



Hybrid



Electric

Explore our Technologies

AC Motor Controller

Gen5 size9

Reference Manual V2.6



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Chapter 1: Legal Disclaimer

Chapter 1 - Legal Disclaimer

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Licenses

No license to the BorgWarner's intellectual property or the intellectual property of third parties has been granted by this manual.

Important safety information

Electric vehicles (and their component parts such as motors, controllers and batteries) can be dangerous and cause severe damage to property and individuals if not handled correctly. All testing, fault-finding and parameter adjustment should be carried out by competent personnel. Incorrect parameter configuration or wiring can lead to an unsafe or dangerous system.

When setting up a new vehicle configuration, the vehicle should be immobilized with drive wheels raised on axle stands until the basic driver controls have been configured and the driver is able to stop the vehicle safely. Before this point, it is possible for full torque to be output from the motor, regardless of the driver demands.

Chapter 2: Introduction

Reliably delivering what's needed today

There are few challenges as important today as creating solutions that support a cleaner, more energy-efficient world. This requires a commitment to constantly improve the transportation of people and things. We, at BorgWarner, made that commitment decades ago and have since been creating technologies to improve efficiency, emissions, and performance in all types of vehicles.

Constantly pursuing what's next

Our proven track record has made us propulsion system leader for combustion, hybrid, and electric vehicles. We uncover strong trends and use smart science and technology to address a future based on varying regulations, consumer demands and automaker requirements.

Product leadership that's changing the world

Our employees have earned trusted partnerships with customers and suppliers around the world. We leverage these relationships to gain a deeper understanding of the challenges at hand and then do what it takes to develop the next solution. Our strong operations and commercialization expertise result in high volume availability of competitive, efficient products that truly drive change.

BorgWarner enables the switch - To highly efficient electric drives

Chapter 2 - Introduction

2.1 About BorgWarner's Technologies

Transforming vehicles to more fuel efficient, cleaner technologies requires a collaborative partner who understands the evolution of mechanical to electric systems. Our expertise in both provides the critical underpinnings of efficient and powerful propulsion. Integrating electronics into the mechanical system is the key to performance, packaging and cost. This is evidenced across a full line of our combustion, hybrid and EV products for light vehicles, medium and heavy-duty vehicles as well as off-highway applications.

2.2 Purpose of this Manual

To support decision-makers, the first four chapters of this manual are intended to provide an overview of the Gen5-S9 motor control product, and where this product could be applied.

The installation instructions in this manual, which have been written for qualified automotive electrical and mechanical installation engineers, presents the basics of installing the Gen5-S9 motor controller. Guidance is provided to support engineers when configuring motor control systems, sizing a motor, and selecting system components, options, and accessories. The installation instructions are housed in chapters five to eight.

Please pay special attention to the information relating to warnings, cautions and notes when they appear in the manual.

2.2.1 Scope of this manual

This Application reference manual provides important information on configuring motor control systems using Gen 5 Size 9 controllers as well as details on sizing and selecting system components, options and accessories. This version of the manual applies to all controllers with BorgWarner part numbers, where x can be any digit:

- **636A34901**
- **636A349xx**

2.2.2 Related documents

The following documents are available from BorgWarner or Authorized Distributors:

- DVT User Manual
- The Object Dictionary providing important information about CANopen communication and configuration
- Application Notes:
 - H-protocol
 - I-protocol
 - proCAN
 - HVLP + D8 + Gen5 Encoder configuration
 - Vehicle EMC recommendations
 - CustomCode

2.3 Sales and Technical support

BorgWarner is a major OEM focused business; however, we have an extensive authorized distributor network who can provide you with technical or commercial support. Please find the details of your nearest distributor through the following link <https://www.borgwarner.com/aftermarket/controllers-converters/distributor-search>

For direct customers of BorgWarner please contact one of the following BorgWarner offices for assistance:

- North American Office:
 - BorgWarner Southborough Inc. (US.drives.sales@borgwarner.com)
- European Office (+ rest of world):
 - BorgWarner Systems Lugo S.r.l. (drives.sales@borgwarner.com)

2.4 Document Conventions

The following conventions are used within this document. Special attention must be paid to the information presented in Warnings, Cautions and Notes when they appear in this manual. Examples of the style and purpose of each are shown below:

Convention	Description
	A warning is an instruction that draws attention to the risk of injury or death and tells you how to avoid the problem.
	A caution is an instruction that draws attention to the risk of damage to the product, process or surroundings.
	A note indicates important information that helps you make better use of your BorgWarner product.
Illustrations	Orthographic illustrations are drawn in third angle projection.
Units	SI units are used throughout.

