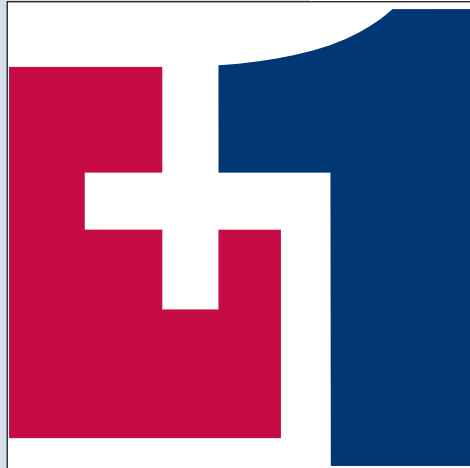
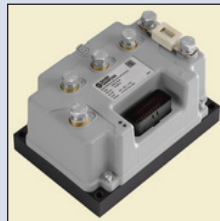




PLUS+1  
Inverter Family

Technical  
Information



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## 1. About This Manual

### 1.1 PLUS+1 Inverter Family Technical Information

This manual is designed to be a comprehensive PLUS+1™ Inverter inverter family reference tool for vehicle OEM design, engineering, and service personnel. It is one of three primary sources of PLUS+1 Inverter product technical information. The other two sources are: individual PLUS+1 Inverter product data sheets and the PLUS+1 Graphical User Interface Development Environment (GUIDE) Software User Manual

### 1.2 What information is in this manual?

This manual describes electrical details that are common to all PLUS+1 AC Drive inverters hardware, including general specifications, basic operating system, input and output parameters, environmental ratings and installation details.

### 1.3 What information is in product data sheets?

Parameters and engineering data that are unique to an individual PLUS+1 AC Drive inverter are contained in the respective inverter product data sheet. Data sheets contain the following information:

- Numbers and types of inputs and outputs
- Inverter maximum current and voltage capacity
- Power supply current capacity
- Inverters installation drawings
- Inverters weights
- Product ordering information

### 1.4 What information is in the PLUS+1 GUIDE Software User Manual?

Detailed information regarding the PLUS+1 GUIDE software tool set that is used to build PLUS+1 machine management solutions is contained in the user manual. This technical information manual covers the following broad topics:

- How to use the GUIDE graphical application development tool to create machine applications
- How to configure input and output parameters
- How to download GUIDE applications to target PLUS+1 hardware
- How to upload and download tuning parameters
- How to use the diagnostic and service tool

Additional, secondary information such as: Tech Notes and other application notes are also available on SD website. PLUS+1 Inverter product literature is on line at: [www.sauer-danfoss.com](http://www.sauer-danfoss.com) and [www.sauer-danfoss-plus1.com](http://www.sauer-danfoss-plus1.com)

## 2. MI 06, 48V, 400A Inverter



*Fig 1 PLUS+1 Inverter MI 06*

### 2.1 Inverter Typical Applications

PLUS+1 Inverter are a unique family of inverters as well as machine controllers in one enclosure. They are designed to control AC induction motors used in a variety of battery powered material handling equipment and machinery to provide propel, steering and work functionality. The unique requirements of electric vehicle control necessitate that the specifications and typical use of PLUS+1 AC input/outputs to be different than the input/output specifications common to other PLUS+1 devices of Sauer-Danfoss. Typical applications of PLUS+1 Inverter include, but are not limited to:

- Walkie/rider pallet and various types of low lift warehouse trucks
- Walk behind stacker lift trucks and order pickers
- Reach narrow-aisle and 4 way warehouse trucks
- Sweepers/scrubbers
- Side loaders
- Counterbalanced trucks
- Tow tractors and airport ground support vehicles
- Electric, platform and neighborhood vehicles
- Golf cars
- Turf care equipment and machinery
- Aerial (telescopic boom and scissor lift) access equipment

**2.2 PLUS+1 Inverters fit with other Sauer Danfoss PLUS+1 products.**

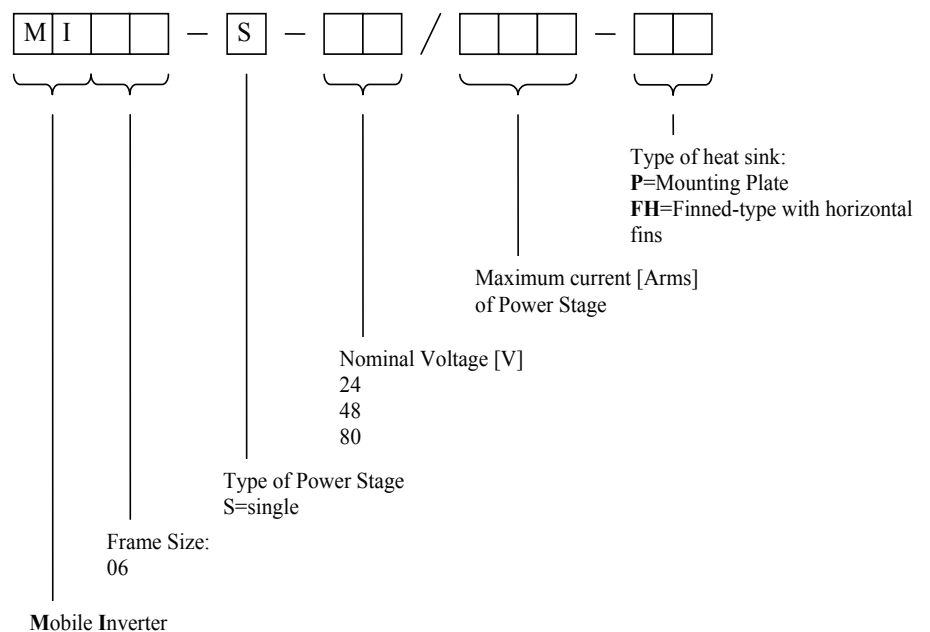
The PLUS+1 Inverter inverter family represents a major extension to Sauer Danfoss machine management products. In addition to the PLUS+1 Inverter family of inverters, discussed in this manual, these also include: vehicle microcontrollers, graphical display terminals and operator input devices, such as joysticks and finger tips.

The PLUS+1 products provide flexible, expandable, powerful and cost effective total machine management systems. Current users of PLUS+1 should note the PLUS+1 Inverter inverters inputs and outputs are defined differently from the PLUS+1 microcontrollers.

These devices communicate with one another and with other intelligent systems over a machine Controller Area Network (CAN) data bus. PLUS+1 hardware products are designed to be equally effective in a distributed CAN system, with intelligence in every node, or as stand-alone control for smaller machine systems. PLUS+1 systems are incrementally expandable: additional nodes can be easily added to the machine CAN bus to increase system capabilities or computational power.

**3. PLUS+1 Inverter Naming Convention**

**3.1 PLUS+1 Inverter Master Model Code (Example: M400-PI 06-S-48/400-P)**



*Fig 2 PLUS+1 Inverter Naming Conventions*

## 4. User Liability and Safety Statements

### 4.1 OEM Responsibility

The OEM of a machine or vehicle in which PLUS+1 electronic controls are installed has the full responsibility for all consequences that might occur. Sauer-Danfoss has no responsibility for any consequences, direct or indirect, caused by failures or malfunctions.

- Sauer-Danfoss has no responsibility for any accidents caused by incorrectly mounted or maintained equipment.
- Sauer-Danfoss does not assume any responsibility for PLUS+1 products being incorrectly applied or the system being programmed in a manner that jeopardizes safety.
- All safety critical systems shall include an emergency stop to switch off the main supply voltage for the outputs of the electronic control system. All safety critical components shall be installed in such a way that can be switched off at any time. Please note the power stage capacitors will maintain a stored energy of over 20W and could therefore supply connected components for some seconds after emergency stop is switched off. The emergency stop must be easily seen and must be accessible to the operator.

## 5. PLUS+1 Inverter Power Stage Specification

### 5.1 MI 06 Ratings

- The MI 06 inverter is designed to operate with a nominal voltage supply of 24V, 36V, and 48V. The inverter will operate with full functionality if the supply voltage is in the voltage range specified for each of the 24V, 36V, 48V:

### 5.2 Power Data for MI 06

Type: MI- 06-S	24V/400	48V/400
Size	MI 06	MI 06
Nominal voltage [VDC]	24	36 or 48
Input voltage range [VDC]	16–36	24–62
Nominal current ([3 ~Arms] <sup>1)</sup>	200	200
Maximum current ([3 ~Arms] <sup>2)</sup>	400	400
Peak current ([3 ~Arms] <sup>3)</sup>	420	420
Output voltage ([Vrms] <sup>4)</sup>	3 x 0-16	3 x 0-24 or 3 x 0-32
Dimensions [mm]	W 140 H 200 D 120	W 140 H 200 D 120
Power connectors	M10	M10

- 1) @ 8kHz switching frequency
- 2) S2-2min
- 3) for 10 seconds
- 4) @ input voltage = nominal voltage



## 6 Input/Output Types and Specifications

### 6.1 Input/Output Types

PLUS+1 Inverters perform two functions:

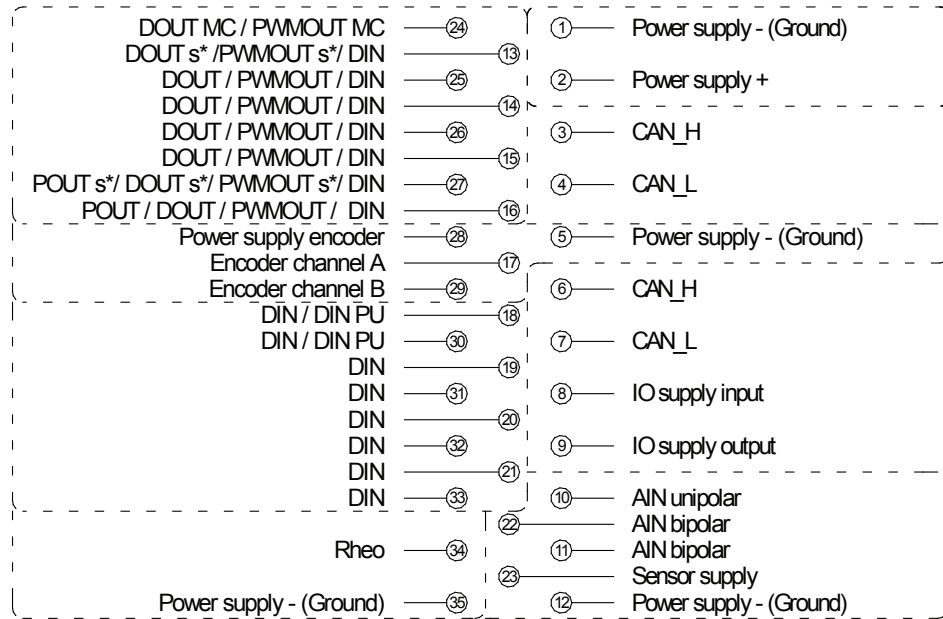
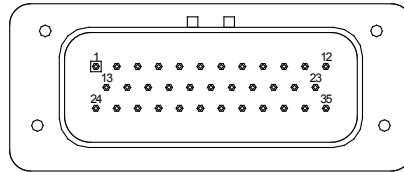
- Motor Control
- Application Control

The corresponding hardware sections have separate power supply pins which may be supplied by different voltages. The Motor Control section is typically powered by the vehicle's main supply voltage. The application control section is independent. It may be connected to the vehicle main power supply or to any other power supply (e.g. AC/DC converter) within the specified voltage range.

