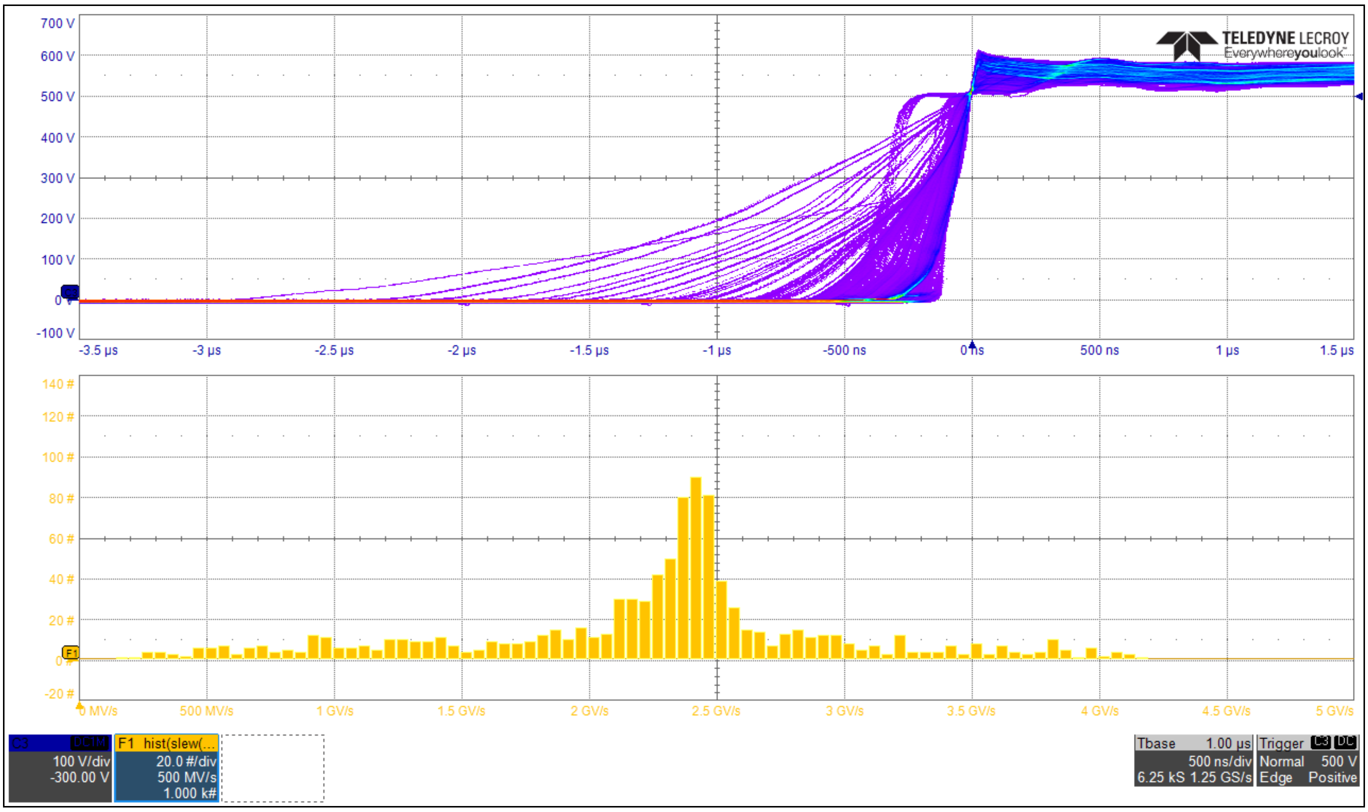

Figure 26 V_{CE} voltage slope and dv/dt histogram during turn-off

4.5 Thermal behavior of the inverter under high overload

A typical drive overload pulse pattern is shown in Figure 4. In a period of 5 minutes, a 1-minute overload condition of 150% of the nominal current is required.

