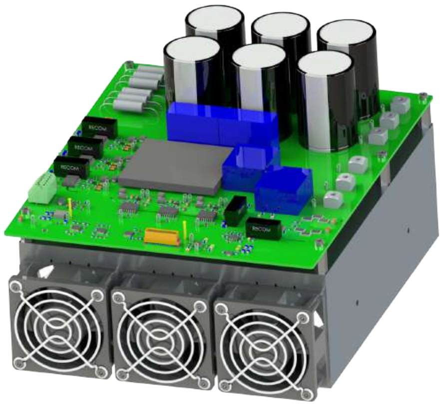
10 kVA, 800 VDC Three phase voltage source converter

PCO02-10T800 Technical Reference

Rev. 1.0

April 2024



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About This Manual

This document serves both as a datasheet and as a user manual for the PCO02-10T800. This power converter is based on three half-bridge IGBT modules from Semikron connected as a three-phase voltage source inverter, and is able to output 10 kVA at an output voltage of 400 V_{RMS}.

Even though the power converter is a three-phase voltage source inverter, other topologies can also be implemented on the basis of the three half bridges it incorporates (AC to DC active rectifier, active filters, DC to DC converter, interleaved converters, . . .). In addition, this module incorporates sensors for the measurement of 2 output currents, the DC Bus voltage level and the module's temperature.

Information About Cautions

This book may contain cautions.

> **IMPORTANT NOTICE**
> **This is an example of a caution**

A caution statement describes a situation that could potentially damage your hardware, or other equipment. The information in a caution is provided for your protection. Please read each caution carefully.

Related Documents

Semikron SKiiP 23AC12T4V1 Datasheet

1 Introduction to PCO02-10T800

The PCO02-10T800 is a versatile power electronics platform that allows designers to implement the most used power converter topologies in a digital control environment. It includes all the necessary hardware elements to implement a grid connected inverter with up to 10 kVA, power rating achieved at 400 V_{RMS} and 15 A_{RMS}.

The power converter is a three-phase voltage source inverter, but other topologies can be implemented on the basis of the three half bridges it incorporates (AC to DC active rectifier, active filters, DC to DC converter, interleaved converters, . . .). Semiconductors are packed in a reliable and compact Semikron module and can be controlled uniquely. The module includes semiconductor temperature measurement for safety. DC bus voltage and the current of two legs are also measured. These measurements allow for high flexibility in implementing converter topologies and control structures. All the voltage and current measurements have galvanic isolation.

In the Semikron power module, there are six semiconductors, and each one of them has their own driver. The six drivers are isolated, and include under voltage and overcurrent protection, fault reporting, and soft turn-off under fault conditions, when transistors are forced to open.

The connection to the control system is done by a single flat cable connector mounted on the PCB. It is used for both sending and receiving signals to and from the control system, including the 24V and ± 15V power supplies, the PWM and fault signals, and the voltage and current measurements.

In addition, a discharge circuit for the DC bus capacitors is implemented with six series-connected 15kΩ resistors paralleled to the capacitor bank. In Figure 1, a rendered image of the converter is shown.

Figure 1: Rendered image of PCO02-10T800

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This document serves as a datasheet and user manual for PCO02-10T800. Figure 2 shows the block diagram of the PCO02-10T800, where all the parts and functions can be seen.

