SCHWARZMÜLLER
INVERTER

MEMBER OF THE SAUER-DANFOSS GROUP

PLUS+1™ Inverter Family

User Manual 70200001

PLUS+1™ Inverter Family
User Manual
Revisions

Version History

Table of Versions

Date	Page	Description	Version
14.09.2010	All	First edition	1.0
18.10.2011	54	Document CAN Bus wiring hints mentioned	1.1
06.02.2012	26	recommendation fuse added	1.2
16.04.2012	All	MI03-X1 and MI08 added	1.3

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Contents

1. Introduction – About this Manual

1.1. PLUS+1 INVERTER FAMILY TECHNICAL INFORMATION

This manual is designed to be a comprehensive PLUS+1™ inverter family reference tool for vehicle OEM design, engineering and service personnel. It is one of five primary sources of the PLUS+1 Inverter product technical information.
The other four sources are:

- Individual PLUS+1 Inverter product data sheets
- The PLUS+1 Graphical User Interface Development Environment (GUIDE) Software User Manual
- The application interface document
- The PLUS+1 library

1.2. WHAT INFORMATION IS IN THIS MANUAL

This manual describes electrical details that are common to all PLUS+1 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 SHEET

Parameters and engineering data that are unique to an individual PLUS+1 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 capability
- Power supply current consumption
- Inverter installation drawings
- Inverter 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

1.5. WHAT INFORMATION IS IN THE API

Detailed information for the Parameter interface between the internal Inverter control Software and the PLUS+1 Application Software created in PLUS+1 GUIDE.
The Application Layer Interface (API) document contains the following information:

- Variable Name with short description
- Variable Type
- Variable Function & Scaling

1.6. PLUS+1 LIBRARY

Sauer-Danfoss provides a library of defined Software function and applications that can be used in PLUS+ 1 products. This library contains Compliance Blocks for PLUS+1 products and Function Blocks for defined functions that can be used to create an individual application Software in PLUS+1 GUIDE. Additionally fully approved application software for standard applications is available and will be continuously enlarged.

The PLUS+1 Library is part of the PLUS+1 GUIDE software tool and also available on the website: www. sauer-danfoss-plus1.com

Additional, secondary information such as: Tech Notes and other application notes are also available on website. PLUS+1 Inverter product literature is on line at: www.schwarzmueller-inverter.com

2.1. PLUS+1 INVERTER FAMILY

PLUS+1 Inverter MI03

PLUS+1 Inverter MI04

PLUS+1 Inverter MI06

PLUS+1 Inverter MI08

PLUS+1 Inverter MI20

2.2. INVERTER TYPICAL APPLICATIONS

PLUS+1 Inverters is 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 Inverter input/output to be different than the input/output specifications common to other PLUS+1 devices. Typical applications of PLUS+1 Inverters 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 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

2.3. PLUS+1 INVERTERS FIT WITH OTHER PLUS+1 PRODUCTS

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

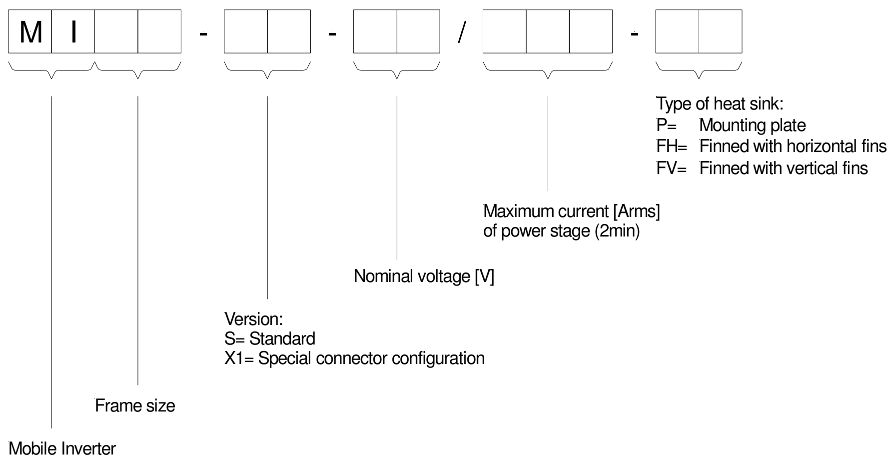
The PLUS+1 products provide flexible, expandable, powerful and cost effective total machine management systems. Current users of PLUS+1 should note that the PLUS+1 Inverters inputs and outputs are defined differently from the PLUS+1 microcontrollers.

These devices communicate with each other 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 added easily to the machine CAN bus to increase system capabilities or computational power.

3.1. PLUS+1 INVERTER NAMING CONVENTION

PLUS+1 Inverter Master Model Code

Example: MI 06-S-48/400-P



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. Schwarzmüller Inverter has no responsibility for any consequences, direct or indirect, caused by failures or malfunctions.

- Schwarzmüller Inverter has no responsibility for any accidents caused by incorrectly mounted or maintained equipment.

- Schwarzmüller Inverter 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 100Ws 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. RATINGS

The PLUS+1 Inverter Family is designed to operate with a nominal voltage supply of 24V, 36V, 48V and 80V. The inverter will operate with full functionality if the supply voltage is in the voltage range specified for each of the types.

5.2. POWER DATA

Type: MIxx-		S-24 / 240-	S-24 / 300-	S-24 / 400-	S-24 / 550-
Size		MI03	MI04	MI06	MI08
Nominal voltage	[VDC]	24			
Input voltage range	[VDC]	16…36			
Nominal current	[3~ Arms][1)]	120	150	200	275
Maximum current	[3~ Arms][2)]	240	300	400	550
Boost current	[3~ Arms][3)]	260	330	420	600
Output voltage	[3~ Vrms][4)]	3 x 0…16			
Dimensions	W [mm]	140	140	140	150
	H [mm]	200	200	200	225
	D [mm][5)]	90/110	91/111	98/118	100/120
Weight	[kg] [5)]	2,5/2,7	2,8/3,0	3,5/3,7	4,0/4,1
Power connectors		M6	M8	M10	M10

Type: MIxx-		S-48 / 180-	S-48 / 300-	S-48 / 400-	S-48 / 550-
Size		MI03	MI04	MI06	MI08
Nominal voltage	[VDC]	36 – 48			
Input voltage range	[VDC]	18…62			
Nominal current	[3~ Arms][1)]	100	150	200	275
Maximum current	[3~ Arms][2)]	180	300	400	550
Boost current	[3~ Arms][3)]	200	330	420	600
Output voltage	[3~ Vrms][4)]	3 x 0…24 or 3 x 0…32			
Dimensions	W [mm]	140	140	140	150
	H [mm]	200	200	200	225
	D [mm][5)]	90/110	91/111	98/118	100/120
Weight [kg] [5)]		2,5/2,7	2,8/3,0	3,5/3,7	4,0/4,1
Power connectors		M6	M8	M10	M10

Type: MIxx-		X1-80 / 80	S-80 / 300-	S-80 / 400-	S-80 / 650-
Size		MI03	MI08	MI08	MI20
Nominal voltage	[VDC]	80			
Input voltage range	[VDC]	40…105			
Nominal current	[3~ Arms][1)]	40	150	200	325
Maximum current	[3~ Arms][2)]	80	300	400	650
Boost current	[3~ Arms][3)]	90	330	440	715
Output voltage	[3~ Vrms][4)]	3 x 0…53			
Dimensions	W [mm]	140	150		280
	H [mm]	200	225		280
	D [mm][5)]	90/110	110/120		101/143
Weight	[kg]	2,4/2,5	4,0/4,1		9/10,5
Power connectors		M6	M10		

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

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. DC/DC converter) within the specified voltage range.

