

## GENERAL DESCRIPTION

These modules are designed for the low-voltage laboratory implementation of multilevel converters. Versatile power interfaces allow to easily configure the modules for both half- or full-bridge operation. The design is tailored for 19" rack integration with simple interconnections and direct connection to a BoomBox, or any other control platform.

Direct access to the gating signals is offered using optical fiber inputs, while embedded measurement circuits provide direct analog outputs related to the capacitor voltage and one output current using galvanically-isolated sensors.

The modules are well suited for any kind of PWM operation from 0 Hz to 50 kHz and current ratings up to 10 A. The main limitation being the power envelope of the heatsinks, which is limited to approximately 20 W with no airflow and about 30 W with a 1 m/s airflow.

Overvoltage, over-current and over-temperature protections are also integrated on the board for safer use in R&D applications. Besides, these protections are user-programmable through a simple onboard microcontroller and a CPLD.

Finally, the possibility to use alternative or customized mezzanine boards enables the compatibility with future developments and onboard data processing.

## TYPICAL APPLICATIONS

The modules are ideally suited for the implementation of low-voltage prototypes of multilevel converters such as Modular Multilevel Converters (MMC), Cascaded H-bridge (CHB) systems or any similar topology.

Nevertheless, they can also be easily combined to build up simple DC-DC converters, Dual-Active Bridges (DHB), resonant converters, back-to-back systems, etc.

## KEY FEATURES AND SPECIFICATIONS

- 10 A / 400 V maximum ratings, limited by losses
- 600 V / 50 A IGBTs
- 230 A maximum current (1 ms)
- 2x20 W TDP envelope
- Isolated TO247 transistor packages
- 0-1.35 mF / 400 V DC bus, depending on configuration
- Up to 50 kHz switching frequency
- $\pm 3$  kV galvanic isolation (1 s) /  $\pm 560$  V (permanent)
- 4 optical inputs / 1 optical output
- 2 analog outputs
- Single +5 V power supply
- Embedded voltage and current measurement
- Over voltage/current/temperature protection
- User-configurable CPLD
- 100x260 mm Eurocard form factor
- Forward compatible with imperix RealSync technology and the related mezzanine board

## GENERAL SCHEMATIC

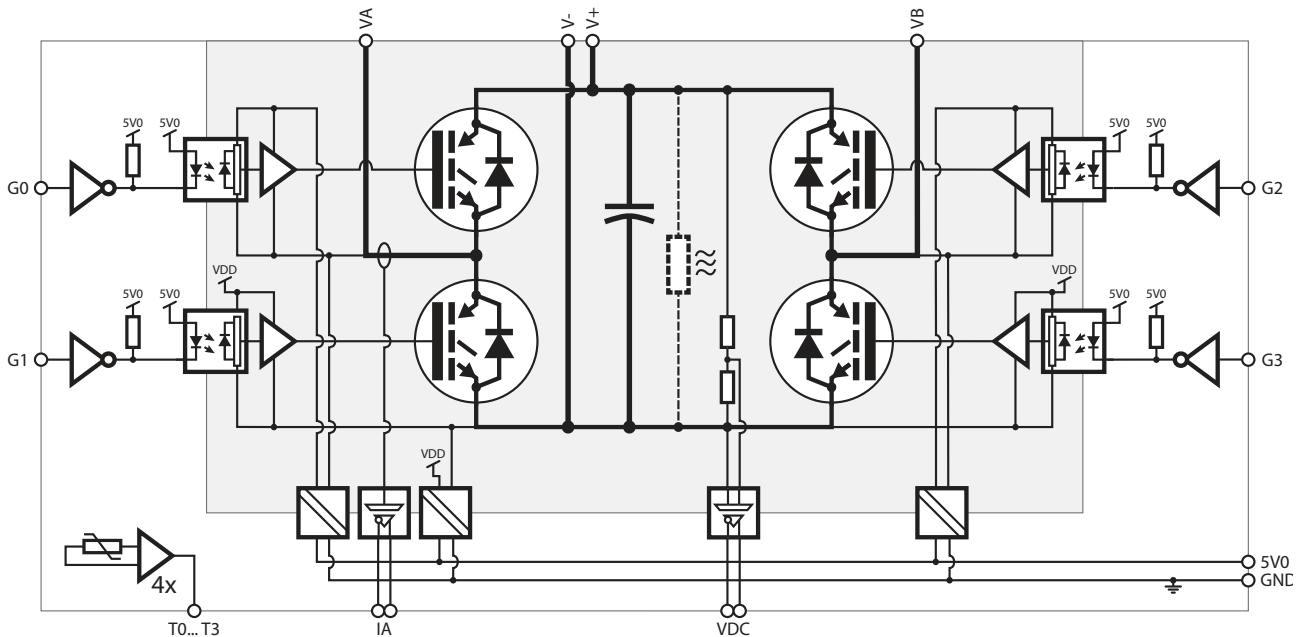


Fig. 1. Simplified schematic of the power stage of the H-bridge module. Embedded logic circuits and I/O connectors not shown.