This portion of the technical information manual provides specifications for each PLUS+1 Inverter input/output type.

Power supply – (Ground)	C1p-01
Power supply +	C1p-02
CAN H	C1p-03
CAN L	C1p-04
Power supply – (Ground)	C1p-05
CAN H	C1p-06
CAN L	C1p-07
I/O supply input	C1p-08
IO supply output	C1p-09
AIN unipolar	C1p-10
AIN bipolar	C1p-11
Power supply – (Ground)	C1p-12
DOUT safety / PWMOUT safety/ DIN	C1p-13
DOUT / PWMOUT / DIN	C1p-14
DOUT / PWMOUT / DIN	C1p-15
POUT / DOUT / PWMOUT / DIN	C1p-16
Encoder channel A	C1p-17
DIN / DIN PU	C1p-18
DIN	C1p-19
DIN	C1p-20
DIN	C1p-21
AIN bipolar	C1p-22
Sensor supply	C1p-23
DOUT MC / PWMOUT MC	C1p-24
DOUT / PWMOUT / DIN	C1p-25
DOUT / PWMOUT / DIN	C1p-26
POUT safety / DOUT safety / PWMOUT safety / DIN	C1p-27

Encoder supply	C1p-28
Encoder channel B	C1p-29
DIN / DIN PU	C1p-30
DIN	C1p-31
DIN	C1p-32
DIN	C1p-33
Rheo	C1p-34
Power supply - (Ground)	C1p-35



s\* = safety

**Caution:**  
 The functionality and the specifications of PLUS+1 Inverter inputs and outputs are different from other PLUS+1 controllers and I/O expanders.

The following table lists MI XX input and output types and typical usage:

*Input/Output Types*

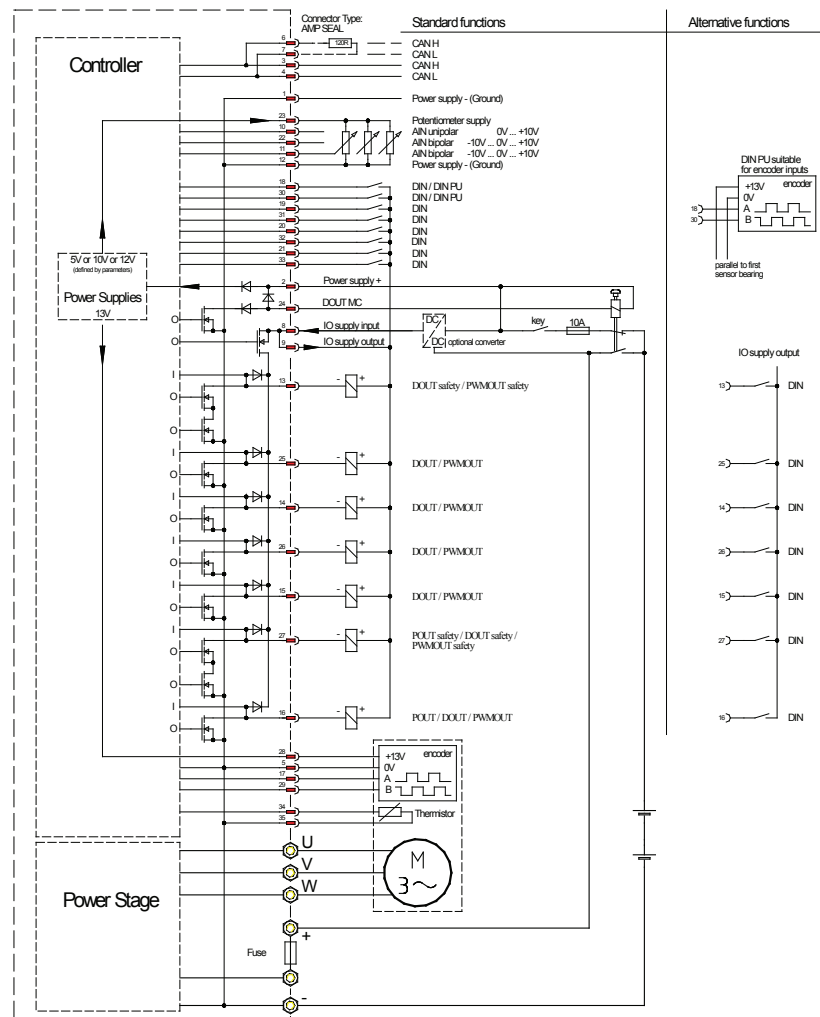
Function	Description	Typical usage
DIN	Digital input, high active	Standard digital inputs
DIN PU	Digital input with pull-up resistor, low active	Interface input from external components with open-collector outputs such as encoders (for motor encoder there are separate inputs available)
AIN unipolar	Analog input 0 to 10V	Inputs for set value potentiometer, throttle, mini lever,...
AIN bipolar	Analog input -10 to +10V	Interface input from vehicle master controller providing set value for speed and driving direction (-10V to 0V: backward, 0V to +10V: forward)
Rheo	Rheostat input. Measurement of an external resistance between this pin and minus power supply.	Motor temperature sensor
Encoder channel A channel B	Paired inputs driven from a quadrature encoder. Encoder with open-collector or push-pull outputs can be used	Must be used for motor speed feedback encoder.
DOUT	Digital output, low-side-switch with free wheeling diode to I/O supply output	Driver for external components, like electromagnetic brakes, on/off valves, contactors...
PWMOUT	Same as DOUT, but pulse width modulated signal with a frequency of 100Hz. Pulse width programmable 0 to 100% with a resolution of 10%.	Simple PWM control of external inductive loads with on/off functionality (electromagnetic brakes, on/off valves, contactors) in order to reduce power consumption and heat
POUT	Current controlled output, superposed with dither signal, low-side-switch with free wheeling diode	Driver for proportional valves
DOUT MC	Same as DOUT, but free wheeling diode to main power supply (C1-P2)	Driver for main contact. This output provides a reverse polarity protection for the inverter in combination with the main contact. (see further description at 6.5.3).
PWMOUT MC	Same as DOUT MC, but in PWM mode (like PWMOUT)	Driver for main contactor. This output provides a reverse polarity protection for the inverter in combination with the main contactor. (see further description at 6.5.3).
DOUT safety	Same as DOUT, but with additional safety transistor	Driver for safety critical on/off component, like electromagnetic brake or lowering valve..
PWMOUT safety	Same as PWMOUT, but with additional safety transistor	Driver for safety critical on/off component, like electromagnetic brake or lowering valve in PWM mode

The following ratings apply to all input and output types:

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MI XX-S-	24/xxx	48/xxx	80/xxx
Protection			
Max. input voltage [V]	36	62	105
Max. input voltage spikes for < 100ms [V]	36	72	120

## 6.2 Input/Output Wiring Principles

The following diagram shows the wiring principle of the inputs and outputs.



### 6.3 Input/Output Supply Voltage

PLUS+1 Inverters have a separate input pin and output pin for the power supply to I/O external components connected to the interface. The I/O supply voltage is independent of the vehicle's main power supply. It can be connected to the vehicle main power supply or to any other power supply (e.g. DC/DC converter) in the specified voltage range.

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MI XX-S-	24/xxx	48/xxx	80/xxx
<b>I/O supply input</b>	Power supply input for I/Os		
Maximum current [ADC]	8,0		
Max. input voltage [VDC]	36	62	105
Min. input voltage [VDC]	12		
<b>I/O supply output</b>	Power supply output for I/Os		
Maximum current [ADC]	8,0		
Output voltage	I/O supply input		

**Warning:**

The output pins are equipped with integrated free wheeling diodes. This feature provides easier wiring for the user, but it is not possible to protect the diodes against overvoltage.

Full protection of the outputs are only given for short connections to voltages not exceeding that at pin C1-P8 and C1-P9.

All external I/O components which are connected to any I/O pin must be supplied by the I/O supply output pin C1-P9.

## 6.4 Inputs

### 6.4.1 Digital (DIN)

Digital inputs connected to PLUS+1 Inverter dedicated DIN pins are debounced in system software with a user configurable time in the range of 0 to 100ms. Digital input debounce is defined as an input being in a given state for the configured debounce time before a state change is reported. The sample time of digital inputs is 1ms.

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: Mlxx-S-	24/xxx	48/xxx	80/xxx
DIN	Digital input with pull down		
Logic	+high-active		
Input resistance $\Omega$	18 k	18 k	47 k
Low-level [V] max.	3,75		
High-level [V] min.	9,0		

### 6.4.2 Multi Function Inputs (DIN, DIN PU, Freq)

The characteristics of Multi Function Input pins are GUIDE software controlled. The inputs can be high active with pull down resistors (DIN) or low active with pull-up resistors to +15V (DIN PU). The inputs can be used as digital inputs, single counters or paired to one quadrature counter driven from a quadrature encoder. If the inputs are used in counter mode the status of the digital input signals can be read in parallel. The digital inputs signals are debounced in system software with a user configurable time in the range of 0 to 100ms. Digital input debounce is defined as an input being in a given state for the configured debounce time before a state change is reported. The sample time of digital inputs is 1ms.