Table 1 - Conventions

2.5 Our Controllers - An Overview

BorgWarner controllers are designed to control the following motors, in battery and generator-powered applications:

- 3-phase AC induction motors
- 3-phase permanent magnet AC (PMA) motors, both surface and interior magnet

The controller adapts its output current to suit the loading conditions and the ambient temperature in which it is operating - temporarily shutting down if necessary. As a safety feature, the controller will protect itself if the low voltage circuits are incorrectly wired.

Signal wiring and power connections are designed to be as simple and straight forward as possible.

Analogue and digital signal inputs and outputs are provided for switches, sensors, contactors, hydraulic valves, and CAN communications.

The controller can be configured to share its I/O, share its results or take commands from other controllers or displays on the CAN bus.

Configuration and control of BorgWarner controllers is fully customizable.

However, for a bespoke solution, please contact us for further information.



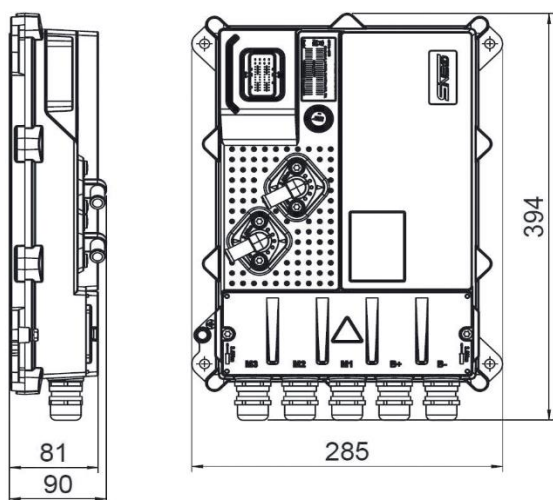
Chapter 3: About Gen 5 Size 9

Chapter 3 - About Gen5 size9

3.1 Overview of Specification

The Gen5 range of motor controllers utilize a highly flexible control logic architecture to deliver a unique feature-rich set of functions and is well-matched to satisfy automotive, commercial and construction markets' electrification needs. The range of High Voltage High Power (HVHP) controllers are specifically aimed at vehicle OEMs and system integrators to offer them a compact, lightweight, robust and cost-effective, class-leading suite of solutions covering traction, hybridization, power generation and sub-system electrification.

Dimensions



Intelligent I/O

The Gen5-S9 includes a fully integrated set of inputs and outputs designed to handle a wide range of vehicle functions. This eliminates the need for additional external I/O modules or vehicle controllers and connectors.

- All I/O protected to 40V
- 4 analog inputs 0 – 10V allowing for easy configuration of dual throttle and dual footbrake applications
- 2 PT1000/KTY84 thermistor inputs
- 4 digital inputs
- 2 PWM analogue outputs and 2 digital outputs (high side)
- 3 programmable power supplies (1x200mA 2x100mA voltage configurable)

Key Parameters

- Operating voltage range 128V to 450V, with derating after 420V
 - 450 Arms (1min)
 - 200 Arms (1hour+)
- Safety
 - Tested to EMC Reg. 10
 - Passive HVIL safety functionality
- Environmental
 - -40°C to +85°C operation, IP6K9K, ISO 16750
 - Coolant flow rate water-glycol 10l/minute, derating starts 55°C coolant
- Encoders
 - Incremental AB
 - Hall effect UVW
 - Sin/Cos
 - Resolver (variable gain)
- Motors
 - AC Induction
 - Permanent magnet synchronous

Smart Communications

Using 'custom code' functionality allows the communications protocols and data contained within the messages to be modified specifically for your application. For bespoke solutions, please contact us for further information.