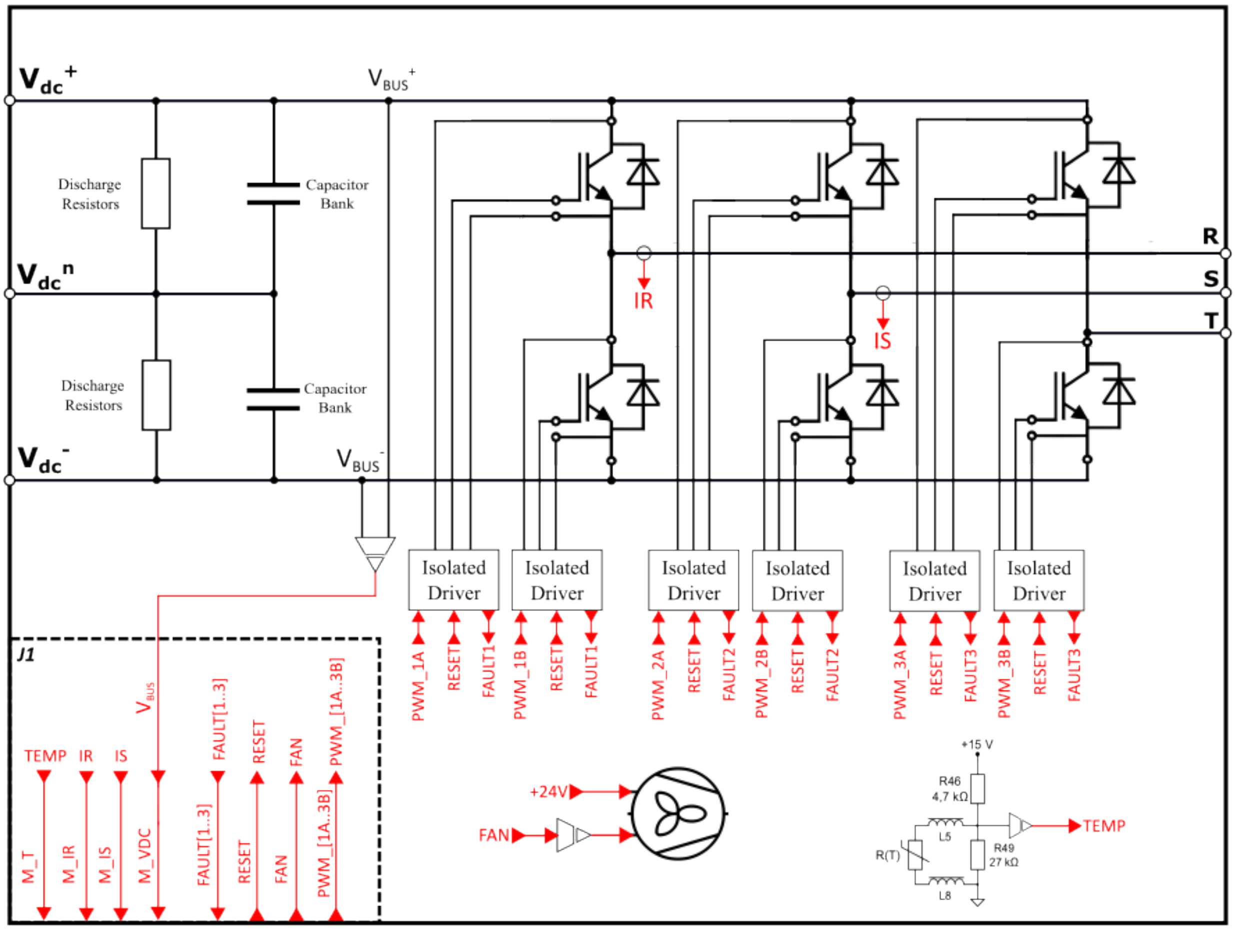

Figure 2: Block diagram of the PCO02-10T800 converter.

2 Electrical characteristics

Symbol	Description	Min.	Typ.	Max.	Unit
	Main Parameters				
V_{ac}	Output rated voltage (50 Hz)		400		V_{rms}
I_{out}	Output rated current (50 Hz) @ $T_a = 40°C$		15		A_{rms}
S_{out}	Output power @ $T_a = 40°C$		10		kVA_{rms}
V_{dc}	DC bus voltage			800	V
f_s	Switching frequency		20		kHz
T_a	Ambient temperature		40		°C
	Digital inputs				
V_{xi_H}	High-level signal	2,00	3,30	5,00	V
V_{xi_L}	Low-level signal	0,00	0,00	0,80	V
	Digital outputs				
V_{xo_H}	High-level signal @ $I_{oH} = -32mA$		Open Collector		V
V_{xo_L}	Low-level signal @ $I_{oH} = 32mA$			0,55	V
	Measurements				
DC Voltage sensor	Input voltage measurement range	0		930,81	V
	Output voltage measurement range	0,00		10,00	V
	Gain		$1,07433 \cdot 10^{-2}$		V/V
	Accuracy		±5		%
	Bandwidth		15,78		kHz
Current sensor	Primary current		± 25		A_{rms}
	Secondary current		± 25		mA_{rms}
	Configurable Gain		1 : 1000		A/A
	Accuracy		±0, 5		%
T+	Semiconductor minimum recommended operating temperature output voltage (-40°C)		1,61		V
	Semiconductor casing maximum temperature output voltage (150°C)		4,95		V
	Power supply				
V_s	24 V power supply voltage	22	24	26	V
ΔV_s	24 V power supply ripple		200		mV
I_s	24 V power supply current		1	3	A
V_{s19}	+15 V output power supply voltage	14	15	16	V
V_{s20}	-15 V output power supply voltage	-16	-15	-14	V
$I_{s19,20}$	±15 V power supply current			240	mA

Table 1: PCO02-10T800 electrical characteristics.

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3 General Description

3.1 System components

Preceding the description of the individual components of the PCO02-10T800 and their function, the figure below, figure 3, displays a rendered image of the power converter, in which its main components are identified:

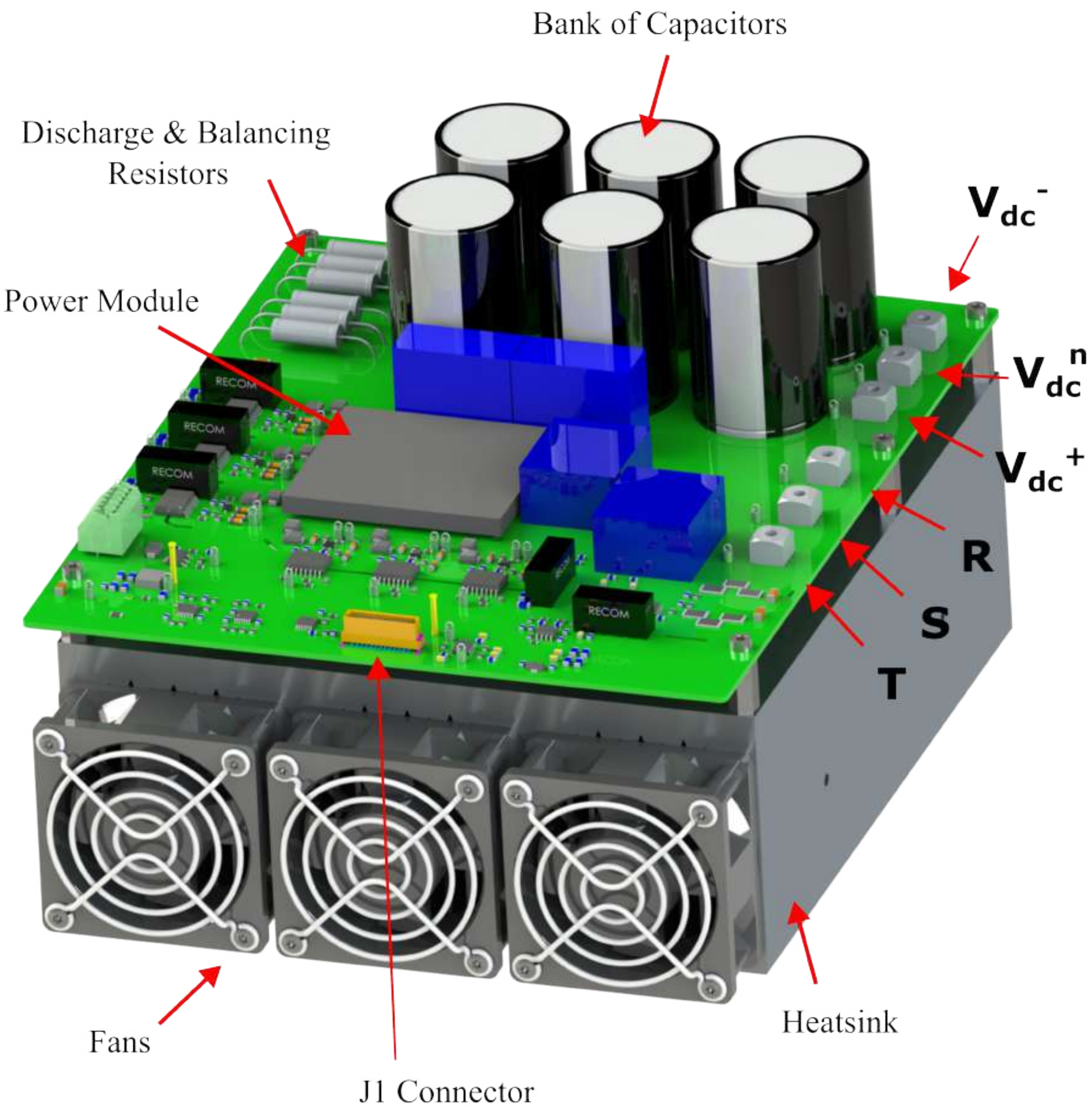

Figure 3: Rendered image of the converter

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3.1.1 IGBT module

The PCO02-10T800 power converter is composed by three half-bridges connected as a three-phase voltage source inverter, as seen in Figure 4. Each half bridge gives an output phase voltage. The output voltage is controlled by the switching signals of the transistors (PWM signals) coming from the control system through connector J1 and the DC bus voltage at the input. These connections are shown in detail in subsection 3.2.

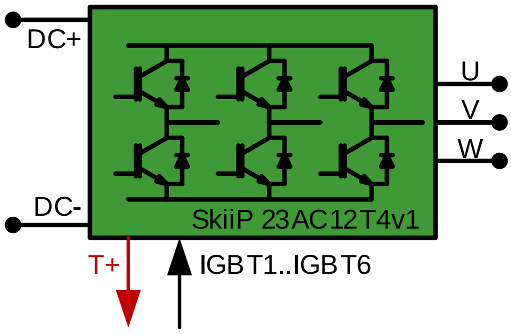

Figure 4: Circuit diagram of the IGBT module

The IGBT module used in PCO02-10T800 is the SKIIP 23AC12T4V1 module by SEMIKRON. For further information regarding the modules, see the SEMIKRON datasheet.

3.1.2 Driver Circuit

All the driver circuitry required by the IGBT module is included in the printed circuit board of PCO02-10T800. As mentioned above, each transistor from the module has its own driver and can be controlled independently.

Nonetheless, no cross conduction protection or dead-time insertion in complementary PWM signals is implemented in the PCO02-10T800, since these features must be implemented in the control system by the user. Figure 5 shows the pin configuration of the gate driver IC, in which the pins that this subsection will focus on can be observed, FAULT, RESET, and IN+, where the PWM signal reaches the IC.

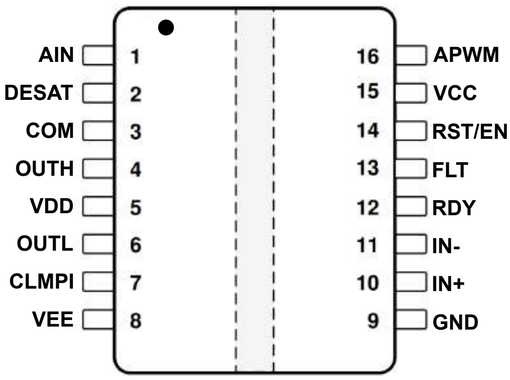

Figure 5: UCC21759-Q1 Gate Driver Pin Configuration

The driver circuitry is based on the UCC21759-Q1 by Texas Instruments, which includes many protection

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features, mainly the under-voltage lock-out (UVLO), which protects the driver from an isolated power supply failure. This system, in case of a failure, is in charge of stopping the switching of the transistors and sending an error signal to the control system.

Moreover, the DESAT function, an additional safeguarding feature, prevents the desaturation of the IGBT modules, therefore protecting them from overcurrents. This function works by having the DESAT pin monitor the IGBT's V_{ce} voltage. When the DESAT fault is detected, the soft turn-off is triggered, in the meantime minimizing the short circuit energy while reducing the overshoot voltage on the switches. This soft turn-off mechanism prevents the destruction of the IGBT from large induced voltages.

The DESAT fault detection circuitry must remain disabled for a short time period following the turn-on of the IGBT to allow the collector voltage to fall below the DESAT threshold. The DESAT blanking time is calculated in terms of external capacitance, FAULT threshold voltage and DESAT charge current, resulting in a leading edge blanking time of 200 ns.