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: Mlxx-S-	24/xxx	48/xxx	80/xxx
DIN	Digital input with pull down		
Logic	high-active		
Input resistance $\Omega$	18 k	18 k	47 k
Low-level [V] max.	3,75		
High-level [V] min.	9,0		
DIN PU	Digital input with pull up resistor to +15V		
Logic	low-active		
Input resistance $\Omega$ to +15V	1,1 k		
Low-level [V] max.	3,75		
High-level [V] min.	9,0		
Maximal Frequency in counter mode [Hz]	100		
Quad counter mode	counts 4 pulses per encoder period		

### 6.4.3 Analog input with unipolar range (AIN unipolar)

The sample time for analog inputs is 1ms. For each analog input a separate first order filter in the system software is available with a configurable filter time constant in the range of 10ms to 200ms. The filter can be bypassed by setting the filter time constant to 0.

This analog input provides additional safety functions. The input voltage range of 0 to 10V is converted to the range of 10% to 90% of the DSP input range and is provided to two separate DSP channels. This allows the detection of any failure on the hardware input circuit as well as the detection of an input voltage out of the specified range. A “out of range” or “hardware error” will be reported at the corresponding API variable .PinStatus.

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MI XX-S-	24/xxx	48/xxx	80/xxx
<b>AIN unipolar</b>	Analog input unipolar		
Resolution	12 bit		
Input resistance $\Omega$	120 k		
Voltage range [V]	0–10		
Recommended resistance range of external potentiometer $\Omega$	1 k–10 k		
Protection			
Max. input voltage [V]	36	62	105
Max. input voltage spikes for < 100ms [V]	36	72	120

### 6.4.4 Analog input with bipolar range (AIN bipolar)

The sample time for analog inputs is 1ms. For each analog input a separate first order filter in the system software is available with a configurable filter time constant in the range of 10ms–200ms. The filter can be bypassed by setting the filter time constant to 0.

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MI XX-S-	24/xxx	48/xxx	80/xxx
<b>AIN bipolar</b>	Analog input bipolar		
Resolution	12 bit		
Input resistance $\Omega$	120 k		
Voltage range [V]	-10–10		
Recommended resistance range of external potentiometer $\Omega$	1k–10 k		
Protection			
Max. input voltage [V]	36	62	105
Max. input voltage spikes for < 100ms [V]	36	72	120

#### 6.4.5 Rheo

This input has a pull up resistor of 10kΩ to +5V. The system software calculates the resistance of the connected external load in the range of 0 to 12kΩ. If the resistance is higher than 12kΩ the results of the calculation shows 12kΩ and an "Input out of rang" status is reported at the API variable .PinStatus

A first order filter in the system software is available with a configurable filter time constant in the range of 10ms—200ms. The filter can be bypassed by setting the filter time constant to 0.

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MI XX-S-	24/xxx	48/xxx	80/xxx
Rheo	Measurement of an external resistance to minus power supply (e.g. motor temperature sensor)		
Range of resistance Ω	0–12 k		
<b>Protection</b>			
Max. input voltage [V]	36	62	105
Max. input voltage spikes for < 100ms [V]	36	72	120

#### 6.4.6 Encoder channel A, encoder channel B

Paired inputs driven from a quadrature encoder. The inputs have pull-up resistors of 1,1kΩ to encoder supply. Encoders with open-collector or push-pull outputs and 32–1024 pulses per revolution can be used.

##### Note

The field oriented motor control requires the speed feedback value, measured with a quadrature encoder.

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MI XX-S-	24/xxx	48/xxx	80/xxx
Encoder channel A / Encoder channel B	Square wave signal from encoder with 90° phase shift between channel A and channel B		
Internal structure	Internal pull-up-resistors to power supply encoder		
Pull-up-resistor Ω	1,1 k		
Maximum frequency [kHz] (open collector)	10		
Maximum frequency [kHz] (push-pull)	100		
Low-level (maximum) [V]	1,77		
High-level (minimum) [V]	7,1		
<b>Protection</b>			
Max. input voltage [V]	36	62	105
Max. input voltage spikes for < 100ms [V]	36	72	120



### 6.5 Inputs/Outputs

**Warning:**

Single outputs can source up to 3 amps. However, the total output current must not exceed 8 amps.

#### 6.5.1 General Purpose Input/Output (DOUT/PWMOUT/DIN)

The characteristics of General Purpose Input/Output pins are GUIDE software controlled. A General Purpose Input/Output pin can be programmed to work as digital output in binary mode (DOUT), as PWM output (PWMOUT) or as digital input (DIN).

The output configuration is an open collector sinking output with overload and open circuit detection.

If a General Purpose Input/Output pin is programmed as “PWM output” the output signal is pulse width modulated with a constant duty cycle. The PWM frequency is constant 100Hz and the duty cycle has a resolution of 10% and is defined by software.

Hint: The purpose of the PWMOUT mode is only simple voltage control. For closed loop current control use POUT mode on a according pin.

If a General Purpose Input/Output pin is programmed as digital input the signal is debounced in system software with a user configurable time in the range of 0 to 100ms. Digital input debounce is defined as an input being in a given state for the configured debounce time before a state change is reported. The sample time of digital inputs is 1ms.

Note: The status of the pin can be read in GUIDE software in all configuration modes using the API variable “DigIn”. The debouncing is only active in DIN mode.

**Caution**

Damage to the module outputs may occur. If battery voltage is applied to a module output pin the module will be powered up. If significant current is driven through an output pin, the module will be damaged.

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MI XX-S-	24/xxx	48/xxx	80/xxx
DOUT/PWMOUT	Digital output		
Internal structure	low-side-switch with free wheeling diode		
Cathode of free wheeling diode connected to	I/O supply output		
Signal output delay	Max. 1ms + application SW loop time.		
Nominal current [A]	2.0		
Maximum current [A] (for min. 1 second before overload protection activated)	3.0		
Overload protection	Non-damage, current/thermal limit with status indication; automatic latch off /resume		

Resistance to minus power supply $\Omega$	136 k		
Maximum load resistance $\Omega$ @ 12V I/O-supply voltage (Higher resistances will be reported in GUIDE as "output disconnected")	45 k		
Open circuit detection	<p>Fault indication provided. If the voltage at the output pin in OFF state is less than 9V the Pin-status "Output disconnected" will be reported. Considering the internal resistance of 136kOhm the load resistance should be maximum 45kOhm at 12V I/O-supply voltage. For higher I/O-supply voltages the maximum load resistance can be calculated with the formula :</p> $R_{\max} = \left( \frac{V_{io}}{9V} - 1 \right) * 136k\Omega$ <p>With <math>V_{io}</math>= I/O-supply voltage</p>		
Max. resistance, ON state RDSon[Ohm]@25°C	0.2		.25
DIN	Digital input with pull down		
Logic	High-active		
Input resistance $\Omega$	18 k	18 k	47 k
Low-level [V] max	3,75		
High-level [V] min.	9,0		

---

0.2

.25

**6.5.2 General Purpose Proportional Input/Output (DOUT/PWMOUT/DIN/POUT)**

The characteristics of General Purpose Proportional Input/Output pins are GUIDE software controlled. A General Purpose Input/Output pin can be programmed to work as digital output in binary mode (DOUT), as PWM output (PWMOUT), as proportional output, closed loop current controlled (POUT) or as digital input (DIN).

For specification in DOUT, PWMOUT and DIN mode refer to General Purpose Input/Outputs (Section: 6.5.1)

In POUT mode the output is closed loop current controlled by a hardware two-level controller. The frequency of the output signal is varying between 500Hz and 2kHz. The current set-value is defined by software. A set-value of 0 will switch off the output completely. A dither signal with a fixed frequency of 62.5Hz can be added with a software defined amplitude up to 250mA.

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MI XX-S-	24/xxx	48/xxx	80/xxx
<b>POUT</b>	current controlled output - superposed with dither signal		
Internal structure	low-side-switch with free wheeling diode		
Cathode of free wheeling diode connected to	I/O supply output		
Current range [A]	0–2,0		
Dither signal frequency / amplitude	62,5 Hz / 0–0,25 A		
Repeat accuracy from unit to unit	<10mA (for set values 0–330mA) < 3% (for set values 330mA–2A)		
Switching frequency [Hz]	500–2000		
Overload protection	Non-damage, current/thermal limit with status indication; automatic latch off /resume		
Resistance to minus power supply [Ohm]	136 k		
Maximum load resistance [Ohm] @ 12V I/O-supply voltage (Higher resistances will be reported in GUIDE as "output disconnected")	45 k		
Open circuit detection	Fault indication provided. If the voltage at the output pin in OFF state is less than 9V the Pin-status "Output disconnected" will be reported. Considering the internal resistance of 136kOhm the load resistance should be maximum 45kOhm at 12V I/O-supply voltage. For higher I/O-supply voltages the maximum load resistance can be calculated with the formula : $R_{\max} = \left( \frac{V_{io}}{9V} - 1 \right) * 136k\Omega$ With Vio= I/O-supply voltage		
Max. resistance, ON state, R[Ohm]@25°C	0.2	0.2	.25

### 6.5.3 Main contact output (DOUT MC / PWMOUT MC)

The main contact output is a special output pin with the purpose to drive the vehicle's main contact. In difference to standard output pins the free wheeling diode is connected to the pin "Power supply +" instead of "I/O supply output". This is because the main contact is typically supplied in parallel to "Power supply +" with the vehicle's battery voltage via the vehicle's key switch. Another diode protects this output against reverse polarity. Together with the main contact this circuit provides the reverse polarity protection for the inverter, because the main contact can only switch the battery to the power stage if the polarity is right.

The main contact output can be programmed to work as digital output in binary mode (DOUT MC) or as PWM output (PWMOUT MC). The output configuration is an open collector sinking output with overload and open circuit detection. If the output is programmed as "PWM output" the output signal is pulse width modulated with a constant duty cycle. The PWM frequency is constant 100Hz and the duty cycle has a resolution of 10% and is defined by software.

Note The purpose of the PWMOUT mode is only simple voltage control.

Caution: If the main contact output pin is used for another purpose than to drive a main contact, the load has to be supplied in parallel to "Power supply +".