This overload pattern is applied to the inverter by adapting the modulations index via the GUI with the “Load Pulse Pattern Config” sub menu. The temperature of the IGBT module NTC (T_NTC) and the heatsink temperature sensor (T_Heatsink) are recorded with the built-in oscilloscope function of the inverter and the result is shown in Figure 27. The data can be exported as a csv-file.

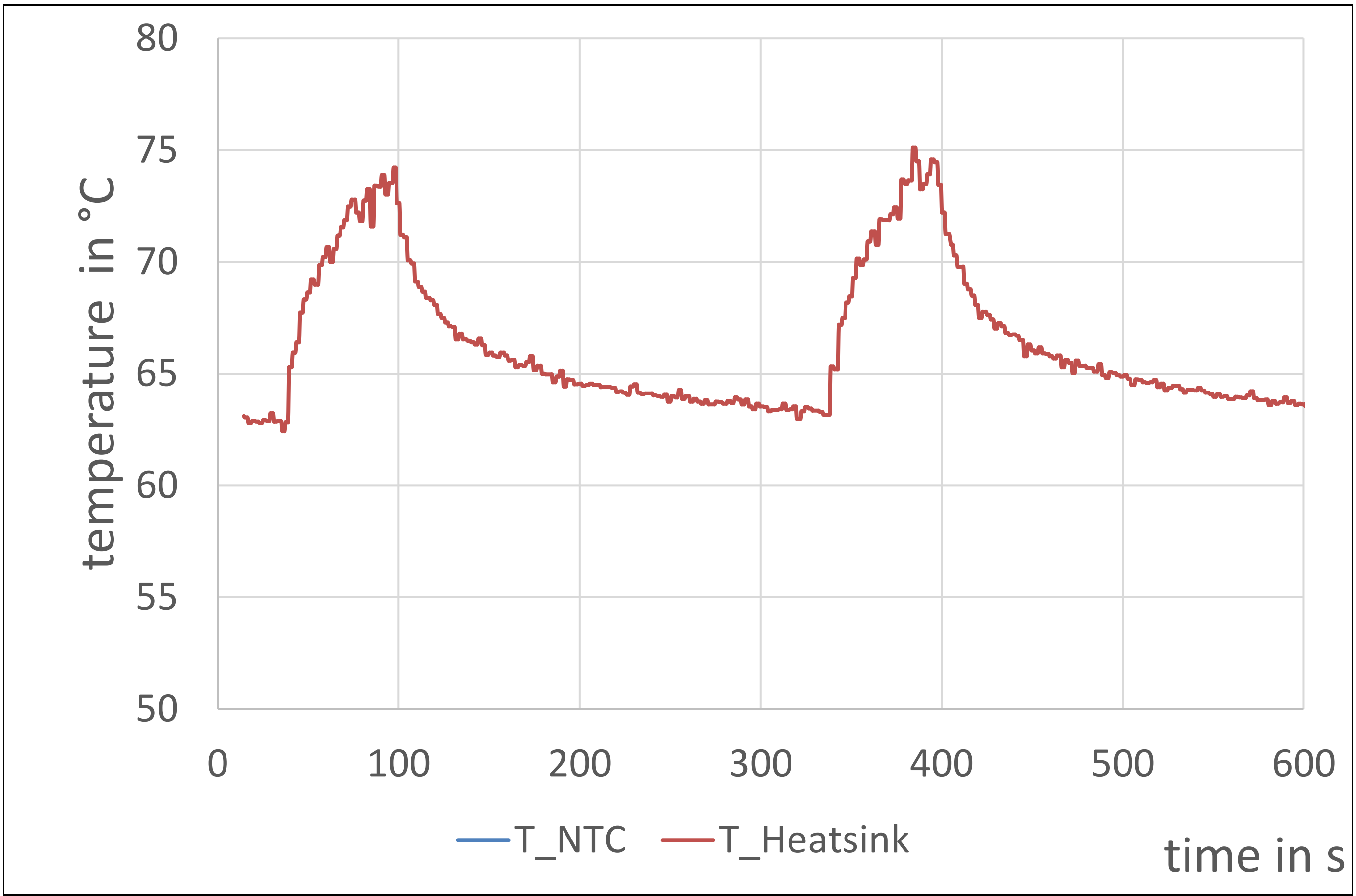

Figure 27 Temperature of the IGBT NTC and heatsink during heavy overload

The temperature of the NTC of the IGBT module increases by 12°C during the overload pattern, the temperature of the heat sink only by 7°C. Both temperatures represent the temperature at the location of the individual temperature sensor. This means the junction temperature of the IGBT is much higher and will have higher temperature variation during the overload pattern.