These failure modes (UVLO and DESAT) generate a unique open-collector fault signal for each driver. The two fault outputs for each half-bridge are connected together so as to generate a unique open-drain fault signal for each half-bridge. This results in three fault signals, available in the digital section of connector J1.

The FAULT signal is latched persistently after a fault situation. In order to restore the operation of the driver, the RESET signal can be used by the control system. Regarding this signal, in proximity to the IC a pull-down resistor is placed, resulting in a digital signal which must be implemented by the user's control system that resets the gate drivers when the pin is set to low.

Last but certainly not least, the IN+ pin of the integrated circuit refers to a non-inverting gate driver control input, from where the PWM signal sent by the user reaches the driver circuit. This pin, exactly like RESET and FAULT, has a voltage range from -0,3 to 5 V, being the latter the voltage supplied to the IC.

IMPORTANT NOTICE
The only safety features the drivers incorporate are the ones implemented in the driver chip. No additional protection has been implemented in the PCO02-10T800, thus it is strongly advisable to add some sort of protection routine in the control system in the instance that a Fault_Drivers event occurred.
As it has been stated, no cross conduction protection or dead-time insertion in complementary PWM signals has been implemented in the PCO02-10T800, hence, these features must be implemented in the control system by the user.

3.1.3 DC bus capacitor bank

The DC bus capacitor bank is formed by the series connection of two blocks of three parallel-connected 680 µF/450 V electrolytic capacitors. The total capacitance is 1020 µF, and the voltage point in between these two blocks is the midpoint. For safety reasons when connecting capacitors in series, six 15 kΩ series-connected resistors are used to balance capacitor voltages and to ensure the discharge of the capacitors. In addition, 2 snubber capacitors are placed close to the module and, as seen in figure 3.

Owing to the presence of discharge resistors on the circuit, the PCO02-10T800 enables the user to carry out a controlled discharge of the DC bus capacitors, and given the resistance of the resistor and the capacitors being used, it takes 4 and a half minutes to discharge the DC bus capacitors from 800 V DC to

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40 V DC, a non-dangerous voltage level. Additionally, through the use of an external discharge circuit with contactors or similarly-functioning components, this time can be reduced. Moreover, the presence of discharge resistors ensures that, in the event of a loss of power, the capacitors will be automatically discharged to a safe voltage level.

> **IMPORTANT NOTICE**
> **The pre-charge of the DC bus must be implemented by an external pre-charge circuit and monitored by the user's control system. Additionally, it is strongly recommended to implement a control algorithm verifying the pre-charge process not to damage the converter.**

> **IMPORTANT NOTICE**
> **The PCO02-10T800 does not implement any protection function in case of overvoltage at the DC bus capacitors. These features must be implemented in the control system by the user.**

3.1.4 Voltage sensing

One of the many features the PCO02-10T800 includes is the measurement of the DC bus voltage. This functionality is supplied by three of the pins in J1, since it requires a voltage supply level of ±15 V and a connection to the analog GND (AGND). Finally, the measurement is available at M_Vbus, another of the analog pins in J1 (Table 3).

The signal that reaches the connector has been adapted by the printed circuit board circuitry by implementing a gain of $1,07433 \cdot 10^{-2}$, since the sensor's range is 930.81V and the unipolar signal at the output, that has also been filtered, ranges from 0 to 10 V.

This aforementioned adaptation of the DC bus voltage measurement consists of different stages and an amplifier chip at its core, the ACPL-C79B, a device that has a bandwidth of 200 kHz. The first stage includes a first order filter with a cut-off frequency of 15.6 kHz and, right after the amplifier, the third stage acts as a second order filter with a cut-off frequency of 5.4 kHz. All in all, the overall DC bus voltage measurement filter's cutoff frequency is 4.7 kHz.

> **IMPORTANT NOTICE**
> **The voltage at the input of the external voltage measurements shall not exceed 800 V. Exceeding the maximum voltage may cause damages to the converter.**

3.1.5 Current sensing

Given the symmetrical nature of a three-phase system, the measurement of only two phases provides sufficient information for most applications, which is the reason only R and S currents are measured. These current measurements are done by closed-loop hall-effect sensors from LEM, more specifically the LA 25-NP model, with a range of ±36A and a fixed gain of 1 over 1000, which is the ratio of turns between the primary and secondary windings.

The transducers are supplied using the +15V and -15V pins in J1 and the signals produced in the secondary winding, I_R and I_S, are sent to the control board using the same connector. For proper measurement, the user ought to implement a shunt resistor to these signals, with the objective of converting

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these currents into a voltage within a desired range. According to the manufacturer, in order to prevent the saturation of the sensor's output stage, these shunt resistors must have a resistance from 100 Ω to 190 Ω (to measure a current of up to 36A) should the ambient temperature be 70°C (for further information, refer to the transducer's data sheet).

For instance, if it were the case that one wanted to have a bipolar voltage signal from -5V to 5V, since the measuring range is ±36 A, a 138.89Ω shunt resistor must be implemented, as shown in the calculations below:

$$\begin{cases} 36\,A \cdot \dfrac{1}{1000} = 0,036\,A \\ \dfrac{5\,V}{0,036\,A} = 138.89\,\Omega \end{cases} \tag{1}$$

3.1.6 Temperature measurement

The module includes a PTC sensor to measure semiconductor temperature. The resistance dependence from the temperature of this sensor can be computed as

$$\begin{aligned} &R(T) = 1000 \cdot \left[1 + A \cdot (T - 25) + B \cdot (T - 25)^2\right] \\ &A = 7,635 \cdot 10^{-3}\ {}^{\circ}C^{-1} \\ &B = 1,731 \cdot 10^{-5}\ {}^{\circ}C^{-2} \end{aligned} \tag{2}$$

where T is expressed in $^{\circ}C$ and R in Ω.