## MAIN COMPONENTS

Component	Devices	Main specifications
Power switches	4x IXYS IXGR 48N60 C3D1	See below or device datasheet
Capacitors	9x United Chemicon SMQ 0-150uF	400V, $I_{\text{RIPPLE}} > 1.1\text{A}$ per capacitor (option)
Drivers	4x Avago HCPL-3140	0.4 A, 10 kV/us, $V_{\text{IORM}} = 630\text{V}$
Isolated DC/DC Converters	3x Recom RBM0515S	5-15 V, 1W, $V_{\text{IORM}} = 1.1\text{kV}$
Current sensor	1x Allegro ACS709-20	$\pm 37.5\text{A}$ , 120kHz, $\pm 2\%$ accuracy
Voltage sensor	1x Resistive divider + Texas Instruments AMC1200	60kHz, $\pm 0.5\%$ accuracy
Heatsinks	2x Fischer SK 487/84	84 x 52.3 x 28 mm, 2.5 K/W without airflow
CPLD	1x Xilinx XC9536XL-10VQG44C	10ns, 36 macrocells
Microcontrollers	2x Microchip PIC24F04KA201	16bits, 16Mhz, 9x 10-bit ADC @ 500ksps

## ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Test conditions	Min.	Typ.	Max.	Unit
Maximum DC bus voltage <sup>1</sup>	$V_{\text{DC}}$		-	400	-	V
Maximum continuous leg A / leg B current <sup>2</sup>	$I_{\text{A/B,max}}$	$T_j = 25^\circ\text{C}$		56		A
Maximum DC bus ripple current (at 100Hz) <sup>3</sup>	$I_{\text{RIPPLE}}$		-	10	-	A
Maximum working isolation voltage	$V_{\text{IORM}}$		-	560	-	$V_{\text{PEAK}}$
Highest allowable isolation voltage (1s)	$V_{\text{IOTM}}$		-	3.0	-	$\text{kV}_{\text{PEAK}}$
Supply voltage	5V0		4.2	5.0	5.8	V
	12V <sup>4</sup>		4.5	12.0	14.0	V
Highest allowable junction temperature	$T_{\text{J(max)}}$		-	150	-	$^\circ\text{C}$

<sup>1</sup> The maximum DC bus voltage is defined by the specifications of the bus capacitors. Therefore, as for any aluminium electrolytic capacitors, few short-term overvoltages can be tolerated, provided that they involve limited amounts of energy.

<sup>3</sup> The maximum ripple current is defined by the equivalent series resistance (ESR) of the capacitors and relates to Joule losses and lifetime considerations. Therefore, this value can be exceeded, provided that the operating temperature of the capacitors remain low.

<sup>2</sup> In cold conditions, the maximum operating current is limited by the power semiconductors. Otherwise, the current rating of the module is limited by the power envelope of the heatsinks (about 20 W without airflow). This typically restricts the RMS value of the phase-leg current to about 15 A for a switching frequency of 10kHz.

<sup>4</sup> The 12V supply is optional, as it is entirely independent from the module and serves only to supply optional cooling fans that can be mounted on the heatsinks.