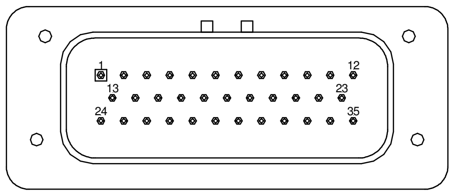
The Application Control section of each PLUS+1 Inverter hardware device (MIxx) has interface pins that support multiple functions as well as pins that support fixed functions. Pins that support multiple input or output functions are user-configurable via the API variable *(.PinConfig)* using PLUS+1 GUIDE software. Refer to product data sheets for the input/output (I/O) content of individual devices.

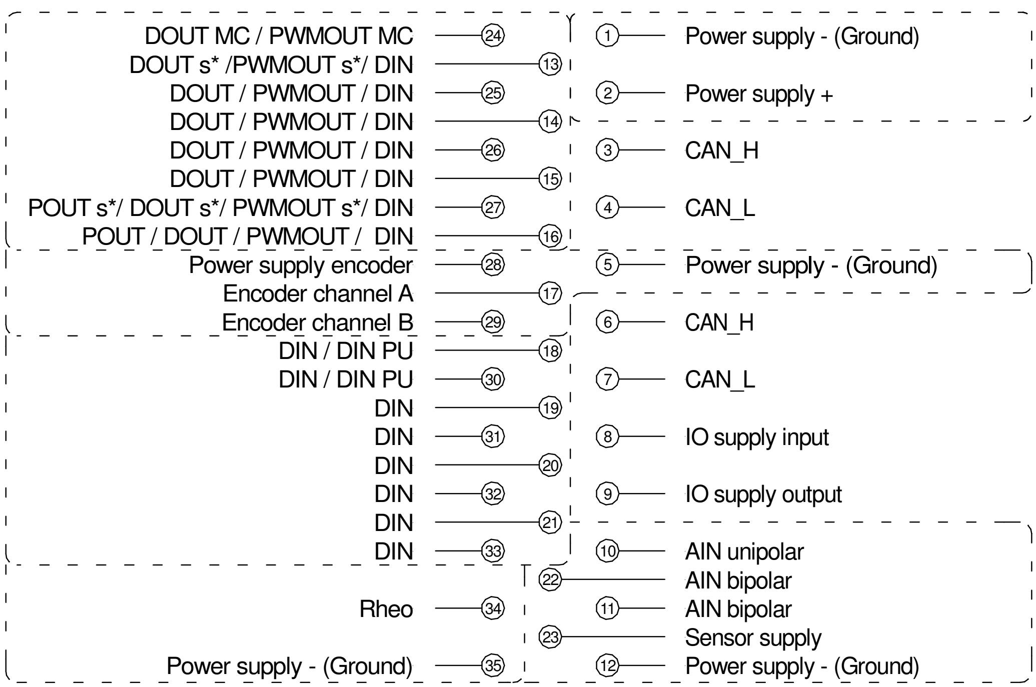
This portion of the technical information manual provides specifications for each PLUS+1 Inverter I/O type.

AMPSEAL 35 Pin Connector

All versions MIxx-S-	Version MIxx-X1-	Pin
Power supply – (Ground)		C1p01
Power supply +		C1p02
CAN High		C1p03
CAN Low		C1p04
Power supply – (Ground)		C1p05
CAN High		C1p06
CAN Low		C1p07
I / O supply input		C1p08
I / O supply output		C1p09
AIN unipolar		C1p10
AIN bipolar		C1p11
Power supply – (Ground)		C1p12
DOUT safety / PWMOUT safety / DIN	not available	C1p13
DOUT / PWMOUT / DIN	not available	C1p14
DOUT / PWMOUT / DIN	not available	C1p15
POUT / DOUT / PWMOUT / DIN	not available	C1p16
Encoder channel A		C1p17
DIN / DIN PU		C1p18
DIN		C1p19
DIN		C1p20
DIN		C1p21
AIN bipolar		C1p22
Sensor supply		C1p23
DOUT MC / PWMOUT MC		C1p24
DOUT / PWMOUT / DIN		C1p25
DOUT / PWMOUT / DIN	not available	C1p26
POUT safety / DOUT safety / PWMOUT safety / DIN		C1p27
Encoder supply		C1p28
Encoder channel B		C1p29
DIN / DIN PU		C1p30
DIN		C1p31
DIN		C1p32
DIN		C1p33
Rheo		C1p34
Power supply – (Ground)		C1p35

6.1. Input / Output Types (continued)





s* = safety

Warnings

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

6.1. Input / Output Types (continued)

The following table lists MIxx input and output types and typical usage:

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, minilever,…
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	Digital output with the same properties as DOUT but using 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 properties as DOUT, but with a free wheeling diode to main power supply (C1-P2)	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).
PWMOUT MC	Same properties as DOUT MC, but in PWM mode (similar to 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 properties as DOUT, but with additional safety transistor	Driver for safety critical on/off component, like electromagnetic brake or lowering valve
PWMOUT safety	Same properties as PWMOUT, but with additional safety transistor	Driver for safety critical on/off component, like electromagnetic brake or lowering valve in PWM mode
POUT safety	Same properties as POUT, but with additional safety transistor	Driver for safety critical proportional valve