The PCO02-10T800 includes an adaptation stage to adapt the output voltage from 1,61 V (-40 °C) to 4,95 V (150 °C), as seen in Figure 6. Temperature measurement is available at connector J1.

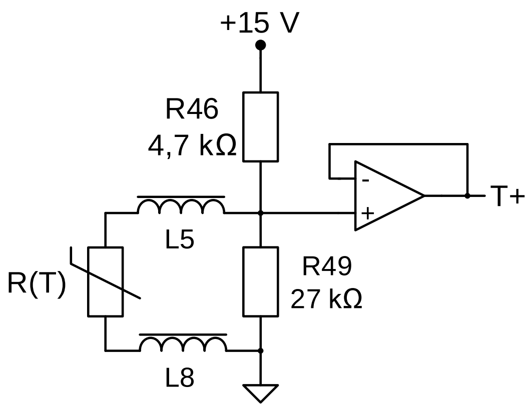

Figure 6: Temperature sensing circuitry

With this adaptation circuitry, the temperature of the resistor can be linearised using

$$T_{module}\,({}^{\circ}C) = 62,359 \cdot T_{+}\,(V) - 134,41 \tag{3}$$

As an example, for a 100°C temperature in thermistor, the resistance will be 1669,99 Ω and the voltage at the measuring point (T+) will be 3,76 V. The temperature of the thermistor is not the temperature of

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the semiconductors. The temperature of the thermistor will be similar to the temperature of the ceramic plate of the semiconductors module and it can be used as a good approximation of the temperature in the surface of the heat sink.

For security reasons, the temperature at semiconductors should not go higher than 150°C, otherwise, semiconductors can be destroyed. For this reason it is recommendable not exceeding 100°C measured in the thermistor. This value is a suggestion for the typical working conditions, which is why it is necessary to realize a thermal study of the converter for each application in order to prevent damages.

It is recommendable to implement a low-pass filter in the ADC adaptation circuitry to filter the commutation noise. The cut-off frequency shall be at least 10 times lower than the switching frequency.

IMPORTANT NOTICE
The PCO02-10T800 does not include any protection against over temperature of the semiconductors. This protection must be implemented by the user through the control system.

3.1.7 Cooling system

The printed circuit board is mounted on top of a heatsink whose main purpose is to dissipate the heat generated in the module. To do so, three 24V fans are attached to the heatsink with the aim of creating airflow through its inner openings. The consumption of the fans is around 170mA each, and they are controlled by the user through the Fan signal. The user control system is responsible for the temperature of PCO02-10T800.

For the semiconductor junction temperature not to exceed a potentially dangerous threshold, which is set at 125 ºC, the temperature of the heat sink should not surpass certain limits. Those limits are dependent upon the power of the output and the switching frequency of PCO02-10T800. The relationship between them is shown in Figure 7.

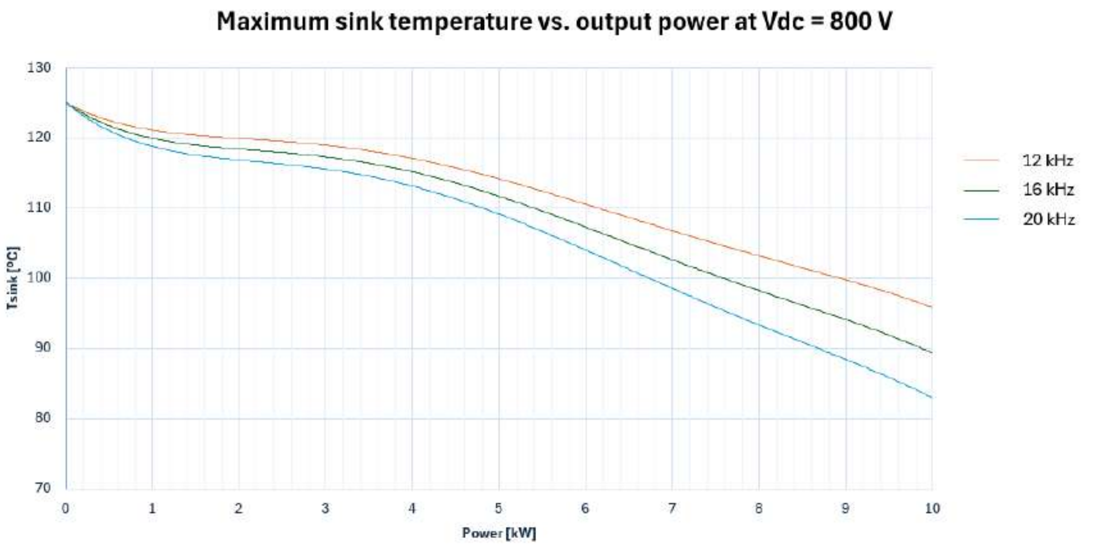

Figure 7: Maximum acceptable sink temperature

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IMPORTANT NOTICE
The PCO02-10T800 does not include any protection against over temperature of the semiconductors. This protection must be implemented by the user in the control system.
The user is responsible for starting or stopping the cooling system in order to control the semiconductors' temperature.

3.2 Connectors

In this subsection, a breakdown of all the pins in the J1 connector, the one with which the user is able to interact with the converter, will be provided.