## POWER CHARACTERISTICS

Parameter	Symbol	Min.	Typ.	Max.	Unit
IGBT blocking voltage	$I_{CES}$	$T_J = 25 \text{ to } 150^\circ\text{C}$	600	-	V
IGBT continuous collector/diode current	$I_{C25}$	$T_J = 25^\circ\text{C}$	56	-	A
	$I_{C110}$	$T_J = 110^\circ\text{C}$	26	-	A
IGBT pulse collector/diode current (1 ms)	$I_{CM}$	$T_J = 25^\circ\text{C}$	230	-	A
IGBT saturation voltage	$V_{CE(sat)}$	$I_C = 15\text{A}, T_J = 25^\circ\text{C}$	2.1	-	V
		$I_C = 15\text{A}, T_J = 125^\circ\text{C}$	1.3	-	V
Diode forward voltage	$V_F$	$I_F = 15\text{A}, T_J = 25^\circ\text{C}, V_{GE} = 0\text{V}$	2.2	-	V
		$I_F = 15\text{A}, T_J = 125^\circ\text{C}, V_{GE} = 0\text{V}$	1.5	-	V
Reverse recovery current	$I_{RRM}$	$I_F = 30\text{A}, V_R = 100\text{V}, di/dt = -100\text{A}/\mu\text{s}$	4	-	A
Reverse recovery delay	$t_{RR}$	$I_F = 1\text{A}, V_R = 30\text{V}, di/dt = -100\text{A}/\mu\text{s}$	100	-	ns
Thermal resistance junction-to-pad	$R_{thJP}$		-	1.5	$^\circ\text{C}/\text{W}$
Thermal resistance heatsink-to-air	$R_{thSA}$		-	2.5	$^\circ\text{C}/\text{W}$
Turn-on losses (inductive load)	$E_{on}$	$I_C = 15\text{A}, V_{CE} = 200\text{V}, T_J = 25^\circ\text{C}$	150	-	$\mu\text{J}$
		$I_C = 15\text{A}, V_{CE} = 200\text{V}, T_J = 125^\circ\text{C}$	250	-	$\mu\text{J}$
Turn-off losses (inductive load)	$E_{off}$	$I_C = 15\text{A}, V_{CE} = 200\text{V}, T_J = 25^\circ\text{C}$	80	-	$\mu\text{J}$
		$I_C = 15\text{A}, V_{CE} = 200\text{V}, T_J = 125^\circ\text{C}$	130	-	$\mu\text{J}$
Case-to-heatsink isolation voltage	$V_{ISO}$	50Hz, 1min	2.5	-	kV

Assuming a phase-leg current of  $8\text{A}_{\text{RMS}}$  and a switching frequency of 10 kHz for each device, these characteristics lead for each phase-leg to approximately:

- » conduction losses: 20W hot / 35W cold
- » switching losses: 4.2W hot / 2.7W cold

The total thermal resistance junction-to-air is approximately 4.0 to 4.5  $^\circ\text{C}/\text{W}$ , leading to a junction temperature of typically 120 to 130 $^\circ\text{C}$  for the above-mentioned operating conditions and losses, assuming an ambient air temperature of 25 $^\circ\text{C}$ .

## CURRENT MEASUREMENT CHARACTERISTICS

Parameter	Symbol	Note	Min.	Typ.	Max.	Unit
Optimized accuracy range	$I_{OPT}$		-	$\pm 20$	-	A
Linear range <sup>5</sup>	$I_{FS}$		-	$\pm 37.5$	-	A
Nominal sensitivity	G	Including a x2 gain on the Mezzanine	-72.0	-74.0	-77.2	mV/A
Total output error <sup>6</sup>	$G_{ERR}$	$T_A = 25^\circ\text{ to } 100^\circ\text{C}$	-	$\pm 0.5$	$\pm 2.0$	%
Bandwidth	$f_{3dB}$		-	120	-	kHz
Measurable slope	$dI/dt$		-	6	-	A/ $\mu\text{s}$
Maximum working isolation voltage	$V_{IORM}$		-	390	-	$V_{DC}$

## VOLTAGE MEASUREMENTS CHARACTERISTICS

Parameter	Symbol	Note	Min.	Typ.	Max.	Unit
Measurement range	$V_{OPT}$		0.0	-	400	V
Maximum measurement range <sup>5</sup>	$V_{FS}$		0.0	-	450	V
Nominal sensitivity	G	Including a x2 gain on the Mezzanine	-	-8.9	-	mV/V
Uncalibrated sensitivity error	$G_{ERR}$	25 $^\circ\text{ to } 125^\circ\text{C}$ , including resistive divider		$\pm 2.0$		%
Gain error over temperature	$G_{ERR,t}$	$T_A = 25^\circ\text{ to } 100^\circ\text{C}$		$\pm 0.1$		%
Bandwidth	$f_{3dB}$		-	25	-	kHz
Measurable slope	$dV/dt$		-	220	-	V/ $\mu\text{s}$
Maximum working isolation voltage	$V_{IORM}$		-	1140	-	$V_{DC}$

<sup>5</sup> The integrated current and voltage measurements are isolated onboard, as depicted by Fig. 1. The measured values are available as differential signals on the mezzanine connectors, with voltages ranging in the interval

between 0 and 3.3V. In case imperix ModuLink mezzanine are used, the latter feature an integrated x2 gain.