4.6 Short-circuit measurement

The short-circuit behavior of the drive was tested by using the setup, as shown in Figure 28. A short circuit was applied across the output terminals. The cable length between the terminal U and DC- is 1.2 m and has a cross section of 6 mm^2. The drive was powered up and ready for the short-circuit test.

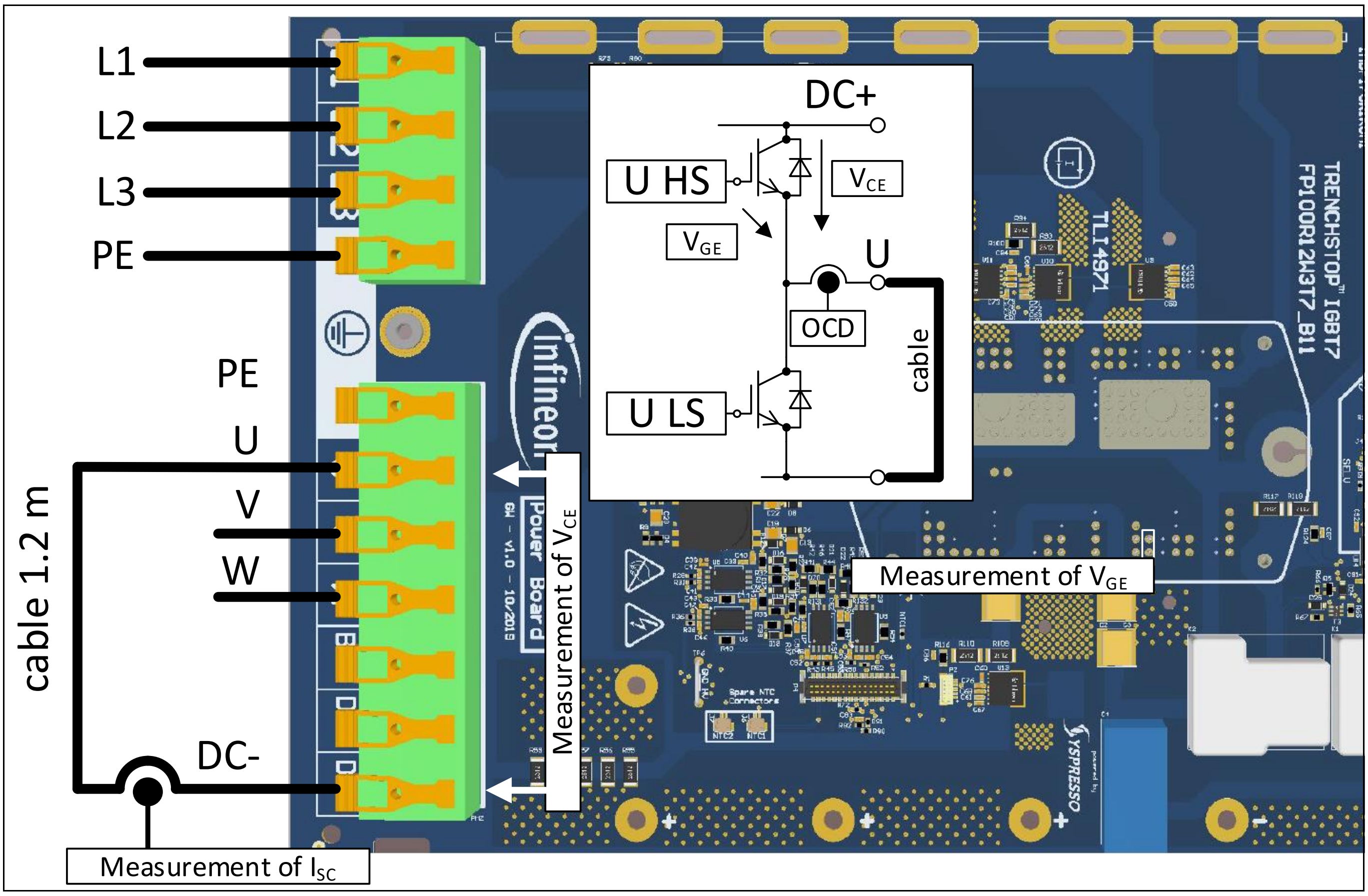

Figure 28 **Short circuit setup**

The short-circuit test can now be performed via the GUI. You will find the “Short Circuit Test Pulse” section at the “Config” tab. Here you can select the “Pulse length.” It