This connector is a 26 pin IDC connector by Harting, reference number 15120262601000, therefore a recommended female connector is another one from Harting, reference number 15290262502000. Down below, an image of the former is shown.

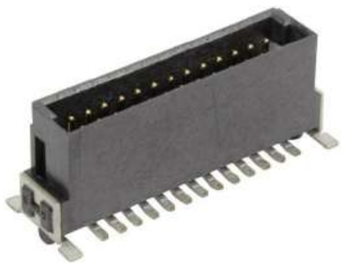

Figure 8: 26 pin IDC connector found in the PCO02-10T800 [Harting]

3.2.1 J1 connector, Digital Signals

The J1 connector has a 13×2 pin arrangement and, as has been repeatedly expressed throughout the document, it is the connector with which the user is able to communicate with the PCO02-10T800. Rather than having two different connectors, one for all the analog signals and a second for the digital ones, J1 connector incorporates both kinds of electrical signals, just as it can be seen in Figure 9, which shows the connector's schematics, which include the digital signals displayed in red and the analog ones shown in blue.

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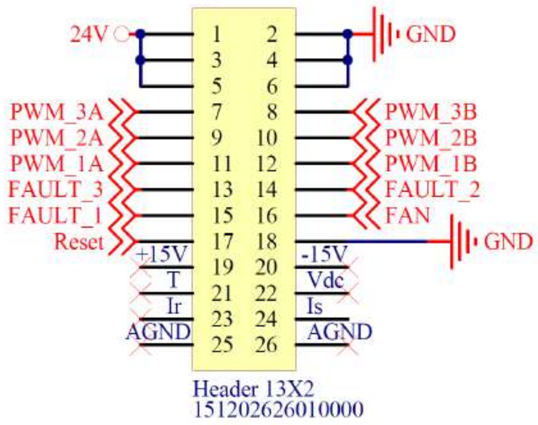

Figure 9: Schematics of the J1 connector

Pin arrangement and function of the digital signals of the J1 connector is summarized in Table 2.

Pin	Pin name	Function	Description
1	+24 V	Power	Power supply +24 V_{DC}
2	GND	Power	Ground for power supply
3	+24 V	Power	Power supply +24 V_{DC}
4	GND	Power	Ground for power supply
5	+24 V	Power	Power supply +24 V_{DC}
6	GND	Power	Ground for power supply
7	PWM_3A	Digital input	PWM TH signal
8	PWM_3B	Digital input	PWM TL signal
9	PWM_2A	Digital input	PWM SH signal
10	PWM_2B	Digital input	PWM SL signal
11	PWM_1A	Digital input	PWM RH signal
12	PWM_1B	Digital input	PWM RL signal
13	FAULT_3	Digital output	Driver error. Active low
14	FAULT_2	Digital output	Driver error. Active low
15	FAULT_1	Digital output	Driver error. Active low
16	FAN	Digital input	Fan control
17	Reset	Digital input	Driver reset. Active low
18	GND	Power	Ground for power supply

Table 2: J1 connector, digital pins, pin function and arrangement

In subsection 3.2.3, more information about the requirements the signals must meet will be presented.

3.2.2 J1 connector, Analog signals

The analog pins in J1 are the pins 19 to 26, 8 pins tasked with both supplying the sensors in the system and ensuring that those measurements are available for the user.

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Pin arrangement and function of the analog signals of the J1 connector is summarized in Table 3.

Pin	Pin name	Function	Description
19	+15 V	Power	Power supply +15 V_{DC}
20	-15 V	Power	Power supply -15 V_{DC}
21	T	Analog output	Semiconductor module temperature
22	Vdc	Power	DC bus voltage
23	Ir	Analog output	R phase current
24	Is	Analog output	S phase current
25	AGND	Power	Analog Ground
26	AGND	Power	Analog Ground

Table 3: J1 connector, analog pins, pin function and arrangement

Just as in subsection 3.2.1, a more in-depth description of the characteristics that these signals must adhere to is provided in the following subsection.

3.2.3 J1 connector, Electrical characteristics

The following table shows in more detail the requirements the signals previously presented must meet:

Symbol	Description	Min.	Typ.	Max.	Unit
	Power supplies				
V_s	24 V power supply voltage	22	24	26	V
ΔV_s	24 V power supply ripple		200		mV
I_s	24 V power supply current		1	3	A
V_{s19}	+15 V output power supply voltage	14	15	16	V
V_{s20}	-15 V output power supply voltage	-16	-15	-14	V
$I_{s19,20}$	±15 V power supply current			240	mA
	Digital Signals				
PWM_X	Digital PWM signals	-0,3		5	V
$FAULT$	Driver error. Active low	-0,3		5	V
$Reset$	Driver reset. Active low	-0,3		5	V
FAN	Fan control signal	-0.3		5	V
	Analog Signals				
I_r	R phase current measurement	-0,036		0,036	A
I_s	S phase current measurement	-0,036		0,036	A
V_{dc}	DC bus voltage measurement	0		10	V
T	Semiconductor module temperature measurement	1,61		4,95	V

Table 4: J1 connector, electrical characteristics

3.2.4 Power connectors

PCO02-10T800 contains 6 identical power connectors from Würth Elektronik. The DC power connectors are J4, J5 and J6, and the phase connectors are J7, J8 and J9, as shown in the following table.

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Connector	Label	Function	Description
J4	DC-	Power	DC bus power ground
J5	DCn	Power	DC bus midpoint
J6	DC+	Power	DC bus voltage
J7	R	Power	R phase voltage
J8	S	Power	S phase voltage
J9	T	Power	T phase voltage

Table 5: Power connectors

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4 Operation

4.1 Start-up

4.1.1 Electrolytic capacitors

Electrolytic capacitors need a reforming procedure if no voltage has been applied for at least one year.