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MI XX-S-	24/xxx	48/xxx	80/xxx
Main Contactor Output	Digital output for main contact		
Internal structure	low-side-switch with free wheeling diode		
Cathode of free wheeling diode connected to	Power supply +		
Signal output delay	Max. 1ms + application SW loop time.		
Nominal current [A]	2,0		
Maximum current [A] (for min. 1 second before overload protection activated)	3,0		
Short circuit to ground protection	Non-damage, current/thermal limit with status indication; automatic latch off /resume		
Resistance to minus power supply Ω	136 k		
Maximum load resistance Ω @ 12V I/O-supply voltage (Higher resistances will be reported in GUIDE as "output disconnected")	45 k		
Open circuit detection	Fault indication provided. If the voltage at the output pin in OFF state is less than 9V the Pin-status "Output disconnected" will be reported. Considering the internal resistance of 136kOhm the load resistance should be maximum 45kOhm at 12V I/O-supply voltage. For higher I/O-supply voltages the maximum load resistance can be calculated with the formula : $R_{\max} = \left(\frac{V_{io}}{9V} - 1\right) * 136k\Omega$ With Vio= I/O-supply voltage		
Max. resistance, ON state RDSon[Ohm]@25°C	0,2	0,2	.25

#### 6.5.4 Outputs with enhanced safety (DOUT safety, PWMOUT safety, POUT safety)

Output pins which are marked with the extension “safety” are equipped with a redundant safety transistor. The safety transistor is connected in series to the standard output transistor. In case of an unintended activation of the output caused by a transistor fault the second transistor will switch off the output. At each switching cycle the functionality of both transistors are checked by system software. If a transistor is damaged and can no longer switch off, the second transistor takes over the full functionality of the output and the API variable .SafetyStatus shows a “Safety Error”. The output will now work like a standard output.

This feature provides a very high safety on the appropriate outputs. Those outputs should be reserved to drive components related to safety critical functions like electromagnetic brake or lowering valve.

## 7. Power Supply

### 7.1 Control Power supply

The main power supply for the control circuits has to be provided at pin C1p02. The pre-charge circuit for the power stage capacitors which is supplied by the same pin, causes a inrush current significantly higher than the nominal supply current.

Type: MI	24/xxx	36 - 48/xxx	80/xxx
Power supply +	Power supply input for internal power supplies of control circuits		
Input voltage range [VDC]	16-36	18-62	40-105
Supply current (typ.) @ nominal voltage [A]	0,24	0,13	0,1
Inrush current [A] (<100ms)	24	10	7
Power supply - (Ground)	Power supply and signal ground		
Internal structure	Connection with minus power supply		

## 7.2 Auxiliary power supplies

### 7.2.1 Sensor power supply

PLUS+1 inverters provide a sensor power supply pin with a programmable output voltage of 5V, 10V or 12V. Typically this power supply is used for throttles, foot pedals or mini-levers. If the supply voltage has influence to the sensor signal a feedback value C1p23.Volt is available to consider the actual voltage into the calculation of the set value out of the sensor signal.

Type: MI	24/xxx	36 - 48/xxx	80/xxx
<b>Sensor supply</b>	Power supply for external sensors		
Programmable output voltage [VDC]	5 / 10 / 12		
Tolerance [%]	5		
Maximum output current [A]	0.1		
Protection			
Max. input voltage [V]	36	62	105
Max. input voltage spikes for < 100ms [V]	36	72	120
Over current, short circuit	Current limitation at 0,1 A		

### 7.2.2 Encoder power supply

PLUS+1 inverters provide another auxiliary power supply with a fixed voltage and a current feedback (C1p28.FeedbackValue), typically used for encoder supply.

Nominal Voltage [V]	24	36-48	72-80
Type: MI	24/xxx	36 - 48/xxx	80/xxx
<b>Encoder supply</b>	Power supply for encoder (e.g. sensor bearing)		
Supply voltage [VDC]	13V ± 10%, Ri = 30 Ohm		
Protection			
Max. input voltage [V]	36	62	105
Max. input voltage spikes for < 100ms [V]	36	72	120
Over current, short circuit	Current limitation at 110 mA		

### 7.3 Power Stage supply

The power stage supply is conducted with screws, named “+” and “-“. An additional screw allows the assembly of a power fuse on top of the inverter housing.

Fuse shown for illustration purposes only and is not delivered with inverter

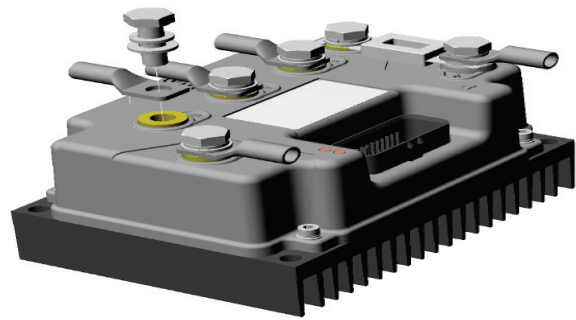


Fig 3: Installation Illustration

Make sure that the cable shoe directly lies on the brass sleeve.

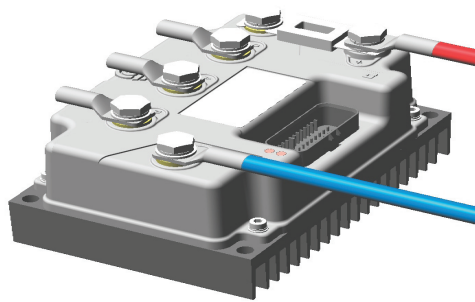


Fig. 4: Connection with fuse

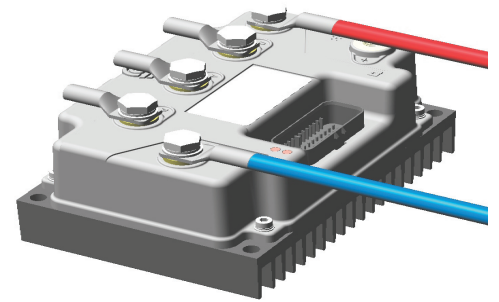
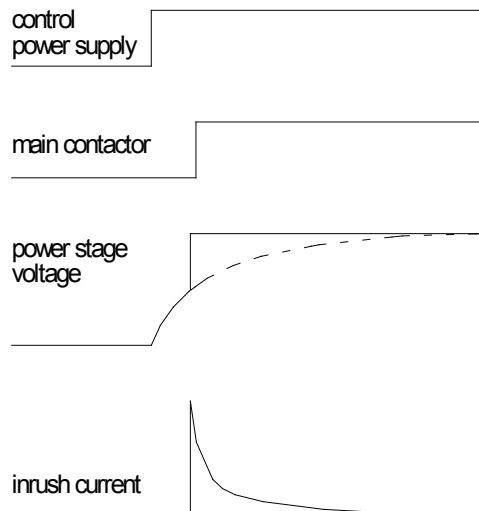


Fig.5: Connection without fuse

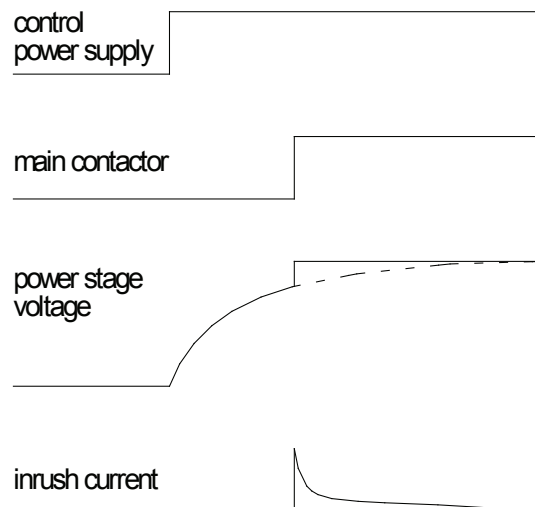
### 7.3.1 Pre charging of capacitors

The power stage capacitors are pre charged by the control power supply (C1p02) via a PTC resistor. The inrush current of the power stage supply is dependant on the voltage level of the power stage capacitors at the time of connecting voltage to the power stage. Means the time between switching control power supply and power stage supply is determined for the peak value of inrush current. In practice a compromise between start-up time and inrush current has to be found.

Short delay for main contactor:



Longer delay for main contactor:





## 8. Protection

### 8.1 Self test at Power up

At power up a self test routine is performed to detect failures in the hardware of the power stage or external wiring.

The system software is processing following steps:

- Configuration of the I/Os and sensor power supply
- Test of DC link voltage
- Test of hardware watchdog
- Start of PLUS+1 application software
- Test of power stage
- EEPROM CRC check

The API variable Self test displays Errors, Warnings and the Status of the Self test. For details please refer to the API description.

During the tests the power stage is locked by system software, means the application software can not enable the power stage before the tests are passed.

If one of the tests fail with an error the power stage will be locked permanently.

If an overvoltage error occurs at any time during the execution of the self test routine, all test will be skipped and a self test error will be reported: "Test not passed, because of hardware overvoltage protection"

#### 8.1.1 EEPROM CRC check

At the end of the self test routine a CRC check of the EEPROM data will be performed. The EEPROM is split into three sections

Production data: Data stored at production of the device in a protected memory area to adjust software scaling to actual hardware

User data: Memory area accessible by the user

Error History data: Memory area where the error history data are stored

If the CRC check fails for the production data area an error will be reported, because wrong data can lead to incorrect behavior.

If the CRC check fails for the user data area only a warning will be reported. Appropriated reaction should be programmed in the PLUS+1 application software.

If the CRC check fails for the Error History data area only a warning will be reported. The functionality of the device is unlimited but the error history data may be corrupted.

### 8.1.2 DC Link Test

With the DC link test a short circuit in the DC link circuit (internal hardware, like capacitor board or external wiring) can be detected. Before the main contact will be closed the capacitor bank is pre-charged via a resistor, powered by the power supply voltage (C1p02).

Test algorithm:

- Wait until  $V\_DC\_Link > \text{Threshold voltage (1.6V – 3.5V)}$
- The test is OK as soon as this condition is fulfilled.

If this condition is not fulfilled within 5 seconds after power-on, the test failed. ->

- Selftest.Error Bit0=1 (Error Link Circuit)
- The main contact output and the power stage are locked permanently (C1p24. Locked=1 ; PowerStage.Locked=2)
- all following tests will be skipped

If this error occurs:

- Switch off power supply
- Disconnect the power cables + and –
- Switch on power supply again

If the DC-Link test shows no error anymore there is a short circuit in the wiring of the power cables + and – or the load in that circuit is too high and pushes down the DC-Link voltage.