<sup>6</sup> When calibrated under stabilized operating temperature conditions, superior performance can be achieved.

**COMPATIBLE MEZZANINES**

The modules are compatible with various types of mezzanines, including:

- » The ModuLink mezzanine is meant to provide basic input/output support, featuring optical inputs and analog outputs. Additionally, the error signal is also relayed to the master controller.

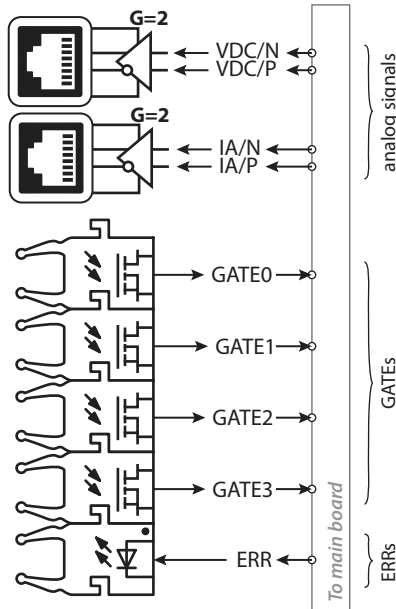


Fig. 2. Functional view of the ModuLink mezzanine.

- » The RealSync mezzanine is part of the future generation of the BoomBox control platform and will feature bidirectional Gigabit Ethernet-class communication with the central controller. Besides, the board also embeds an Artix 7 FPGA and a high-end microcontroller. This mezzanine will be publicly released simultaneously with the third generation of the BoomBox hardware.
- » Any custom-made mezzanine that fits the mechanical design and possesses the suitable connectors.

**ADDITIONAL FEATURES**

*Discharge resistor*

An optional 10 kΩ/10W resistor can be mounted on the module in order to provide a passive discharge mechanism. Assuming an onboard capacitance of 5 mF, this results in a time constant of 50 s.

*Connections*

The power connections are located on top of the module, using M3 screw terminals, as shown in Fig. 4. This authorizes the easy reconfiguration of the topology, while guaranteeing robust mechanical contacts.

*Temperature measurements*

The modules embed 4 inputs for temperature sensors. Their simplified schematic is given in Fig. 3. These inputs are best suited with 5 to 50 kΩ NTC thermistors.

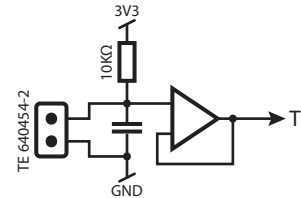


Fig. 3. Simplified schematic of one temperature input.

Eq. (1) and Eq. (2) describe the relationship between the measured temperature and the corresponding voltage. For the pre-mounted chips,  $B = 3435 K$  and  $R_{25} = 10 K\Omega$ .

$$V_{T1} = \frac{R_{NTC}}{R_{NTC} + 10K} \cdot 3.3V \tag{Eq. 1}$$

$$R_{NTC} = R_{25} \exp \left[ B \left( \frac{1}{T} - \frac{1}{298.15} \right) \right] \tag{Eq. 2}$$

Temperature limits are defined in the MCU2 microcontroller, whose operation is described in the *embedded circuit logic and protection* section.