One possible solution is to apply a step by step DC voltage with a variable voltage source with current limitation (the current can be also limited with a resistance between the electrolytic capacitors and the power supply). The voltage should vary from 0 V to the rated voltage, with steps of 80 V every 5 minutes.

IMPORTANT NOTICE
Do not immediately apply full DC voltage or electrolytic capacitors may explode.

4.1.2 DC Pre-charge

A pre-charge of the DC bus capacitors must be done prior to operation. However, the PCO02-10T800 does not include a pre-charge system for the DC bus, therefore, it is essential to make use of an external DC pre-charge system.

Figure 10 shows a block diagram in which an example of the connection of a pre-charge circuit for a DC voltage source is shown.

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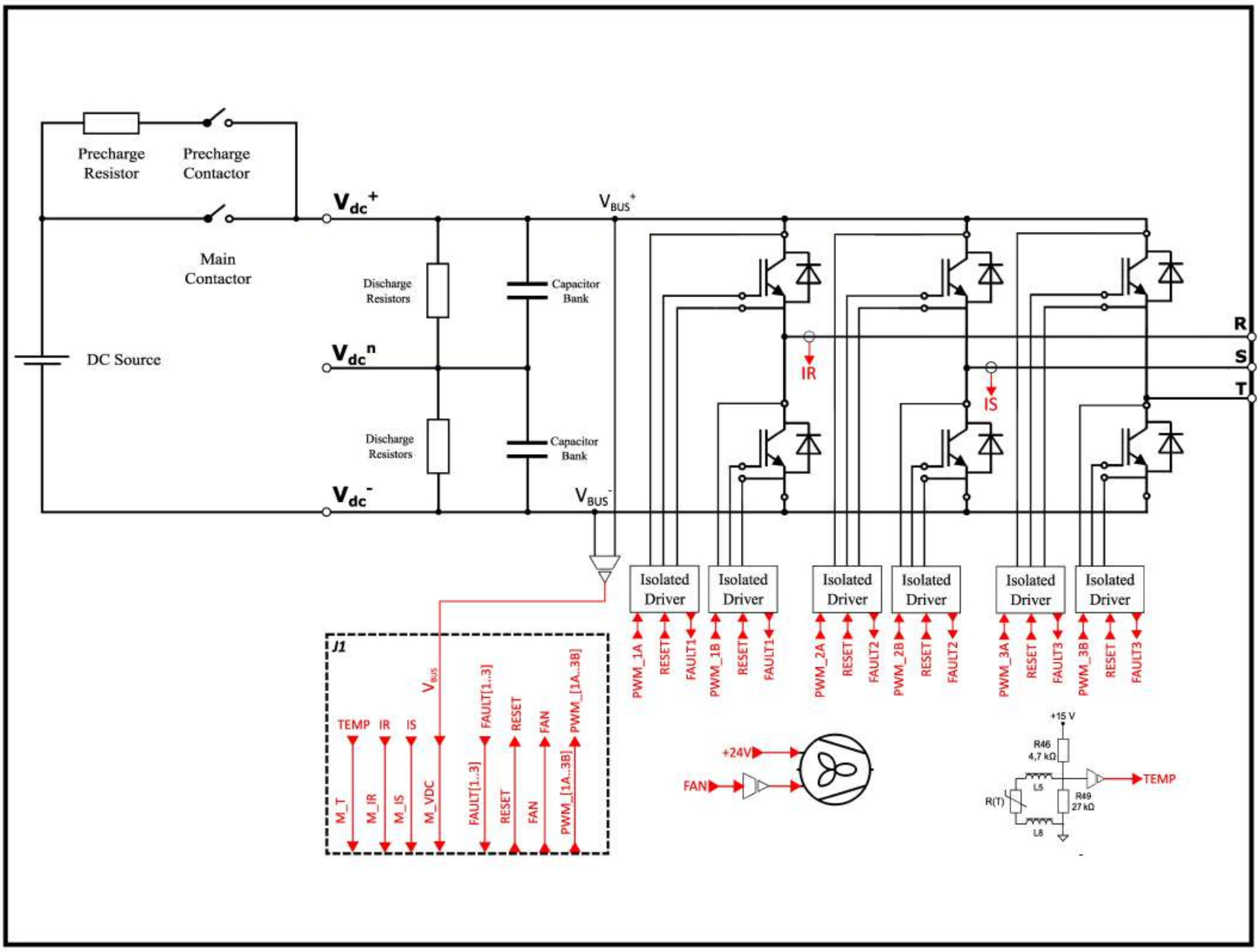

Figure 10: DC bus pre-charge connection example for a DC voltage source

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The pre-charge procedure implemented by the user should be as follows:

1. Connect the PCO02-10T800 to the Control Board through the J1 connector.
2. Supply the control system and therefore the PCO02-10T800 and all the monitoring devices contained within it.
3. Ensure that the DC bus voltage is 0 V.
4. Close the relay to the precharge circuit until the precharge of the DC bus capacitors is completed.
5. Once the desired DC bus voltage level is reached, the main contactor should be closed.
6. After closing the DC source main contactor, the precharge contactor can be opened.
7. The operation may be started.

Instead of a DC precharge circuit, the converter may be precharged from the AC (or output) side with an analogous circuit design. In this case, the DC link will be energized through the freewheeling diodes of the power semiconductor modules.