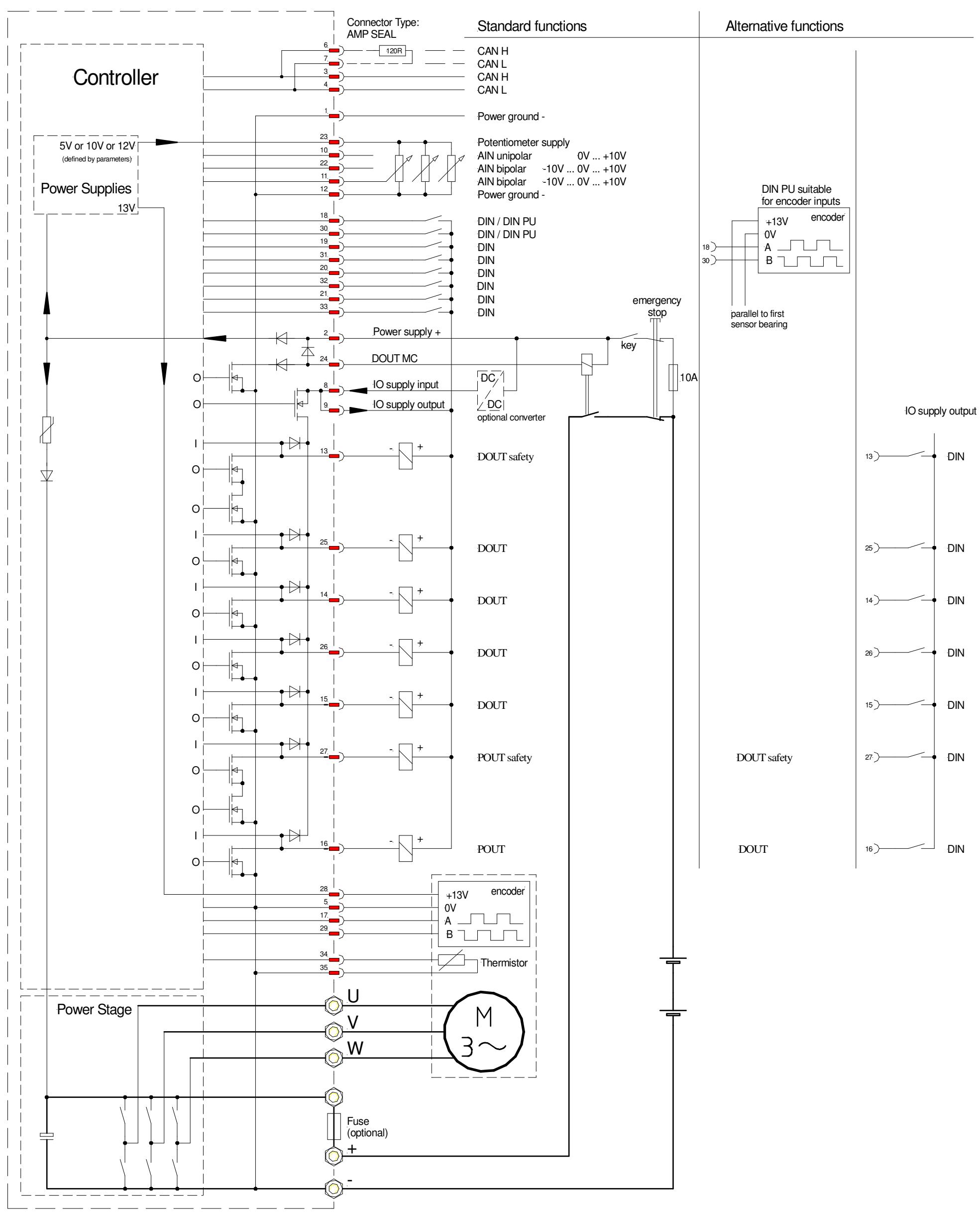
6.1. Input / Output Types (continued)

The following ratings apply to all input and output types:

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MIxx-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 PRINCIPLE

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 external components (such as relays, valves, vehicle brake, switches). The external I/O component 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: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
IO supply input	Power supply input for IOs		
Maximum current [ADC]	8.0		
Voltage range			
Max. input voltage [VDC]	36	62	105
Min. input voltage [VDC]	12		
IO supply output	Power supply output for I/Os		
Maximum current [ADC]	8.0		
Output voltage	I/O supply input		

Warnings

All output channels contain free-wheeling diodes to make wiring as easy as possible. Therefore

- it is mandatory that the positive poles of all loads are connected to Pin9 of connector 1.
- be aware that any voltage to the outputs that is higher than the voltage at pin 9 will destroy the free-wheeling diodes.
- connect Pin8 with the source that has to supply the connected components

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: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
DIN	Digital input with pull down		
Logic	High-active		
Input resistance [Ω]	18 k	18 k	47 k
Low-level max. [V]	3.75		
High-level min. [V]	9.0		

6.4. Inputs (continued)

6.4.2. Multi Function Input (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 input 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: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
DIN PU	Digital input with pull up resistor to +15V		
Logic	low-active		
Input resistance to+15V [Ω]	1.1 k		
Low-level max. [V]	3.75		
High-level min. [V]	9.0		
Maximum 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: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
AIN unipolar	Analog input unipolar		
Resolution	12 bit		
Input resistance [Ω]	120 k		
Voltage range [V]	0…10		
Recommended resistance range of external Potentiometer [Ω]	1k …10 k		

6.4. Inputs (continued)

6.4.4. Analog Inputs with Bipolar Range (AIN bipolar)

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

Nominal Voltage [V]	**24**	**36 - 48**	**72 - 80**
Inverter Type: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
AIN bipolar	Analog input bipolar		
Resolution	12 bit		
Input resistance [Ω]	120 k		
Voltage range [V]	-10…10		
Recommended resistance range of external potentiometer [Ω]	1k ….10 k		

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 sensor 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 range" 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 to 2000ms. The filter can be bypassed by setting the filter time constant to 0

Nominal Voltage [V]	**24**	**36 - 48**	**72 - 80**
Inverter Type: MIxx-	**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		

6.4. Inputs (continued)

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 to 1024 pulses per revolution can be used.

Warnings

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: MIxx-	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)	50		
Low-level (max.) [V]	1.77		
High-level (min.) [V]	7.1		

6.5. INPUTS / OUTPUTS

Warnings

Single outputs can sink up to 3 Amps. However, the total output current for the application control section of the device 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.

The purpose of the PWMOUT mode is simple voltage control. For closed loop current control use the POUT mode on an appropriate pin.

6.5. Inputs / Outputs (continued)

6.5.1. General Purpose Inputs / Outputs (DOUT/PWMOUT/DIN) (continued)

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.

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.

Nominal Voltage [V]	**24**	**36 - 48**	**72 - 80**
Inverter Type: MIxx-	**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 condition **(DOUT)**	Reactions time minimum 1ms, dependent on application SW loop time.		
Signal condition **(PWMOUT)**	Programmable PWM signal from 0% to 100% with 10% steps. PWM frequency = 100Hz.		
Nominal current [A]	2.0		
Maximum current [A] (for min. 1 second before overload protection activated)	3.0		
Over load protection	Non-damage, current / thermal limit, status indication at ON state, automatic latch off/resume		
Resistance to minus power supply in OFF state [Ω]	136 k		
Max. load resistance [Ω] @ 12V I/O-supply voltage (A higher resistance works, but will be detected as "output disconnected")	45 k	266 k	468 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 : $R_{max} = (\frac{Vio}{9V} - 1) * 136k\Omega$ With Vio= I/O-supply voltage		
Max. resistance, ON state R_{DSon} @25°C [Ω]	0.2	0.2	0.25

6.5. Inputs / Outputs (continued)

6.5.2. General Purpose Proportional Inputs/Outputs (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 varies 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. The dither amplitude will be limited to the actual current set-value dynamically.

Nominal Voltage [V]	**24**	**36 - 48**	**72 - 80**
Inverter Type: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
POUT	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]	0,04…2,0		
Dither signal frequency / amplitude	62,5 Hz / 0… 0,25 A		
Repeat accuracy from unit to unit	< ± 10mA (for set values 0 to 330mA) < ± 3% (for set values 330mA to 2A)		
Switching frequency [Hz]	500… 2000		
Over load protection	Non-damage, current / thermal limit, automatic latch off/resume		
Resistance to minus power supply in OFF state [Ω]	136 k		
Max. load resistance [Ω] @ 12V I/O-supply voltage (A higher resistance works, but will be detected as "output disconnected")	45 k	266 k	468 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 : $R_{max} = (\frac{Vio}{9V} - 1) * 136k\Omega$ With Vio= I/O-supply voltage		
Max. resistance, ON state R_{DSon} @25°C [Ω]	0.2	0.2	0.25

6.5. Inputs / Outputs (continued)

6.5.3. Main Contactor Output (DOUT MC/PWMOUT MC)

The main contactor output is a special output pin designed to drive the vehicle's main contactor. 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 contactor 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 contactor this circuit provides the reverse polarity protection for the inverter, because the main contactor can only switch the battery to the power stage if the polarity is correct.