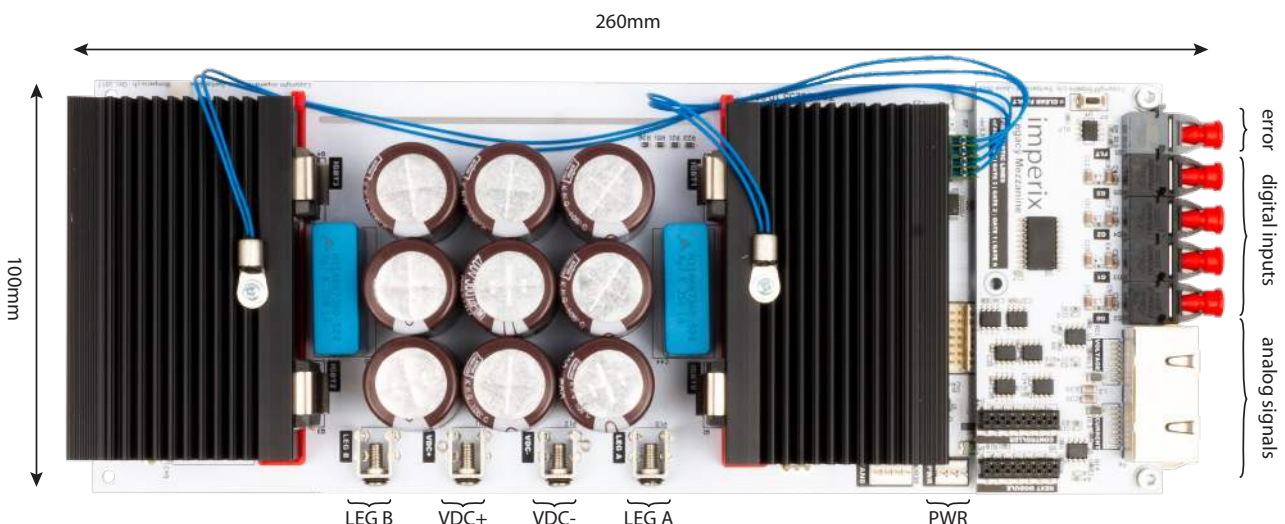


Fig. 4. Top view of the module with its main inputs/output connections.

**Power supply supervision**

The main 5V power supply is monitored by the **MCU2** microcontroller, which triggers a fault signal in case of inappropriate voltage. This operation is described in the *embedded circuit logic and protection* section.

**User-programmable CPLD**

The modules feature a user-programmable CPLD, allowing to easily modify the coding /decoding of the gating signals (from the optical fibers), or to implement special behaviors in case of faults (overvalues).

**EMBEDDED LOGIC AND PROTECTION**

The modules embed a digital supervisory system that guarantees their integrity by a continuous monitoring of the measurements given by the voltage and current sensors, as well as the temperature probes and power supply voltage(s). The main components of this circuit are as follows :

- » **MCU1** is continuously sampling the voltage and current at approx. 150 ksp/s. Upon the detection of an overvalue, the MCU triggers the corresponding flag.
- » **MCU2** is continuously sampling slow variables such as temperatures, power supply voltage(s) or other measurements. Upon the detection of an overvalue, the MCU triggers the corresponding error flag.
- » The user-programmable **CPLD** is at the heart of the supervisory system and has three main tasks :
  - » Generating the final gating signals based on those received through the optical fibers, possibly involving some decoding of the switching states.

- » Enforcing a specific switching state in case of a fault. This may be a blocked state or a short circuit depending on the desired behavior and the cause of the fault.
- » Generating a set of flags based on the faults provided by the microcontrollers.

**Default configuration**

The modules are provided with a default configuration in which the four optical inputs are directly corresponding to the four gating signals. Besides, the safety thresholds are defined as follows :

Signal name	Fault-triggering when
Cell output current	$ I_A  > 25A$
Capacitor bank voltage	$V_{DC} > 420V$
Heatsink temperature (1 and 2)	$T > 90^{\circ}C$
5V power supply	$V_{5V} < 4.5V$ or $V_{5V} > 5.5V$

The global error signal transmitted by the mezzanine is turned off upon a fault detection (active low). When a faults is tripped, it can be acknowledged manually by pressing the corresponding button on the mezzanine.

**Custom configuration**

Along with the board, imperix provides a default CPLD source so as to allow the user to implement and reprogram the board with custom firmware in order enable extra features such as :

- » A different coding of the gating signals signal,
- » A cell bypass function (i.e. custom gating signal configuration in case of faults);
- » Another I/O or safety configuration.