is recommend to set the pulse length to 8 µs. Then you have to select the switch you want to test; in this case “U LS” (phase U, low side switch). To start the test click on “Fire.”

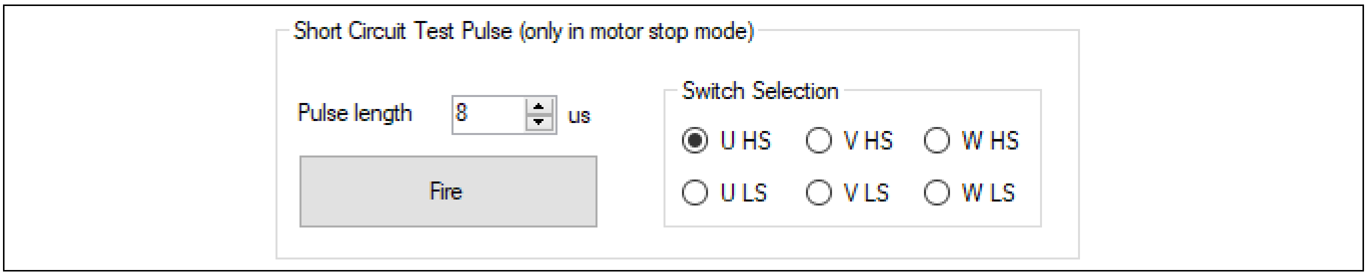

Figure 29 **GUI of the "Short Circuit Test Pulse"**

For verification if the short-circuit turn-off of the IGBT behaves correctly, the following voltages and currents were measured, see Figure 30. The gate emitter voltage (V_{GE}), the collector-emitter voltage (V_{CE}) and the current flowing through the short-circuit cable (I_{SC}) are shown in the figure.