The main contactor 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.

The PWMOUT mode is intended to be used only for simple voltage control.
The main contactor output may be locked (*C1p24.locked*=1) if a failure was detected at the DC-Link test at power up.

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

Nominal Voltage [V]	**24**	**36 - 48**	**72 - 80**
Inverter Type: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
DOUT MC / PWMOUT MC	Digital output for main contactor		
Internal structure	Low-side-switch with free wheeling diode		
Cathode of free wheeling diode connected to	Power supply +		
Signal condition **(DOUT MC)**	Reactions time minimum 1ms, dependent on application SW loop time.		
Signal condition **(PWMOUT MC)**	Programmable PWM signal from 0% to 100% with 10% steps. PWM frequency = 100Hz.		
Nominal current [A]	2.0		
Maximum current [A] 6)	3.0		
Over load protection	Non-damage, current / thermal limit, status indication at ON state , automatic latch off/resume		
Resistance to minus power supply in OFF state [Ω]	136 k		
Max. load resistance [Ω] @ 12V I/O-supply voltage (A higher resistance works, but will be detected as "output disconnected")	45 k	266 k	468 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 : $R_{max} = (\frac{Vio}{9V} -1) * 136k\Omega$ With Vio= I/O-supply voltage		
Max. resistance, ON state R_{DSon} @25°C [Ω]	0.2	0.2	0.25

Damage to the application control section of the inverter may occur. If voltage is applied to the main contactor output the application control section of the inverter will be powered up. If significant current is driven through the main contactor output, the module will be demaged.

6.5. Inputs / Outputs (continued)

6.5.4. Output 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 is checked by system software. If a transistor is damaged and can’t switch off anymore the second transistor takes over the full functionality of the output and the API variable .SafetyStatus shows a “Safety Error”. Afterwards the output will work like a standard output.

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

The technical specification is identical to standard outputs of the type DOUT, PWMOUT and POUT.

Nominal Voltage [V]	**24**	**36 - 48**	**72 - 80**
Inverter Type: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
DOUT safety / PWMOUT safety	Digital output for safety relevant components e.g. magnetic brake.		
Internal structure	Low-side-switch with (additional safety switch in series and) free wheeling diode		
Cathode of free wheeling diode connected to	I/O supply output		
Signal condition **(DOUT safety)**	Reaction time minimum 1ms, dependent on application SW loop time		
Signal condition **(PWMOUT safety)**	Programmable PWM signal from 0% to 100% with 10% steps. PWM frequency = 100Hz		
Nominal current [A]	2.0		
Maximum current [A] (for min. 1 second before overload protection activated)	3.0		
Resistance to minus power supply in OFF state [Ω]	136 k		
Max. load resistance [Ω] @ 12V I/O-supply voltage (A higher resistance works, but will be detected as “output disconnected”)	45 k	266 k	468 k

6.5. Inputs / Outputs (continued)

6.5.4. Output with Enhanced Safety (DOUT safety/PWMOUT safety/POUT safety) (continued)

Nominal Voltage [V]	24	36 - 48	72 - 80
Inverter Type: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
POUT safety	Current controlled output for safety relevant components e.g. lower valve – superposed with dither signal		
Internal structure	Low-side-switch with additional safety switch in series and free wheeling diode		
Cathode of free wheeling diode connected to	I/O supply output		
Current range [A]	0…2.0		
Dither signal frequency / amplitude	62,5Hz / 0…0,25 A		
Repeat accuracy	< ± 10mA (for set values 0 to 330mA) < ± 3% (for set values 330mA to 2A)		
Switching frequency [Hz]	500…2000		
Resistance to minus power supply in OFF state [Ω]	136 k		
Max. load resistance [Ω] (A higher resistance works, but will be detected as "output disconnected")	45 k	266 k	468 k

7.1. CONTROL POWER SUPPLY

The main power supply for the application control circuits has to be provided at pin C1p02 (power supply +) and C1p01 (power supply -). The pre-charge circuit for the power stage capacitors which is supplied by the same pin causes an inrush current significantly higher than the nominal supply current.

Nominal Voltage [V]	24	36 - 48	72 – 80
Inverter Type: MIxx-	**24/xxx**	**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 (<100ms) [A]	24	10	12
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 (X1 version: 10V fixed). Typically this power supply is used for throttles, foot pedals or mini-levers. A feedback value *C1p23.Volt* is available to factor the actual voltage into the calculation of the set value out of the sensor signal. A voltage higher than 15V will be reported as 15V (*C1p23.Volt*=15000) and the status "feedback value out of range" will be reported (*C1p23.PinStatus*=1)

If the output value of a sensor depends proportionally on its supply voltage (potentiometer) then it is highly recommended to use the feedback value *C1p23.Volt* to monitor the actual voltage and to react in application software if the voltage drops due to a short circuit or overload.

Nominal Voltage [V]	24	36 - 48	72 – 80
Inverter Type: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
Sensor supply	Power supply for external sensors		
Output voltage [VDC]	S-versions: 5 / 10 / 12 programmable X1 version: 10		
Tolerance [%]	5		
Max. output current [A]	0.1		
Over current, short circuit	Current limitation at 0,1A		

7.2. Auxiliary Power Supplies (continued)

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. A current higher than 100mA will be reported as 100mA (*C1p28.FeedbackValue*=1000) and the status "value out of range" will be reported (*C1p28.PinStatus=1*).

Nominal Voltage [V]	**24**	**36 - 48**	**72 - 80**
Inverter Type: MIxx-	**24/xxx**	**48/xxx**	**80/xxx**
Encoder supply	Power supply for encoder (e.g. sensor bearing)		
Supply voltage [VDC]	13V ± 10%, Ri = 30 Ω		
Over current, short circuit	Current limitation at 0,1A		

7.3. POWER STAGE SUPPLY

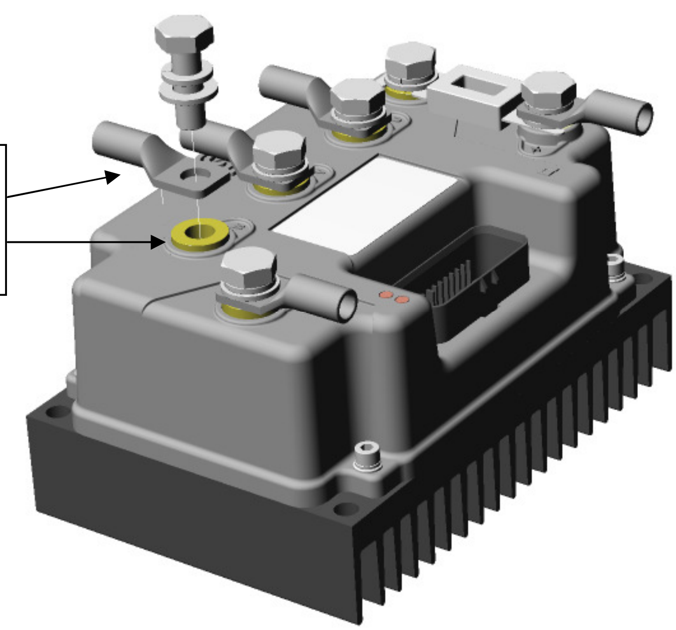
The power stage supply is connected using screws, labeled "+" and "-". For each inverter a fuse shall be installed, whenever possible near the energy source (battery). An additional screw also allows the assembly of a power fuse on top of the inverter housing.