> **IMPORTANT NOTICE**
> **Do not immediately apply full DC voltage or capacitors may explode**

4.2 Security Precautions

4.2.1 General precautions

Do not disconnect any cable under load nor pull any cable, since it could cause their breaking or unplugging.

Before any intervention, the user must ensure that no high voltage is still present on the DC bus capacitors or other elements and shut down any power supply connected to the PCO02-10T800. Likewise, under no circumstances should the converter be manipulated when in operation, and therefore, when high voltage can be measured at the DC bus capacitors.

The system in which the PCO02-10T800 is to be incorporated should be up to safety standards, the placement of safety elements such as an emergency stop button, fuses, and a power indicator light is strongly advisable. In addition, all personnel working on the power converter must be qualified and in possession of all the specialized equipment required in this field of work, such as insulated hand tools and gloves, safety glasses and footwear as well as protective clothing.

4.2.2 Earthing

According to standard IEC 60439-1, the exposed conductive parts must be connected to the protective circuit using the appropriate connections.

All accessible metal parts (heat sink) should be grounded. PCO02-10T800 metal parts are designed to ensure earthing continuity. After mounting, the electrical resistance between earth and any accessible metal surface should be checked and measured to less than 3 mΩ.

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For a correct earthing connection, a spacer has been prepared to connect the earth cable. In the board is marked with Earth, placed between the connectors J6 and J7. The other spacers must not be used as earth connector.

4.2.3 Maintenance

It is highly recommended to clean the PCO02-10T800 regularly in order to avoid short-circuits between phases or in the DC bus, effectively removing all dust and dirt that will have collected on the converter's conductive parts.

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5 Mechanical drawings

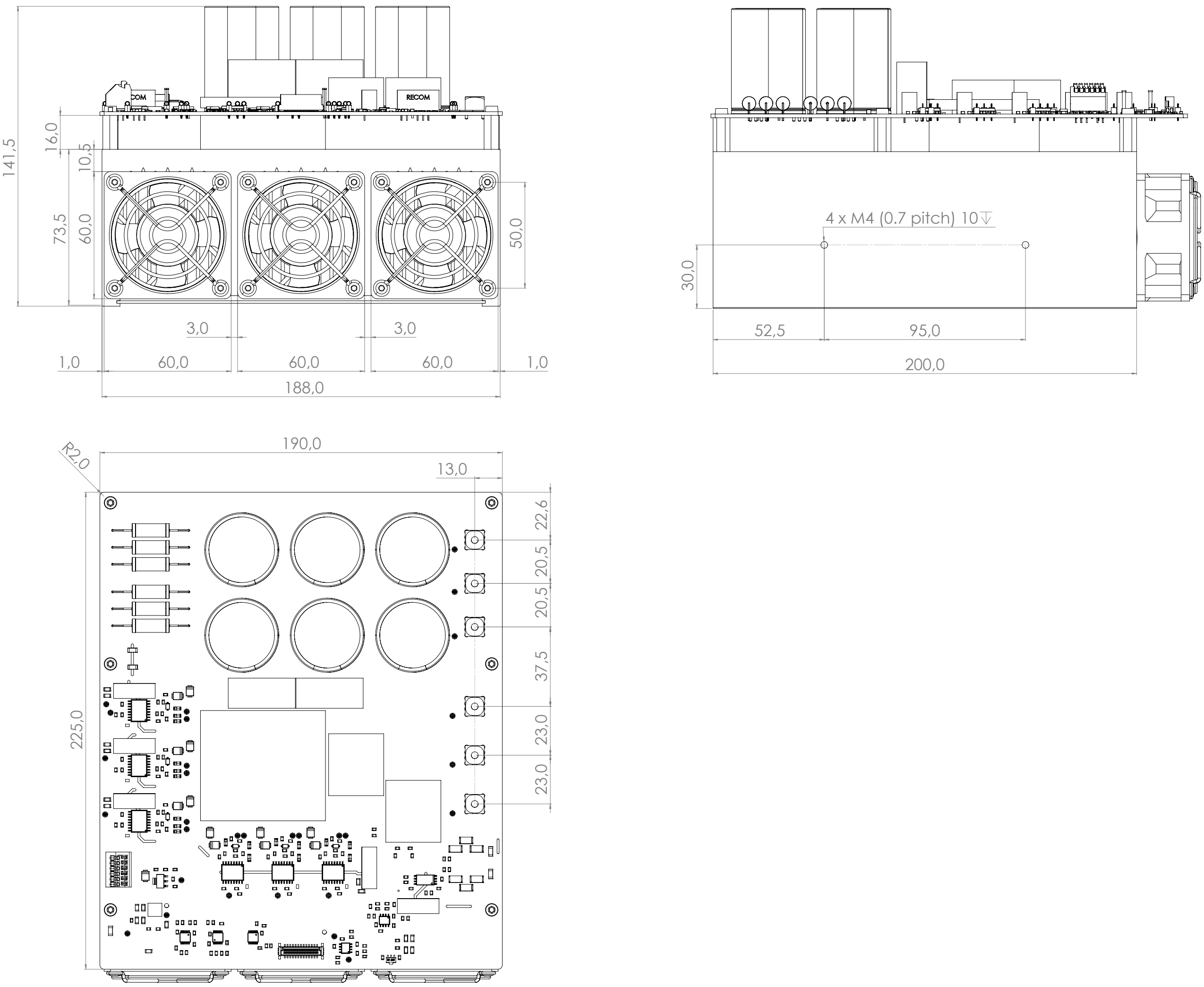

Figure 11: PCO02-10T800 Front, top, and side view mechanical drawings.

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