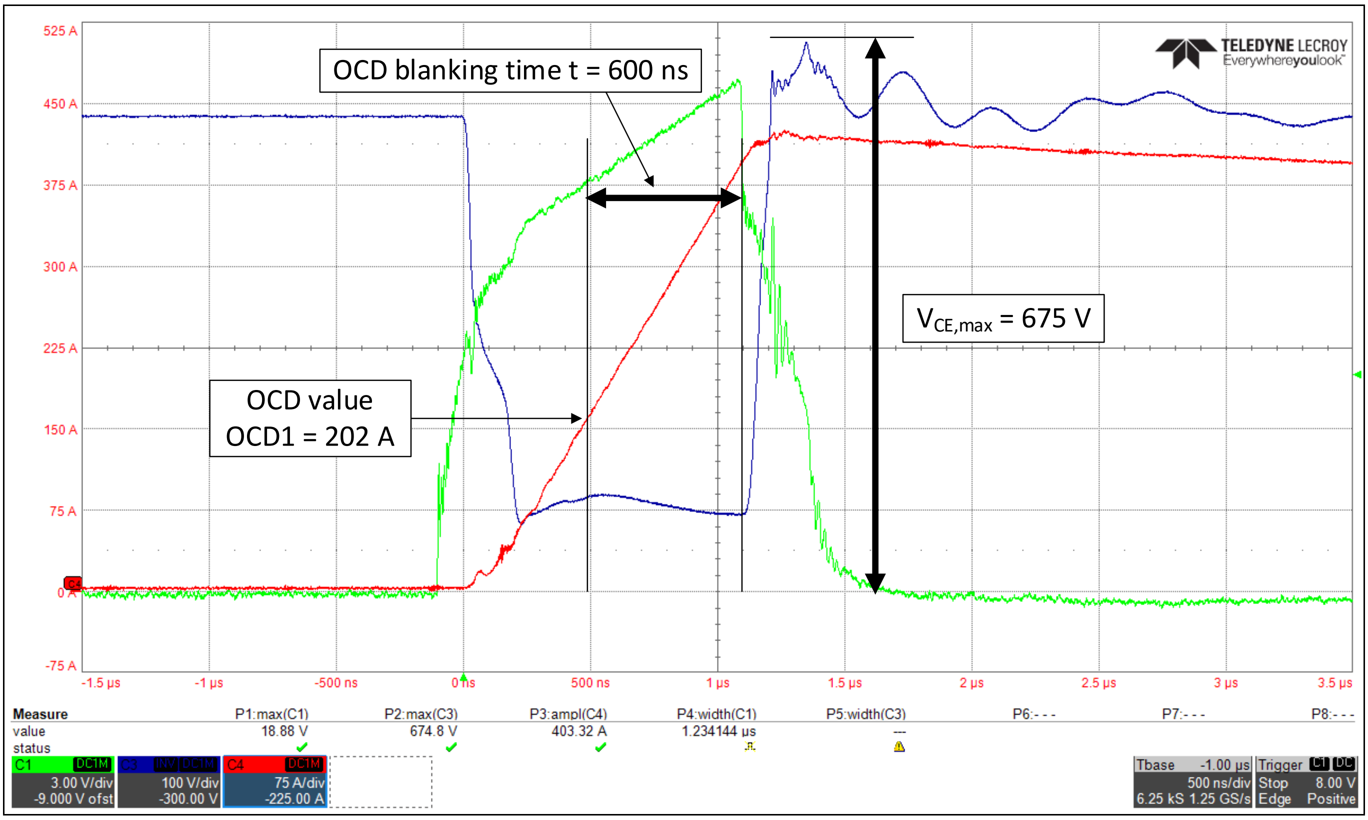

Figure 30 **Short circuit measurement**

The overcurrent detection (OCD) level of the current sensor is set to 168% of the nominal current measurement range of 120 A. Hence, the OCD current level is 202 A. The oscilloscope measurement in Figure 30 shows that the OCD signal of the current sensors triggers after 600 ns, then the IGBT is commanded to turn-off, and the current I_{SC} declines. The overvoltage overshoot due to the di/dt is moderate with a maximum value of 675 V, hence an overvoltage of approximately 90 V. This is well within the IGBT 1200 V maximum rating.

5 References and appendices

5.1 Abbreviations and definitions

Table 13 Abbreviations

Abbreviation	Meaning
CE	Conformité Européenne
EMI	Electromagnetic interference
UL	Underwriters Laboratories
IGBT	insulated-gate bipolar transistor
SiC	silicon carbide
MOSFET	metal–oxide–semiconductor field-effect transistor
GUI	graphical user interface
PCB	Printed circuit board
SELV	safety extra-low voltage
FELV	functional extra-low voltage

5.2 References

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[2] Infineon Technologies AG. AppNote TLI4971 Electrical Drive (2019): High Voltage General Purpose Drive (GPD) with Hall-Effect Current Sensor. V1.0 www.infineon.com

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[7] Infineon Technologies AG. Datasheet (2018): XMC4300 Microcontroller Series for Industrial Applications. V1.1 www.infineon.com

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1.00	2021-01-29	First release

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