The inverter is equipped with steel screw assemblies. Don't use additional washers. Make sure that the cable shoes lay directly on the brass sleeves of the inverter.

Details for Power Stage wiring see: 14.2.2.

Warnings

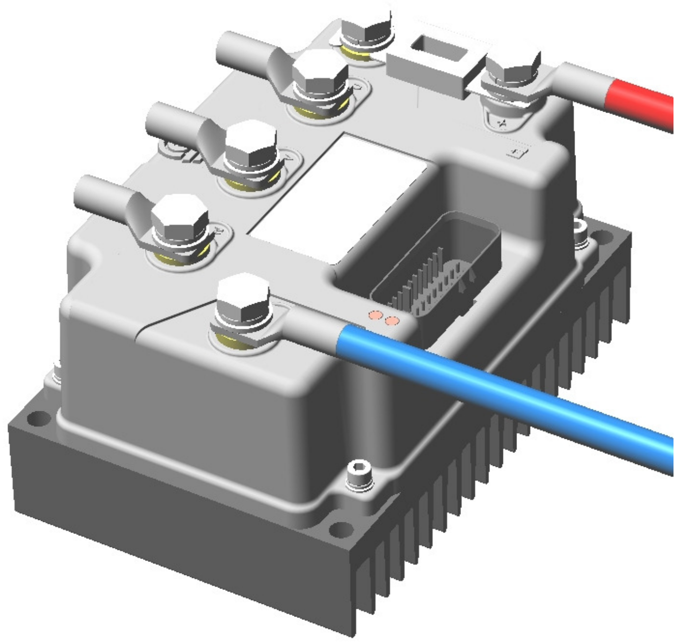
As the currents can be in the range of some hundred Amps, a proper electric contact between brass sleeves and cable shoes is essential to avoid hot spots.



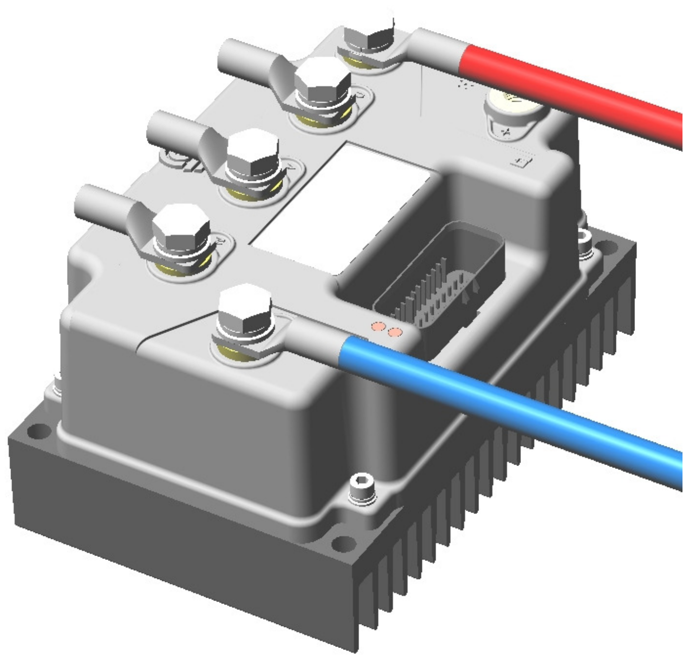
Make sure that the cable shoe directly lies on the brass sleeve.

7.3. Power Stage Supply (continued)

Connection with a fuse



Connection without a fuse

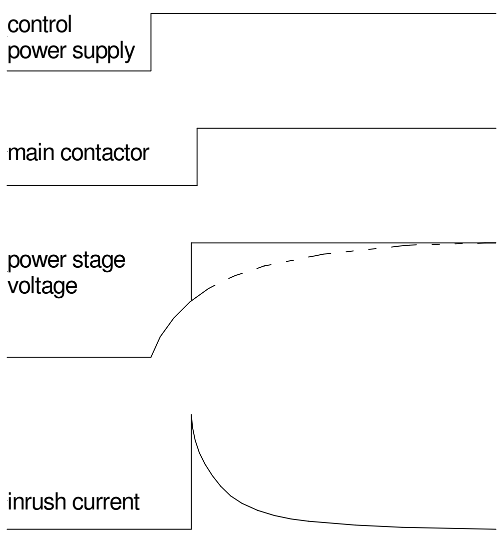


7.3. Power Stage Supply (continued)

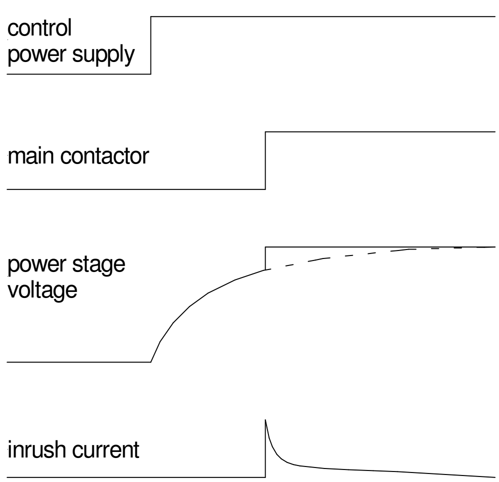
7.3.1. Pre-charging of capacitors

The power stage capacitors are pre charged by the control power supply (C1p02) via a positive thermal coefficient (PTC) resistor. The inrush current of the power stage supply is dependent on the voltage level of the power stage capacitors at the time of connecting voltage to the power stage. The time between switching control power supply and power stage supply is responsible for the peak value of the inrush current. In practice a compromise between start-up time and inrush current has to be found. The easiest way is to switch on the main switch immediately after the start of the application software. The PLUS+1 Inverter function block library provides a function block “main contactor” which allows a controlled switching of the main contactor at a defined voltage level.

Short delay for main contactor:



Longer delay for main contactor:



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:

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

The API variable *Selftest* 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 fails with an error the power stage will be locked permanently.

If an over voltage 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 over voltage protection"

8.1.1. EEPROM CRC Check

First 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 is stored

If the CRC check fails for the production data area, an error will be reported (*Selftest.Error* Bit7=1) since wrong data may lead to incorrect behavior. The self test routine will be skipped and the power stage and the main contactor output will be locked.

If the CRC check fails for the user data area only, a warning will be reported. Appropriated response to this failure 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 device is functional but error history data might be corrupted.

8.1. Self Test at Power Up (continued)

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 contactor gets closed, the capacitor bank is pre-charged via a resistor, powered by the power supply voltage (C1p02).

Test algorithm:

- Wait until V_DC_Link > Threshold voltage (1.6V – 3.5V)
- The test is OK as soon as this condition is fulfilled.
- If this condition is not fulfilled before 5s after power-on, the test failed. ->
  - *Selftest.Error Bit0=1 (Error Link Circuit)*
  - The main contactor 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 with the power cables disconnected shows no error, there is either a short circuit in the wiring of the power cables + and – or the load in that circuit is too high and pulls down the DC-Link voltage.