If the error still occurs there is a failure in the inverter.

### 8.1.3 Hardware Watchdog

In addition to the internal DSP watchdog PLUS+1 Inverters have a separate hardware watchdog. This watchdog is triggered by a toggle signal, generated by system software. If the trigger signal is not toggling anymore the watchdog hardware disables the power stage and all interface outputs.

The hardware watchdog will be checked by the self test routine at power up.

The result can be a Warning or an Error:

Warnings:

PLUS+1 inverters are designed and produced with a very high quality standard.

The hardware watchdog is an additional feature which increases the safety of the inverter beyond the DSP watchdog. If the hardware watchdog test results in a warning, the inverter's functioning is monitored by the DSP watchdog only. If this is the only error the inverter can be used without the higher safety of the additional hardware watchdog. It doesn't mean the inverter works unsafe at all. Appropriate actions should be taken in the PLUS+1 Application Software dependant on the safety requirement of the application.

- Selftest.Warning Bit0=1: Failure in Watchdog circuit, limited operation possible.

The Watchdog can't switch off the power stage and the outputs.

- Selftest.Warning Bit1=1: Watchdog not tested, because of low DC-Link voltage.

A minimum DC-Link voltage is necessary to perform the Watchdog test. If this voltage is not reached 5 seconds after start of Watchdog test routine the test will be skipped and this warning will be reported.

Type: MI	24/xxx	36 - 48/xxx	80/xxx
Minimum DC-Link voltage to perform Watchdog test [V]	5.2	10	11

#### Errors

- Selftest.Error Bit1=1: Watchdog error, operation impossible

The power stage and the outputs are always disabled. The inverter can't be used anymore. The following tests will be skipped.

#### 8.1.4 Power Stage Test

The power stage test will be performed as soon the DC-Link voltage reached 90% of the power supply voltage (C1p02). The application software has already started and can close the main contact to shorten the time of charging the DC-Link capacitors. The only criterion to start the power stage test is the level of the DC-Link voltage independent of the status of the main contact.

One of the tests requires a correctly connected motor.

An extensive test of the power stage is performed to detect:

- A shorted power transistor
- A damaged power transistor (can't switch on anymore)

Can only be detected if a motor is connected correctly

- A short circuit of a phase output to -V\_DC\_Link
- A short circuit of a phase output to +V\_DC\_Link
- A Short circuit between two phase outputs (short circuit in wiring or motor)

Error message	Meaning	Recommended recovery actions	Result afterwards and conclusion
Short circuit to -V_DC_Link:  Short circuit to +V_DC_Link:  Shorted power output	Short circuit between a phase output and the + or - power stage supply or between the phase outputs	Switch off power supply Disconnect phase outputs Switch on power supply again	Still the same error: Inverter damaged Only error "Error in motor wiring or power stage": There is a short circuit in the motor or the wiring.
Error in motor wiring or power stage	Motor not connected.  Motor wiring incorrect.  Motor winding broken.	Test motor wiring  Exchange motor	If the error occurs with a correct wired motor the power stage is damaged.

Note: Due to physical limitations it is not possible to detect every short circuit. Depending on the length of the cable, cable wire size and cable routing a short circuit at the end of a cable will have the same electrical behavior as in a correctly wired motor.

## 8.2 Runtime Protection Functions

### 8.2.1 Power Stage Protection

PLUS+1 Inverters provide a number of protection functions with error, warning and status messages. Most of the messages are only reported via API to the application software which has to take the necessary reactions according to the application. The system software reacts only to those errors which would destroy the power stage hardware.

- Overvoltage
- Overcurrent
- Overtemperature and temperature sensor error

If one of these errors occurs:

- The power stage will be disabled (PowerStage.EnableStatus=0)
- The API variable PowerStage.Status displays the error in bitwise representation
  - Bit1 = 1: Overtemperature
  - Bit2 = 1: Sensor Error
  - Bit3 = 1: Overvoltage
  - Bit4 = 1: Overcurrent
- The error will be displayed in the error history memory
- For each of these errors there is a counter which counts the total number of detected errors while lifetime of the inverter

Remark: A 1-0 sequence at PowerStage.Enable clears the bits of these errors, which are not longer present.

#### 8.2.1.1 Overvoltage

The DC\_Link voltage is compared with the maximum value by hardware. If the actual DC\_Link voltage exceeds the maximum value:

- The power stage is disabled by hardware
- An interrupt at the highest level is triggered
- The error handling procedure is performed by software
  - Disable the power stage: PowerStage.EnableStatus=0
  - Display the error: PowerStage.Status Bit3=1
  - Increase error counter: ErrorHistory.AbsOVerErrors
  - Write error history memory

Remark: The actual DC\_Link voltage is also displayed at V\_DC\_Link.Volt

### 8.2.1.2 Overcurrent

In normal operation the current is limited by the software of the current controller. In addition, the current in each phase is limited by hardware. If the actual current exceeds the maximum value the corresponding phase output is switched off for 50µs and a signal is sent to the DSP

This signal triggers a software integrator. If the integrator exceeds a limit (overcurrent signal is active for more than 3 seconds) the error handling procedure is performed:

- Disable the power stage: PowerStage.EnableStatus=0
- Display the error: PowerStage.Status Bit4=1
- Increase error counter: ErrorHistory.AbsOCErrors
- Write error history memory

### 8.2.1.3 Overtemperature

The temperature of the power stage is measured with a PTC resistor and the values are filtered with a time constant of 500ms. The actual temperature is calculated and displayed at PowerStage.Temp in the range of -60°C – 170°C. If the actual value exceeds the temperature limit (stored as production data at EEPROM) an overtemperature error occurs:

- Disable the power stage: PowerStage.EnableStatus=0
- Display the error: PowerStage.Status Bit1=1
- Increase error counter: ErrorHistory.AbsOTErrors
- Write error history memory

### 8.2.1.4 Temperature Sensor Error

The temperature at the power stage is measured with a PTC resistor and the values are filtered with a time constant of 500ms.

If the result of the power stage temperature calculation is out of the sensor range of -60°C to +200°C a temperature sensor error occurs:

- If Unsafe mode is inactive: disable the power stage: PowerStage.EnableStatus=0
- Display the error: PowerStage.Status Bit2=1
- Increase error counter: ErrorHistory.AbsTSensErrors
- Write error history memory
- 

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Note: With the help of Unsafe mode a “limp home mode” can be programmed under GUIDE to allow to drive the truck in case of a temperature sensor error.

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### 8.2.2 Unsafe Mode

The Unsafe mode allows to enable the power stage even if a temperature sensor error would lock it. The unsafe mode is activated when PowerStage Unsafe changes from 0 to 1. To avoid an unintended usage of the unsafe mode, the APL resets the unsafe mode after 60 seconds. Within these 60 seconds the insecure mode can be disabled (by PowerStage Unsafe=0) but not retriggered. In order to recognize the usage of the unsafe mode in case of a service, the usage of the unsafe mode occurrence is stored in the error history memory.

## 9. Power Stage

### 9.1 Enable/Disable

With the variable PowerStage.Enable the power stage can be switched on and off.

Enabling the power stage is only allowed if:

PowerStage.Status Bit1=0	( no Overtemperature )
PowerStage.Status Bit3=0	( no Overvoltage )
PowerStage.Status Bit4=0	( no Overcurrent )
PowerStage.Locked=0	

or

PowerStage.Status Bit2=1	( Temperature sensor error )
PowerStage.Insecure=1	( Insecure mode activated )
PowerStage.Status Bit3=0	( no Overvoltage )
PowerStage.Status Bit4=0	( no Overcurrent )
PowerStage.Locked=0	

A 1 to 0 sequence at PowerStage.Enable resets the PowerStage status bits

PowerStage.Status Bit1	Overtemperature
PowerStage.Status Bit2	Temperature Sensor Error
PowerStage.Status Bit3	Overvoltage
PowerStage.Status Bit4	Overcurrent

The power stage can be disabled because of an error even if PowerStage.Enable is true. Therefore the actual status of the power stage can be read at PowerStage.EnableStatus.

## 9.2 PWM Frequency

The PWM frequency of the power stage can be varied in 4 steps:

- 4 kHz
- 8 kHz (default value)
- 12 kHz
- 16 kHz

with the API variable PowerStage.PWMFreq

A center-aligned modulation method is used, which provides a double PWM frequency to the motor, so in most of the applications 8 kHz provides silent performance

However, if the noise at the motor is too high, the PWM frequency can be increased.

A higher PWM frequency, however, leads to:

- higher power losses
- slightly lower maximum motor voltage (less performance in field weakening area → reduced maximum speed)

### 9.3 Diagnostics

The API provides numerous data for diagnostic purposes of the power stage:

API variable	Description														
PowerStage.EnableStatus	Displays the actual status of the power stage (The power stage can be disabled because of an error even if PowerStage.Enable is true) False: Power Stage disabled True: Power Stage enabled														
PowerStage.Temp	Actual temperature at power stage in degree Celsius														
PowerStage.TempLimit	The temperature limit of the power stage														
PowerStage.HWCurrLimit	Current capability of the power stage Remark: The current may be limited by user current limitation														
PowerStage.Locked	0: unlocked (okay) 1: the power stage is temporarily locked (during initialization and self test) 2: the power stage is permanently locked because of an error. The reason can be found at Selftest.Error or PowerStage.Status														
PowerStage.Status	<table border="1"> <tbody> <tr> <td>Bit0</td> <td>0 = OK 1 = wrong value at PWM Freq</td> </tr> <tr> <td>Bit1</td> <td>0 = OK 1 = Overtemperature</td> </tr> <tr> <td>Bit2</td> <td>0 = OK 1 = Temperature SensorError</td> </tr> <tr> <td>Bit3</td> <td>0 = O 1 = Overvoltage</td> </tr> <tr> <td>Bit4</td> <td>0 = OK 1 = Overcurrent</td> </tr> <tr> <td>Bit5</td> <td>0 = Insecure Mode inactive 1 = Insecure Mode active</td> </tr> <tr> <td>Bit6</td> <td>0 = OK 1 = Power Stage permanently locked because wrong motor data</td> </tr> </tbody> </table>	Bit0	0 = OK 1 = wrong value at PWM Freq	Bit1	0 = OK 1 = Overtemperature	Bit2	0 = OK 1 = Temperature SensorError	Bit3	0 = O 1 = Overvoltage	Bit4	0 = OK 1 = Overcurrent	Bit5	0 = Insecure Mode inactive 1 = Insecure Mode active	Bit6	0 = OK 1 = Power Stage permanently locked because wrong motor data
Bit0	0 = OK 1 = wrong value at PWM Freq														
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Bit3	0 = O 1 = Overvoltage														
Bit4	0 = OK 1 = Overcurrent														
Bit5	0 = Insecure Mode inactive 1 = Insecure Mode active														
Bit6	0 = OK 1 = Power Stage permanently locked because wrong motor data														



## 10. Service Functions

### 10.1 Error History

PLUS+1 Inverters provide an inerasable Error History Memory which tracks all power stage protection errors and selftest errors as integral function of the system software. The application software may provide another error history memory for application errors.