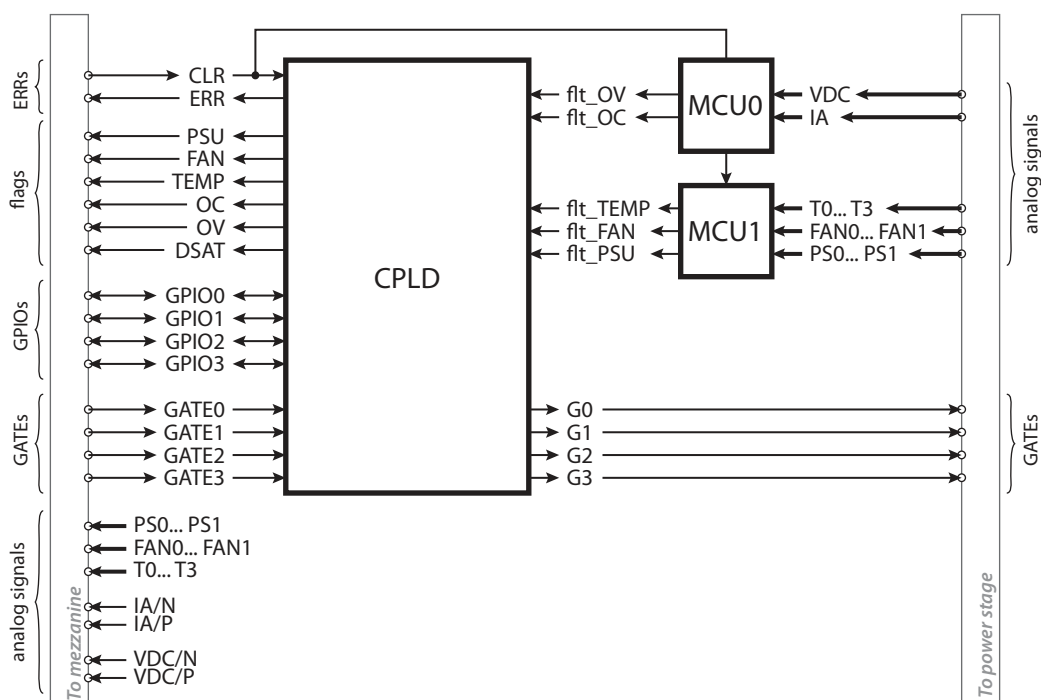
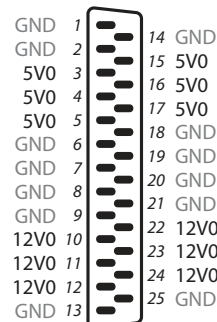
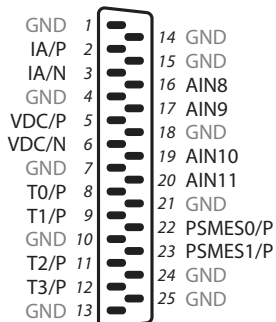
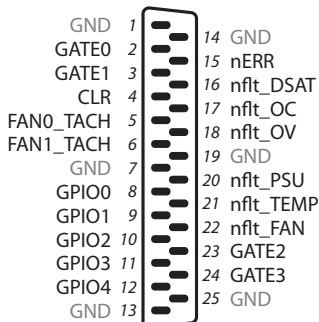


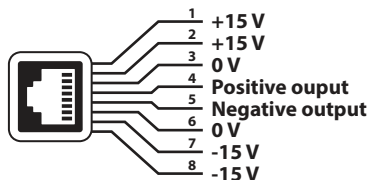
Fig. 5. Onboard protection and logic circuits.

## MEZZANINE CONNECTORS PINOUT

Tree connectors provide the necessary connectivity between the main board of the module and the mezzanine. Their pinout is given below. Imperix can provide details on the mechanical design or 3D file upon request.



## ANALOG OUTPUT CONNECTORS PINOUT



## POWER SUPPLY CONNECTOR

The pinout of the main power connector is as follows:



## ACCESSORIES

- » 19" rack mounting kit (3U 19" open frame, rails)
- » Auxiliary 12V fans
- » Auxiliary 5V power supply

These modules must be used in electric / electronic equipment with respect to applicable standards and safety requirements in accordance with the manufacturer's operating instructions. Caution, risk of electrical shock! When using the devices, certain parts of the modules may carry hazardous voltages (e.g. power supplies, busbars, etc.). Disregarding this warning may lead to injury and / or cause serious damage. All conducting parts must be inaccessible after installation.

## CONTACT

### imperix SA

Rue de l'Industrie 17  
1950 Sion, Switzerland  
phone: +41 (0)27 552 06 60  
fax: +41 (0)27 552 06 69  
www.imperix.ch, sales@imperix.ch

## ABOUT US

Imperix SA (Ltd.) is a company established in Sion, Switzerland. Its name is derived from the Latin verb *imperare*, which stands for controlling and refers to the company's core business: the control of power electronic systems. Imperix SA is commercializing hardware and software solutions related to the fast and secure implementation of pilot systems and plants in the field of power conversion, energy storage and smart grids.

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