If the error still occurs with the disconnected power cables, there is a failure in the inverter power stage and the device must be replaced.

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, the hardware watchdog 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:

PLUS+1 Inverters are designed and produced to 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 functionality of the inverter is limited to the DSP watchdog. If this is the only error, the inverter is still functional.
Appropriated actions should be incorporated in the PLUS+1 Application Software dependent on the safety requirements of the application.

8.1. Self Test at Power Up (continued)

8.1.3. Hardware Watchdog (continued)

- *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.

Nominal Voltage [V]	**24**	**36 - 48**	**72 - 80**
Inverter Type: MIxx-	**24/xxx**	**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 is not functional. Further self tests are discontinued.

8.1.4. Power Stage Test

The power stage test will be performed as soon the DC-Link voltage reaches 90% of the power supply voltage (C1p02). The application software has already started and can close the main contactor 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 contactor.
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 (will not switch on).
  This fault can only be detected if a motor is correctly connected.
- 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)

Errors:

Error message	**Meaning**	**Recommended recovery action**	**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.

Based on some physical limitations it's not possible to detect every short circuit! Dependent on the length of the cable, cable wire size and cable routing, a short circuit at the end of a cable can exhibit the same electrical behavior as a connected 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 reported via the API to the application software which must be programmed to take the necessary response.
The system software reacts only to those errors which would destroy the power stage hardware.

- Over voltage
- Over current
- Over temperature 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: Over temperature*
  - *Bit2 = 1: Sensor error*
  - *Bit3 = 1: Over voltage*
  - *Bit4 = 1: Over current*
- 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 over the lifetime of the inverter

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Writing a 1-0 sequence to *PowerStage.Enable* will clear the errors which are no longer present.

8.2.1.1. Over Voltage

The DC_Link voltage is compared to the maximum allowed value using a hardware comparator. 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.AbsOVErrors*
  - Write error history memory

The actual DC_Link voltage is also displayed at *V_DC_Link.Volt*

8.2. Runtime Protection Functions (continued)

8.2.1.2. Over Current

In normal operation the current is limited by the software 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 50 µs and a signal is sent to the DSP.
This signal triggers a software integrator. If the integrator exceeds a limit (over current 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. Over Temperature

The temperature of the power stage (=the transistors) 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 to 170°C. If the actual value exceeds the temperature limit
(stored as production data in EEPROM) an over temperature 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

In addition to that the inverter types MI03 and MI04 have a second internal measurement which monitors the temperature of the power pcb. Usually the board temperature is below the temperature of the transistors, so the previously mentioned over temperature protection switches off in case of a long overload duration.
In some special cases (very effective forced cooling) it can happen, that the pcb temperature *PowerStage.PCBTemp* can reach critical values long before the temperature near the transistors is too high. In such a case a current derating will take place, starting at 115°C with 100%, ending at 135°C with 0% of the hardware current limit. This derating phase will be indicated at

- *MotorControl.Status* Bit12 = 1

The very unlikely case of pcb temperature > 135°C will be indicated at

- PowerStage.Status Bit10 = 1

8.2.1.4. Temperature Sensor Error

If the result of the power stage temperature calculation or the pcb temperature calculation is out of the sensor range of -60°C to +170°C a temperature sensor error occurs:

- If Unprotected mode is inactive: disable the power stage:
  PowerStage.EnableStatus=0
- Display the error: *PowerStage.Status* Bit2=1 for power stage
  PowerStage.Status Bit11=1 for pcb
- Increase error counter: *ErrorHistory.AbsTSensErrors* for power stage
  ErrorHistory.AbsPCBTSensErrors for pcb
- Write error history memory

8.2. Runtime Protection Functions (continued)

With the help of Unprotected mode (see 8.2.2.) a "limp home mode" can be programmed in GUIDE to allow limited operation in the event of a temperature sensor error.

8.2.2. Unprotected Mode

The unprotected mode allows the power stage to be enabled even if a temperature sensor error would lock it. The unprotected mode is activated when *PowerStage.Unprotected* is changed from 0 to 1. To avoid an unintended usage of the unprotected mode, the APL resets the unprotected mode after 60 seconds. Within these 60 seconds the unprotected mode can be inactivated by *PowerStage.Unprotected*=0 but not retriggered.
In order to recognize the usage of unprotected mode when the machine is serviced, usage of unprotected mode is stored in error history memory.

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 at power stage)
  - *PowerStage.Status Bit3=0* (no Overvoltage)
  - *PowerStage.Status Bit4=0* (no Overcurrent)
  - *PowerStage.Status Bit10=0* (no Overtemperature at PCB)
  - *PowerStage.Locked=0*

  or

  - *PowerStage.Status Bit2=1* (Power stage temperature sensor error)
  - *or*
  - *PowerStage.Status Bit11=1* (PCB temperature sensor error)
  - *and*
  - *PowerStage.Unprotected=1* (Unprotected 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* (Power stage overtemperature Power stage)
  - *PowerStage.Status Bit2* (temperature sensor error Overvoltage)
  - *PowerStage.Status Bit3*
  - *PowerStage.Status Bit4* (Overcurrent)
  - *PowerStage.Status Bit10* (PCB overtemperature)
  - *PowerStage.Status Bit11* (PCB temperature sensor error)

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*
Because a center-aligned modulation method is used which provides the double PWM frequency to the motor in most of the applications 8 kHz provides a silent behavior.

However, if the motor noise is too high, the PWM frequency can be increased.
A higher PWM frequency 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 a number of 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 *Seltest.Error* or *PowerStage.Status*
PowerStage.Status	Bit0 0 = OK 1 = wrong value at PWMFreq Bit1 0 = OK 1 = Overtemperature Bit2 0 = OK 1 = Temperature sensor error Bit3 0 = OK 1 = Overvoltage Bit4 0 = OK 1 = Overcurrent Bit5 0 = Unprotected Mode inactive 1 = Unprotected Mode active Bit6 0 = OK 1 = Power Stage permanently locked because of wrong motor data Bit7 0 = OK 1 = Power Stage permanently locked because of HW watchdog error Bit8 0 = OK 1 = Power Stage permanently locked because of current sensor error Bit9 0 = OK 1 = Power Stage permanently locked because of undervoltage Bit10 0 = OK 1 = PCB overtemperature Bit11 0 = OK 1 = PCB temperature sensor error

10.1. ERROR HISTORY

PLUS+1 Inverters provide an Error History Memory which tracks all power stage protection errors and self test errors as integral function of the system software. The application software might 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 *HourCounter.Inverter* 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 = Temperature sensor error
5 = Unprotected 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
14 = current sensor error
15 = Undervoltage
16 = PCB over temperature
17 = PCB temperature sensor error

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 while lifetime of the inverter.
- *ErrorHistory.AbsOVErrors*: Shows absolute number of detected over voltage errors while lifetime of the inverter.
- *ErrorHistory.AbsOCErrors*: Shows absolute number of detected over current errors while lifetime of the inverter.
- *ErrorHistory.AbsTSensErrors:* Shows absolute number of detected temperature sensor errors while lifetime of the inverter.
- *ErrorHistory.AbsPCBOTErrors:* Shows absolute number of detected PCB overtemperature errors while lifetime of the inverter.
- *ErrorHistory.AbsPCBTSensErrors:* Shows absolute number of detected PCB temperature sensor errors while lifetime of the inverter.