The first part of the Error History Memory consists of 3 API data arrays

- ErrorHistory.Number[0..7]: Error numbers
- ErrorHistory.Counter[0..7]: Number of the same errors in a row
- ErrorHistory.Hour[0..7]: Value of the hour counter when the latest of the same errors in a row occurred

Each data array has 8 elements.

Element 0 shows the latest error.

Element 7 shows the oldest error.

Error numbers:

1 = Overtemperature

2 = Overvoltage

3 = Overcurrent

4 = TemperatureSensorError

5 = Unsafe Mode

6 = DC\_Link error

7 = Watchdog error (limited operation possible)

8 = Watchdog error (operation impossible)

9 = Power Stage error, short circuit to -V\_DC\_Link

10 = Power Stage error, short circuit to +V\_DC\_Link

11 = Error in motor wiring or power stage

12 = Shorted power output

13 = wrong production data in EEPROM detected

The second part of the Error History Memory consists of 4 API variables to count the absolute numbers of detected power stage protection errors during lifetime of the inverter.

- ErrorHistory.AbsOTErrors: Shows absolute number of detected over temperature errors over the lifetime of the inverter.
- ErrorHistory.AbsOVerErrors: Shows absolute number of detected over voltage errors over the lifetime of the inverter.
- ErrorHistory.AbsOCErrors: Shows absolute number of detected over current errors over the lifetime of the inverter.
- ErrorHistory.AbsTSensErrors: Shows absolute number of detected temperature sensor errors over the lifetime of the inverter.

- If the occurred error is the same like the last entry in ErrorHistory.Number[0]
  - Copy the value of HourCounter.Inverter to ErrorHistory.Hour[0]
  - Increment the value of ErrorHistory.Counter[0]
  - Increment the value of the related absolute error counter
- If the occurred error is different to the last entry in ErrorHistory.Number[0]
  - Move all entries of ErrorHistory.Number, ErrorHistory.Hour and ErrorHistory.Counter to the next element.
  - Write the error number to ErrorHistory.Number[0]
  - Copy the value of HourCounter.Inverter to ErrorHistory.Hour[0]
  - Write 1 to ErrorHistory.Counter[0]
  - Increment the value of the related absolute error counter

Example:

Error type	Value of HourCounter
Overcurrent	1000
Overtemperature	2050
Overtemperature	2060
Overtemperature	2065
Overcurrent	3000
Overcurrent	3005
TempSensorError	3100
TempSensorError	3100
TempSensorError	3110
TempSensorError	3120
Unsafe Mode	3300
Unsafe Mode	3310
Unsafe Mode	3316
TempSensorError	3407
TempSensorError	3409

Content of Error History Memory:

Element	ErrorHistory. Number	ErrorHistory.Hour	ErrorHistory Counter
0	4 (TempSensorError)	3409	2
1	5 (Insecure Mode)	3316	3
2	4 (TempSensorError)	3120	4
3	3 (Overcurrent)	3005	2
4	1 (Overtemperature)	2065	3
5	3 (Overcurrent)	1000	1
6	0	0	0
7	0	0	0

ErrorHistory.AbsOTErrors: 3  
 ErrorHistory.AbsOErrors: 0  
 ErrorHistory.AbsOCErrors: 3  
 ErrorHistory.AbsTSensErrors: 6

## 10.2 Hour Counter

PLUS+1 Inverters provide a non resettable hour counter as integral function of the system software. The application software may provide another hour counter for application needs.

API variable	Function	Remark
HourCounter.Inverter	Hour counter [0.001h], not resettable	Counts, when the inverter is power supplied at C1p02
HourCounter.Power	Hour counter [0.001h], not resettable	Counts, when the power stage is enabled

### 10.3 Device Info

The device information variable structure provides device specific information.

API Variable	Description
DeviceInfo.DeadTime	Dead time of power stage 0...6400 [ns]
DeviceInfo.MinTemp	Minimal specified temperature [°C] where the unit will work proper.
DeviceInfo.MinVolt	Minimal specified voltage [mV] where the unit will work proper.
DeviceInfo.MaxVolt	Maximal specified voltage [mV] where the unit will work proper.
DeviceInfo.SerialNoA	First part of the Serial number.
DeviceInfo.SerialNoB	Second part of the Serial number.
DeviceInfo.PartNo0	Defines the hardware assembly with software loaded.
DeviceInfo.PartNo1	Is a S-D part number and is set when customer-specific software and/or parameter settings are loaded from production cell (part number that the customer is ordering).
DeviceInfo.InverterFrameSize	Inverter frame size (6 for MI06, 20 for MI20 and so on)

### 10.4 NV RAM User Data

PLUS+1 Inverters provide a non volatile memory area for user data. This memory area consists of a RAM area with EEPROM backup. In normal operation the memory access for the application software is not different from other RAM areas. If power down is detected by the control hardware the NVRam area will be copied immediately to the EEPROM. An energy buffer inside the control hardware is capable to supply the voltage for the needed time.

At power up the data will be restored to the NVRam area before the application software will be started.

## 11. Motor Control

### 11.1 Control Structure

#### 11.1.1 Field oriented motor control

The main part of the MI XX motor control strategy is the field oriented motor control, which requires a set of motor data. If the motor data are well defined, the torque at the motor shaft follows the torque set value with a delay of maximum 10ms. Compared to the time constants of a vehicle the torque delay time is negligible and the torque transfer function can be assumed to be 1. This allows the optimization of the drive system to be independent on the torque controller. Only the speed controller has to be adapted to the application.

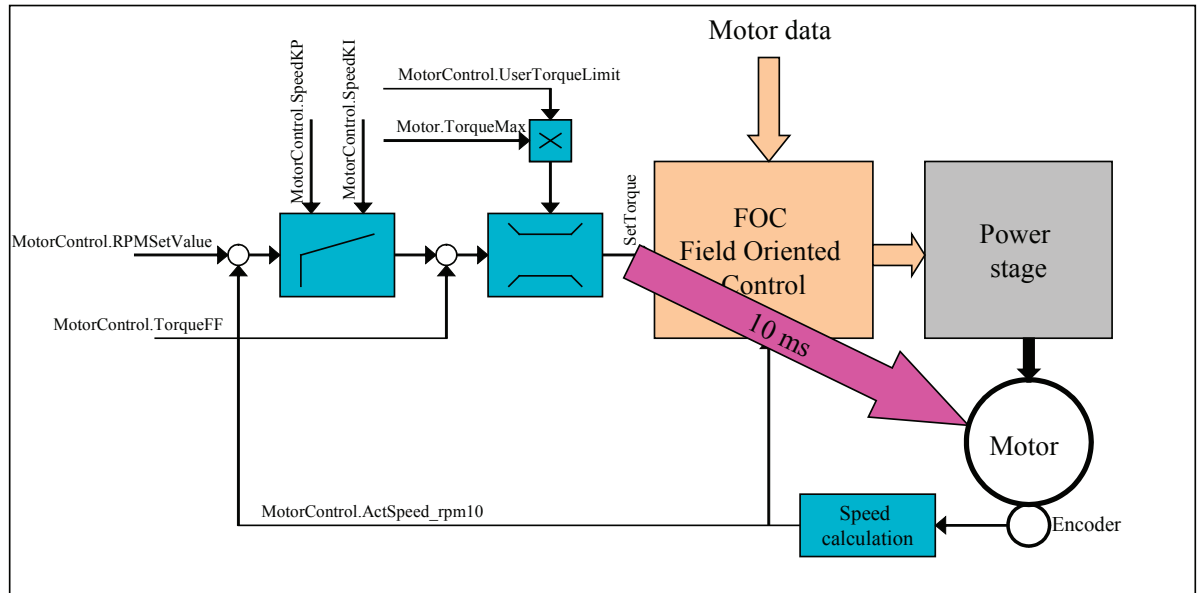


Fig. 6: Motor control

#### 11.1.2 Speed controller

The speed controller has a PI-configuration with an anti-windup. The output of the speed controller is the torque set value. The unit of the proportional gain `MotorControl.SpeedKP` is Nm/rpm. Means how much torque has the motor to provide per rpm deviation.

The unit of the integral gain `MotorControl.SpeedKI` is Nm/rpm/s. i.e. how much the torque set value should increase in one second per rpm deviation.

The control parameters have to be optimization at the final application machine. A standard rule for optimization is:

- Switch off the integral part by `MotorControl.SpeedKI=0`
- Increase the proportional gain until the control starts to oscillate (consider the complete speed range)
- Reduce to proportional gain to 70%
- Keep this proportional gain and do the same now with the integral gain

### 11.1.3 Speed feedback

The field oriented motor control requires a speed feedback value. The quality of the speed feedback signal is very important for the performance of the speed control. Inadequate encoder signals or encoder quality may result to oscillations and insufficient control behavior.

PLUS+1 Inverters require a quadrature encoder with a resolution in the range of 32 to 1024 pulses per revolution mounted directly to the motor shaft. The output of the encoder can be open collector or push-pull. It is very important to feed the API variable `Motor.EncPulses` with the resolution of the used encoder.

The encoder signals have to be aligned with the rotation direction of the motor. If the phase order of the motor current is U-V-W the phase of the encoder signal A has to be before B.

**Warning:**

---

A wrong value at `Motor.EncPulses` can in worst case result in uncontrolled acceleration. If the encoder signal is missing the motor runs with low speed but can provide full torque.

---

Bad encoder signal conditions can result in jerky control behavior.