10.1. Error History (continued)

The listing of errors in the Error History Memory is managed in the following sequence.

- If the current error is the same as 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 current error is different from 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: Errors during live time

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
Unprotected Mode	3300
Unprotected Mode	3310
Unprotected 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 (Unprotected 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

10.1. Error History (continued)

ErrorHistory.AbsOTErrors:	3
ErrorHistory.AbsOVErrors:	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	Hourcounter [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 info 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 properly.
DeviceInfo.MinVolt	Minimal specified voltage [mV] where the unit will work properly.
DeviceInfo.MaxVolt	Maximal specified voltage [mV] where the unit will work properly.
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. NVRAM 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.

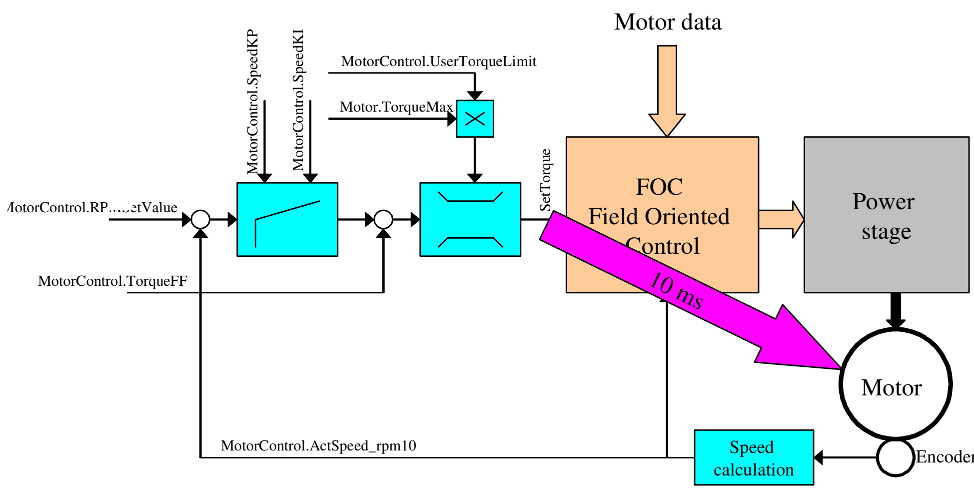
At power up the data will be restored to the NVRam area before the application software starts.

11. Motor Control

PLUS+1 Inverters control three phase AC-induction motors using a field oriented motor control algorithm. This technology combined with predefined motor data, provided by PLUS+1 Motor Compliance Blocks, guarantees optimum motor control performance.
PLUS+1 Motor Compliance Blocks eliminate the need for detailed knowledge about AC motors and field oriented control for successful installation and set-up of the application. Basic knowledge about AC induction motors is helpful, however, for error diagnostics.
PLUS+1 Motor Compliance Blocks for specific motors can be supported by Schwarzmüller Inverter motor characterization.
A motor data setup for Individual motors can be configured based on IEEE standard values. (see Section: 11.2 Motor Definition)

11.1. CONTROL STRUCTURE

11.1.1. Field Oriented Motor Control



The main part of the MIxx motor control strategy is the field oriented motor control. This control requires a set of motor data. If the motor data are well defined (for Schwarzmüller Inverter tested motors the data are available in PLUS+1 Compliance blocks), the torque at the motor shaft follows the torque set value with a maximum delay of 10ms. This allows optimization of the vehicle drive system to be independent of the motor torque control and no further tuning of motor data is required to optimize vehicle performance. Only the speed controller has to be adapted to the application.

11.1. Control Structure (continued)

11.1.2. Speed Controller

The speed controller has a PI-configuration with anti-windup. The output of the speed controller is the torque set value. The proportional gain *MotorControl.SpeedKP* is expressed in Nm/rpm (amount of torque the motor has to provide per rpm deviation from set-point).
The integral gain *MotorControl.SpeedKI* is expressed in Nm/rpm/s. (amount the torque set value should increase in one second per rpm deviation). These control parameters can be optimized at the time of final vehicle performance testing.

A standard rule for speed control tuning is:

- Switch off the integral part by setting *MotorControl.SpeedKI*=0
- Increase the proportional gain until the control starts to oscillate (consider the complete speed range)
- Reduce to proportional gain to 70% of the former value
- Keep this proportional gain and follow the same procedure to tune 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 in 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 provide the API variable *Motor.EncPulses* with the resolution of the encoder used in the application (PLUS+1 Motor Compliance Blocks provide this data).

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.

Warnings

A wrong value entered in *Motor.EncPulses* can in the worst case result in uncontrolled acceleration.
If the encoder signal is missing, the motor will run at 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. Control Structure (continued)

11.1.5. Torque Limitation

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* must be set to 10000 (=100%).
With the variable *MotorControl.ActTorqueLimit* the valid torque limit in 0.001Nm can be read.

The current limitation (see 11.1.6.) may prevent 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*.

The torque limitation (see 11.1.5.) may prevent achievement of maximum current.

11.1.7. Speed Control Versus 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.

Example:

Values for torque control	Values to the 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

The PLUS+1 Inverter function block library provides the function block “Torque Control” which contains the related calculations.

11.2. MOTOR DEFINITION

The field oriented motor control algorithm requires entry of motor data. These are physical data of the motor, independent of the application. No optimization of motor data at final machine performance testing 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. With Motor Compliance Blocks and Open Data Blocks the motor parameters are part of the source code and can only be edited in the PLUS+1 GUIDE. Working with Download Blocks allows the independent handling of application software and motor parameters by downloading two lhx files with the PLUS+1 Service tool.

11.2.1. Electric Motor Compliance Blocks

Motors measured by Schwarzmüller Inverter are supported 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 reflecting 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 appropriate 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 these error signals have to be programmed dependent on the application.

11.2.2. Open Electric Motor Data Function Block

For motors not measured by Schwarzmüller Inverter, the data for motor, encoder and temperature sensor can be edited in the GUIDE template. Required motor data are IEEE values supported by the Motor manufacturer.

11.2.3. Electric Motor Data Download Block

This function block allows set-up of motor data (inclusive encoder and temperature sensor data) using the Service Tool. If the application software allows changing motor data at run time, the Motor Data Download Block has to be installed. As this block requires default values, a Motor Compliance Block or an Open Motor Data Block has to be installed additionally.

11.2 Motor Definition (continued)

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 reinitialization. This has to be done by writing a 0-1 sequence to *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 reinitialization 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 dependent 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 performance 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. Encoder Diagnostics

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 test of the motor encoder can be done by watching the API variables *Motor.EncA* and *Motor.EncB* using the PLUS+1 Service Tool while turning the motor very slowly. Both variables have to change status while turning the motor. This test provides information about the wiring of the encoder.
In the event of motor control instability, the quality of the encoder signals should also be checked.

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. Diagnostics (continued)

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 that can be measured at the motor cables.
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: O = 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 flows from motor to the inverter.

12.1. CAN (CONTROLLER AREA NETWORKS) PORTS

The PLUS+1 Inverters have CAN ports conforming to CAN 2.0B. The 2.0B version of CAN is 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	C1p03
	CAN L	C1p04
2	CAN H	C1p06
	CAN L	C1p07

The C1p03 and C1p04 are internally connected in parallel with C1p06 and C1p07. See:

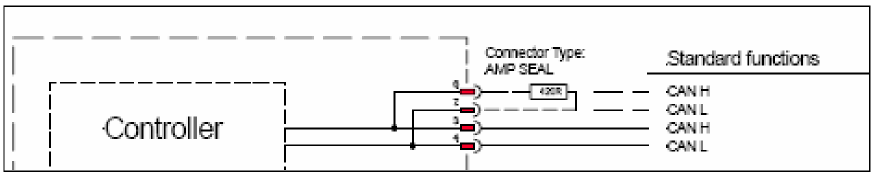


Figure 7: Double CAN port

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. See Figure 8.
Be aware of stub length, see Figure 9 : Bus stubs

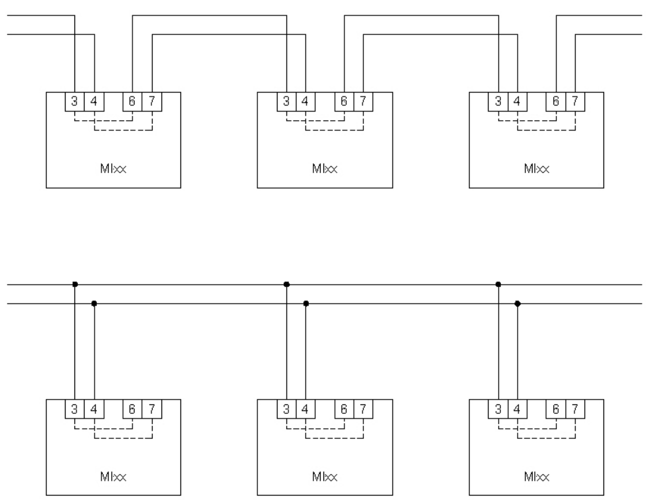


Figure 8: Bus topology

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 FORM 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 9 : Bus stubs) . Lower baud rates allow longer stubs.

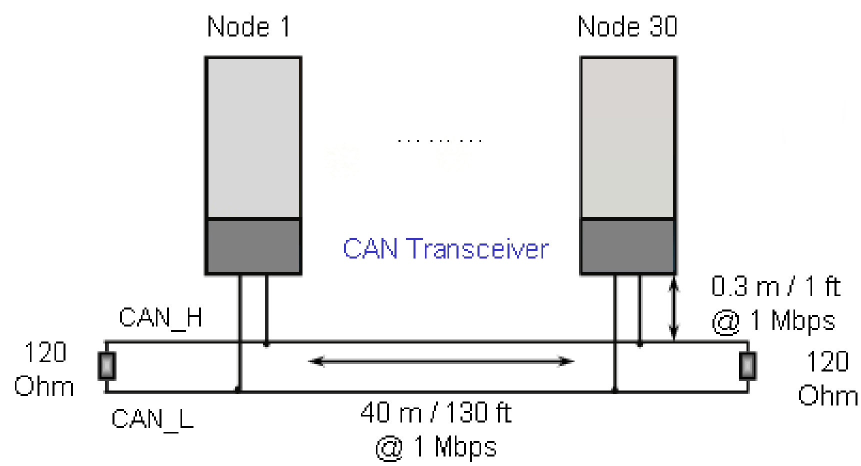


Figure 9 : Bus stubs

Warnings

The programmer of the PLUS+1 application software has to consider a proper reaction on 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 Schwarzmüller Inverter for further information.

13. Product Ratings

13.1. PRODUCT RATINGS

Environmental

Switching frequency	8kHz standard; adjustable 4, 8, 12, 16 kHz
Efficiency	about 95% 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 (104°F)
Maximum heat-sink temperature @ full current	85°C; 185°F
Heat-sink switch off temperature	85°C; 185°F
Relative humidity	100%, condensation is allowed
Operation signal	2 built-in LEDs (red and green)
Signal line connectors	AMP-Seal 35 pins
IP protection	IP67 with membrane
EMC / ESD	EN 12895 / EN 61000-6-2 / EN 61000-6-3 / EN 61000-4-2 / ISO 7637 / 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 recognised
Chemical resistance	ISO 16750-5

All PLUS+1 Inverters are CE compliant

14.1. MATING CONNECTORS

PLUS+1 Inverters use AMPSEAL connectors. Schwarzmüller Inverter has assembled a mating connector kit, referred to as a bag assembly.

Part No information

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

AMPSEAL Mating Connector Part Information

Description	AMPSEAL reference
Crimp tool	AMP PRO-CRIMPER II Hand Tool Assembly 58529-1
Connector plug	PBT, Black 776164-1
Contacts	770854-1 (0.5 – 1.4 mm^2) (20 – 16 AWG)
Sealing plugs	770678-1
Strip length	4.7 to 5.5 mm [0.185 to 0.215 in]
Insulation diameter range	1.7 to 2.7 mm [0.067 to 0.106 in]

14.2. PLUS+1 INVERTER INSTALLATION GUIDELINES

14.2.1. Mounting the Inverter

While the PLUS+1 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.

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.

For the plate-type heat sink version 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.
The mounting surface shall meet the requirements:

Planarity = 0,1mm ⏥ 0,1

Surface roughness R_2 = 40µm

For the finned-type heat sink version it is recommended to ensure 3m/s air speed through the entire heat sink.

14.2.2. Wiring the Power Stage

The power stage is connected using screws, labeled "+, -" and "U, V, W". An additional screw (not MI03 type) allows the assembly of a power fuse on top of the inverter housing.

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 cable shoes.

The inverter is equipped with steel screw assemblies. Don't use additional washers. Make sure that the cable shoes lay directly on the brass sleeves of the inverter.

Fixing torque for power connectors:

Screw size	Inverter type	Fixing torque
M6	MI03	6 Nm
M8	MI04	9 Nm
M10	MI06….MI20	17 Nm

14.2. PLUS+1 Inverter Installation Guidelines (continued)

14.2.2.1. Recommended Main Contactor

A single pole, single throw contactor 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 manufacturer's products are used, the coil currents, pull-in and drop-out times should be investigated to ensure compatible operation.

If the main contactor coil is not wired to C1p24 (Main Contactor Output) the PLUS+1 Inverter will not be able to open the main contactor in serious fault conditions and the inverter will not be protected against reverse battery polarity.

14.2.2.2. Recommended Main Fuse

The main battery cable should be fused with a suitable air-break fuse. The fuse must be sized in relation to protect the motor and cabling. For exact determination consider applicable technical regulations.
For Safety reasons, the use of protected fuses is recommended in order to prevent the spread of fuse particles should the fuse blow.

14.3. PLUS+1 RECOMMENDED MACHINE WIRING GUIDELINES

- All wires must be protected from mechanical abuse. Wires should be ran 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.
- The cables to the battery should be ran side by side and be as short as possible.
- 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 Inverter and ground returned to the power supply pin on the PLUS+1 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.

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 battery cables 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 devices 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 **70100012** *CAN Bus wiring hints* for detailled information how to connect the CG150 to the bus.

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. START UP 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 inverter 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.

Notes