---

### 11.1.4 Torque Feed Forward

A step change in motor load torque will always result in a speed deviation for a short time. The speed deviation will then change the motor torque to the right level to bring the speed back to the set value. Typically such a control cycle takes less than 100ms. If a very fast speed control is needed and the motor load can be estimated, the torque feed forward input (`MotorControl.TorqueFF`) can be used. The estimated motor load torque has to be provided to the feed forward input. A load change will directly result in the right motor torque without a speed deviation. Even if the estimated load is not very accurate the speed deviation can be minimized.

### 11.1.5 Torque Limitations

The torque limitation for the motor is defined in the motor definition data structure `Motor.TorqueMax`. Another torque limitation can be entered at the motor control data structure `MotorControl.UserTorqueLimit`. This value is defined as a percentage of `MotorTorqueMax`. If no torque limitation is needed `MotorControl.UserTorqueLimit` has to be set to 10000 (=100%).

With the variable `MotorControl.ActTorqueLimit` the valid torque limit in Nm can be read.

Note: The current limitation (see 11.1.6) may prevent the achievement of maximum torque.

### 11.1.6 Current Limitation

There are three different current limitations:

Hardware current limit: This is the maximum current capability of the power stage hardware.

Motor current limit: This is the current limit for the motor, defined at `Motor.CurrentMax`.

User current limit: This is the current limit for the application, defined at `MotorControl.UserCurrLimit` as a percentage of the hardware current capability.

The valid current limit can be read with the API variable `MotorControl.ActCurrLimit`.

Note: The torque limitation (see 11.1.4) may prevent achievement of maximum current.

### 11.1.7 Speed Control vs Torque Control

For most applications the preferred control mode is speed control. In some applications torque control may have advantages.

The speed controller can be used for torque control with following consideration:

- Provide the absolute torque set value to the torque limit value of the speed controller
- Provide a speed limit value to the speed set value of the speed controller
- Since the torque limit value accept only absolute values, the sign of the torque set value has to transferred to the speed set value.

Torque Control Values	Values to Speed Controller
Torque set value = 80% Speed limit = 2000 rpm	MotorControl.UserTorqueLimit=8000 MotorControl.RPMSetPoint=20000
Torque set value = -50% Speed limit = 2000 rpm	MotorControl.UserTorqueLimit=5000 MotorControl.RPMSetPoint=-20000

## 11.2 Motor definition

The field oriented motor control requires motor data. These are physical data of the motor, independent of the application. No optimization of motor data at the final application machine is required.

The required motor data have to be provided to the API variable structure Motor.xxx. Because the motor typically comes in a package with encoder and temperature sensor, those data are included in the same structure.

There are three different ways to provide the motor data.

### 11.2.1 Motor Compliance Blocks

Sauer-Danfoss motors come with PLUS+1 Compliance Blocks including all required data for the complete motor package (motor, encoder, temperature sensor) as well as the calculation of the actual motor temperature, the generation of an error signal at over temperature and the surveillance of the minimum and maximum encoder supply current. The name of the compliance block is reflected in the part number of the motor package.

**Plug&Perform:** All adjustments and calculations related to motor, encoder and temperature sensor are done by just installing the right Motor Compliance Block.

The following error signals are provided by the Motor Compliance Block:

MotorData.Motor.MaxTempErr: True if actual temperature exceeds maximum motor temperature (specified inside the compliance block)

MotorData.Enc.MaxCurrErr: True if encoder supply current exceeds maximum (specified inside the compliance block)

MotorData.Enc.MinCurrErr: True if encoder supply current is lower than minimum (specified inside the compliance block). Indicates a disconnection of the encoder, a broken encoder wire or any other encoder failure.

The reaction to those error signals have to be programmed depending on the application.

### 11.2.2 Open Electric Motor Data Block

If a non Sauer-Danfoss motor is used the data for motor, encoder and temperature sensor can be edited in the GUIDE template.

Description of motor parameters

### 11.2.3 Electric Motor Data Download Block

If the application software should allow to change motor data at run time the Motor Data Download Block has to be installed. This allows motor data (inclusive encoder and temperature sensor data) to be downloaded via Service Tool. As this block requires default values a Motor Compliance Block or an Open Motor Data Block has to be installed additionally.

### 11.2.4 Re-initialization of motor data

If motor data are changed during runtime (switch between motor data blocks) the data will only become valid after a re-initialization. This has to be done by a 0-1 sequence at Motor.Reinit. The re-initialization will not be performed until the power stage is disabled and the actual speed is lower than 10 rpm. Motor.Status bit23 is 1 while a re initialization is pending.

## 11.3 Temperature Compensation

For best performance the field oriented motor control includes an adaptation algorithm to consider the influence of the actual motor temperature. As the measurement of the motor temperature is dependant on the application the PLUS+1 application software must provide the actual motor temperature to the field oriented control via API variable Motor.ActTemp. If no temperature sensor is available a constant value of 20°C can be connected to Motor.ActTemp. In this case a lower control performed could be experienced.

Plug&Perform: The needed calculations for temperature compensation are already included in the Motor Compliance Blocks and the Open Motor Data Block.

## 11.4 Diagnostics

The motor control system software provides a number of data for diagnostic purposes.



### 11.4.1 Diagnostics of Encoder:

API variable Descriptions:

API Variable	Description
Motor.EncA	Actual state of the hardware input pin of encoder line A High = True
Motor.EncB	Actual state of the hardware input pin of encoder line B High = True

A simple diagnostic of the motor encoder can be done by watching the API variables Motor.EncA and Motor.EncB via Service Tool while turning the motor very slowly. Both variables have to change the status while turning the motor. This gives you only information about the wiring of the encoder.

In case of problems with motor control the quality of the encoder signals should be checked in addition.

### 11.4.2 Diagnostics of Motor Data

If the motor data provided to the API are invalid the variable Motor.Status will show the status in bitwise pattern.

### 11.4.3 Diagnostics of Motor Control

API variable	Description
MotorControl.ActSpeed	Actual motor speed
MotorControl.ActStatFreq	Actual stator frequency
MotorControl.ActSlipFreq	Actual slip frequency
MotorControl.ActTorque	Actual torque set value
MotorControl.ActQCurrent	Actual Q-axis current. This is the current vector to provide torque.
MotorControl.ActDCurrent	Actual D-axis current. This is the current vector to provide magnetization.
MotorControl.ActCurrent	Actual motor current. This is the current you can measure at the motor cable
MotorControl.ActVoltage	Actual motor voltage (line to line). Because the motor voltage is PWM modulated you can only measure it with a low pass filter.
MotorControl.ActTorqueLimit	Actual valid torque limit. This is the minimum of calculated physical maximum torque (based on the current limit), user torque limit and motor torque limit
MotorControl.ActCurrLimit	Actual current limit This is the minimum of hardware current limit, user current limit and motor current limit)
MotorControl.Gen_Mode	Motor operation mode: 0 = motor mode: Speed and torque are in the same direction. Energy flows from inverter to the motor. 1 = generator mode: Speed and torque are in opposite direction. Energy flow from motor to the inverter.

## 12. Controller Area Networks Specifications

### 12.1 CAN (Controller Area Networks) Ports

The PLUS+1 AC Drive inverters have CAN ports conforming to CAN 2.0B. The 2.0B version of CAN meant for 29 bit identifiers. The significance of the 2.0B version is that this is a full CAN, which translates into extensive hardware filtering of incoming IDs (messages). This in turn leads to a lower load of the CPU, thus allowing for more calculation capability left for the user (customer) application itself.

The inverters have double CAN ports for easy wiring. The pins related are as follows:

Port	Pin name	Pin #
1	CAN H	C1p-03
	CAN L	C1p-04
2	CAN H	C1p-06
	CAN L	C1p-07

The C1p-03 and C1p-04 are internally connected in parallel with C1p-06 and C1p-07. See: Figure 7: Double CAN port below:

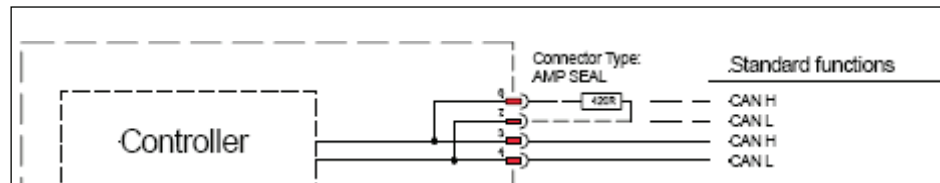


Figure 7: Double CAN port

The double CAN port also gives the opportunity to use daisy-chain or stub wiring of the bus. The advantage of the daisy chaining is that it eliminates connectors in the wiring harness, thus providing higher reliability.

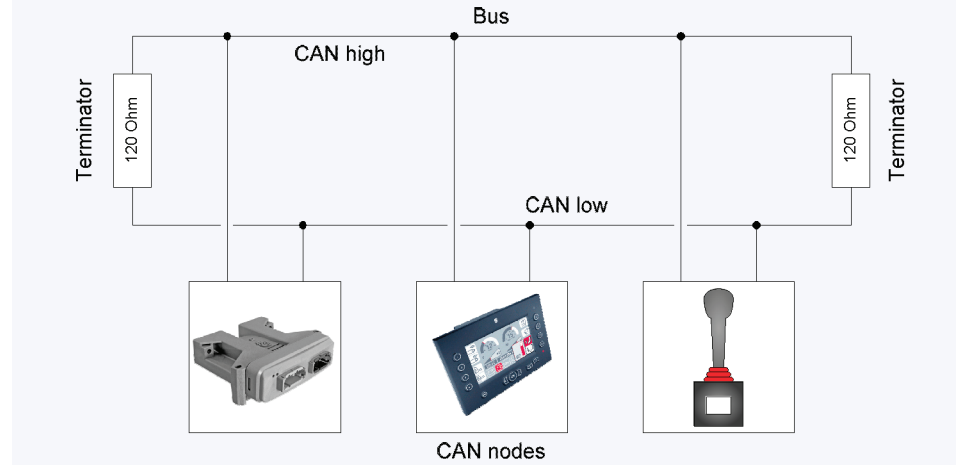


Figure 8: CANbus topology

Be aware of stub length limitations.

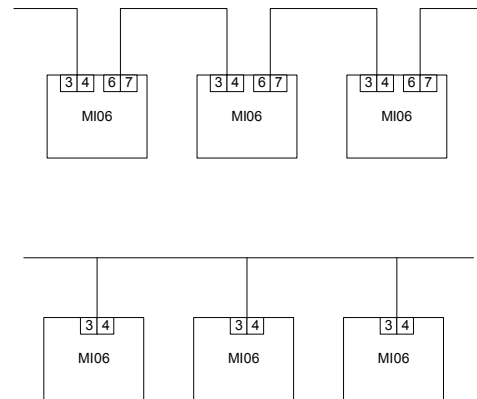


Figure 9 Bus topology

### 12.2 Terminating Resistor

Each end of the CAN bus must be terminated with an appropriate resistance to provide correct termination of the CAN\_H and CAN\_L conductors. The terminating resistor must be kept within the following specification:

Description	Units	Minimum	Maximum	Nominal	Comment
Resistance	ohm	110	130	120	Minimum power dissipation 400 mW

**12.3 Bus stubs (wires from main bus to the unit, also called drop)**

Be aware of the length of the stubs (drops) when used. Max. length @ 1Mbps is 30 cm (see Figure 3). Lower baud rates allow longer stubs.

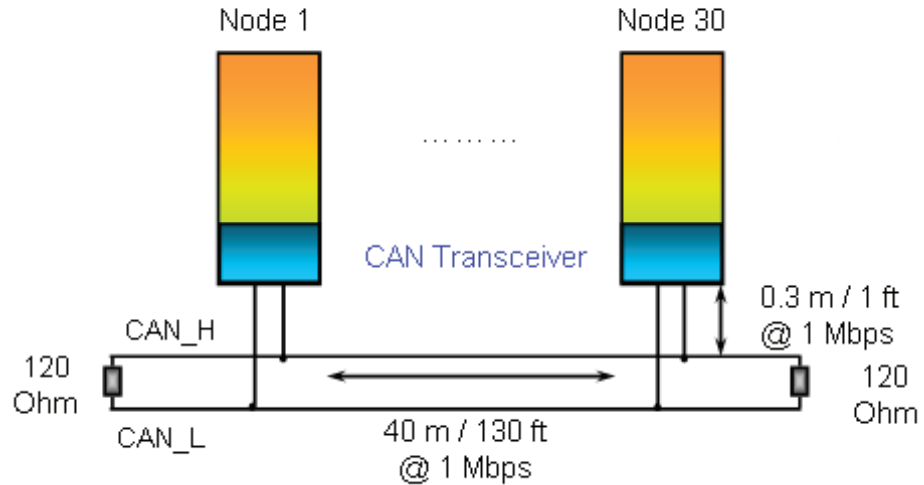


Figure 10: Bus stubs

**Warning:** The programmer of the PLUS+1 application software must consider a proper reaction to a CAN Bus malfunction, dependent on the application requirements.

**12.4 CAN wiring suggestions**

Although the CAN bus is insensitive to electromagnetic interference, it is recommended to use twisted pair with shield. Shield must be connected to ground.

**12.5 CAN protocols**

Different protocols will be available through PLUS+1 GUIDE programming, in the form of function blocks. Contact Sauer-Danfoss for further information.

### 13. Product Ratings

#### Environmental

Switching frequency	8kHz standard; adjustable 4, 12, 16 kHz
Efficiency	Minimum 98% at nominal output
Output frequency	0...300 Hz
Tolerable supply voltage drop	Down to 50% of nominal voltage for max. 50ms.
Ambient temperature range	-40°C–50°C -40°F–122°F
Max. temperature	85°C /185°F
Relative humidity	100%, condensation is allowed
Diagnostics	2 built-in LEDs (red and green)
Signal line connectors	AMP-Seal 35 pins
IP protection	IP64 with membrane
EMC / ESD	EN 12895 / EN61000-6-2 / EN61000-6-3 / EN61000-4-2 / ISO7637;1-3
Safety of industrial trucks – electrical requirements	EN 1175
Vibration, broad-band random, resonance	EN 60068-2-64 / EN 60068-2-28
Shock	EN 60068-2-27
Bump	EN 60068-2-29
Cold	EN 60068-2-1
Heat	EN 60068-2-2
Change of temperature	EN 60068-2-14
Damp heat, cyclic	EN 60068-2-30
UL	UL583 listing pending
Chemical resistance	ISO 16750-5

All PLUS+1 Inverters are CE compliant

### 14. Product Installation and start up

#### 14.1 Mating Connectors

PLUS+1 Inverter use AMPSEAL connectors. Sauer-Danfoss has assembled a mating connector kit, referred to as a bag assembly. Mating connector bag assembly ordering information is found in the product data sheet for each module.

#### AMPSEAL Mating Connector Part Information

Sauer Danfoss Global Part Number	Component
10107896	35 pin AMPSEAL Mating Connector Bag Assembly
10107897	AMPSEAL Connector Crimping Tool 58529-1

#### 14.2 PLUS+1 Inverter Installation Guidelines.

While the PLUS+1 Inverter inverters can be mounted in the vehicle in any position, a careful approach should be adopted when selecting the location in the vehicle for mounting the inverter. In choosing the inverter's position ensure the built in two PLUS+1 Inverter LEDs are visible.

It is recommended that the inverter is assembled to a flat, free of paint surface preferably lightly coated with a thermal transfer compound using the 4 holes provided. It is a requirement for the vehicle mounting surface to be a substantial metal part of the truck for the full PLUS+1 Inverter current ratings to be achieved.

Power connections should be made with flexible heat resisting cables of suitable cross-sectional area allowing the current to be carried. These should be terminated in crimped lugs.

A single pole, single throw contactor (SPST) with silver alloy tips contactor, such as the SW range from Albright International Ltd. is recommended to be fitted:

For currents up to 250A - SW 80

For currents up to 400A - SW 180

For currents above 400A - SW 200

The contactor coil recommended should be specified for "continuous operation".

When alternative manufacturers products are used the coil currents, pull-in and drop-out times should be investigated to ensure compatible operation.

The main battery cable should be fused with a suitable air-break fuse.

Fixing torque for power connectors:

M10 x 1.5 terminals 17 Nm, inverters MI06...MI20

In each case, care must be taken to insure that the PLUS+1 Inverter connector is positioned so that moisture drains away from the inverter. If the inverter is mounted vertically, the connector should be on the bottom. Strain relief for mating connector wires should be provided. The contactor coil recommended should be specified for "continuous operation".

When alternative manufacturers products are used the coil currents, pull-in and drop-out times should be investigated to ensure compatible operation.

The main battery cable should be fused with a suitable air-break fuse.

Fixing torque for power connectors:

M10 x 1.5 terminals 17 Nm, inverters MI 06...MI 20

In each case, care must be taken to insure that the PLUS+1 Inverter connector is positioned so that moisture drains away from the inverter. If the inverter is mounted vertically, the connector should be on the bottom. Strain relief for mating connector wires should be provided.

### 14.3 Recommended Machine Wiring Guidelines

- All wires must be protected from mechanical abuse. Wires should be run in flexible metal or plastic conduits.
  - Use 85° C [185° F] wire with abrasion resistant insulation. 105° C [221° F] wire should be considered near hot surfaces.
  - Use a wire size that is appropriate for the inverter connector.
  - Separate high current wires from sensor and other noise-sensitive input wires.
  - Run wires along the inside of, or close to, metal machine surfaces where possible. This simulates a shield which will minimize the effects of EMI/RFI radiation.
  - Do not run wires near sharp metal corners. Consider running wires through a grommet when rounding a corner.
  - Do not run wires near hot machine members.
  - Provide strain relief for all wires.
  - Avoid running wires near moving or vibrating components.
  - Avoid long, unsupported wire spans.
  - All analog sensors should be powered by the sensor supply from the PLUS+1 AC Drive inverter and ground returned to the power supply pin on the PLUS+1 AC Drive inverter
- 
- Sensor lines should be twisted about one turn every 10 cm (4 in).
  - It is better to use wire harness anchors that will allow wires to float with respect to the machine rather than rigid anchors.

#### Caution

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Damage to the machine control system may occur when welding is being performed on the machine. PLUS+1 AC Drive inverters must be disconnected from the machine wiring harness when welding is being performed on the machine.

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### 14.4 Welding on a Machine Equipped with PLUS+1 Modules

The following procedures are recommended when welding on a machine equipped with PLUS+1 modules:

- The engine should be off.
- Disconnect the negative battery cable from the battery.
- Do not use electrical components to ground the welder. Clamp the ground cable for the welder to the component that will be welded as close a possible to the weld.

#### 14.5 PLUS+1 USB/CAN Gateway

Communication (software uploads and downloads and service and diagnostic tool interaction) between PLUS+1 Inverter and a personal computer (PC) is accomplished using the vehicle's PLUS+1 CAN network.

The PLUS+1 CG150 USB/CAN gateway provides the communication interface between a PC USB port and the vehicle CAN bus. When connected to a PC, the gateway acts as a USB slave. In this configuration, all required electrical power is supplied by the upstream PC host. No other power source is required.

Refer to the PLUS+1 GUIDE Software User Manual 10100824 for gateway set-up information. Refer to the CG150 USB/CAN Gateway Data Sheet 520L0945 for electrical specifications and connector pin details.

#### 14.6 Startup and Recommended Installation Instructions

Working with electric systems can be potentially dangerous. All testing, fault-finding and adjustment should be carried out by competent personnel only. The vehicle's drive wheels should be jacked off the floor and free to rotate during the ensuing procedures. The battery must be disconnected before PLUS+1 Inverters are being replaced or repaired.

Before working on the controls it is recommended to disconnect the battery and connect the B+ and B- inverter terminals via a 10 Ohm, 25 watt resistor to discharge the internal capacitors.

Avoid connecting the controller to a battery with its vent caps removed as due to the inverter's internal capacitance, an arc is likely to occur, when it is first connected. Always wear approved protective equipment.

If the inverter is connected to the battery while charging the voltage must not exceed the specified input voltage of the inverter.





PLUS+1 Inverter Family  
Technical Information  
Notes



## OUR PRODUCTS

Hydrostatic transmissions  
Hydraulic power steering  
Electric power steering  
Electrohydraulic power steering  
Closed and open circuit axial piston pumps and motors  
Gear pumps and motors  
Bent axis motors  
Orbital motors  
Transit mixer drives  
Planetary compact gears  
Proportional valves  
Directional spool valves  
Cartridge valves  
Hydraulic integrated circuits  
Hydrostatic transaxles  
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Electric motors and inverters  
Joysticks and control handles  
Displays  
Sensors

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