Note: key parameters can vary, depending on controller set-up, environmental conditions and motor conditions.

3.2 Compatible Applications and Motors

BorgWarner motor controllers can be used in many applications, such as on-road four-wheel electric vehicles, off-road ATV, utility vehicles and burden carriers, hybrid vehicle systems and electrification of vehicle power train.

Our motor controllers will function with most AC Induction, PMAC SPM and IPM motors, but we recommended the High Voltage Hairpin, HVH250 family of BorgWarner Remy-branded motors.

For all other motors, please check with your supplier to ensure compatibility.

We uncover strong trends
and use smart technologies
to meet customers' demands.



3.3 Product Warranty

Please refer to the terms and conditions of sale or contract under which the Gen5-S9 was purchased for full details of the applicable warranty.

Notes:

Within the agreed warranty period and terms, credit will be given only after return and confirmation of BorgWarner liability. The customer is required to supply conditions during failure, and any other information required to verify the reported defect.



WARNING Do not attempt to open the controller.

Opening the controller may lead to risk of high voltage exposure and associated risks, including death.

There are no serviceable components. Opening the controller will invalidate the warranty.

Do not mechanically modify the controller in any way, as unexpected damage may occur. Mechanically modifying the controller will invalidate the warranty

Chapter 4: Performance

Chapter 4 - Performance

4.1 Motor Speed and Frequency

4.1.1 Overview of maximum motor speeds and frequency

There are many factors influencing the maximum motor speed that can be controlled. Some of the key factors are:

- Number of magnetic poles
- Harmonic content of motor (any non-sinusoidal back emf)
- Encoder accuracy and noise
- 'Sensitivity' of motor (including inductance)
- Required tolerance of torque ripple

A typical range of achievable maximum motor frequency is 600Hz to 1000Hz, however frequencies above 1000Hz can sometimes be achieved if key factors are well managed.

An example of motor speeds and frequencies:

- 5 pole pair PMAC motor:
 - Applied frequency of 600Hz = motor speed of 7200rpm
 - Applied frequency of 1000Hz = motor speed of 12000rpm

As speed, and hence frequencies, become too high, degradation of the current control will occur.



Tough emissions and fuel economy standards –
our system solutions
get the job done.

Chapter 5: Electrical Ratings

Chapter 5 - Electrical Ratings

5.1 Warnings and Cautions



WARNING Electric vehicles can be dangerous. All testing, fault-finding and adjustments should be carried out by competent personnel. The vehicle manufacturer's manual should be consulted before any operation is attempted.



WARNING The battery or DC power source must be disconnected before replacing the controller. After the battery has been disconnected, wait until the internal capacitors are fully discharged ($<1V$) before handling the controller or working near exposed terminals.

Please refer to the chart on page 59, which illustrates discharge time.



WARNING Never connect the controller to a battery with vent caps removed or a generator with an open fuel tank as an arc may occur. This is due to the controller internal capacitance when first connected. Gen5-S9 does not have any built-in pre-charge and so direct connection could result in very high in-rush currents and arcing across contacts in the supply path.



WARNING Do not attempt to open the controller. Opening the controller may lead to risk of high voltage exposure and associated risks, including death. Do not attempt to open the controller as there are no serviceable components. Opening the controller will invalidate the warranty.



CAUTION Use cables of the appropriate rating and fuse them according to the applicable national vehicle and electrical codes.



CAUTION Where appropriate, use of a suitable battery in-line contactor should be considered.



CAUTION Electric vehicles are subject to national and international standards of construction and operation which must be observed. It is the responsibility of the vehicle manufacturer to identify the correct standards and ensure that their vehicle meets these standards. As a major electrical control component, the role of the motor controller should be carefully considered, and relevant safety precautions taken.

BorgWarner controllers have several features that can be configured to help the system integrator to meet vehicle safety standards.



CAUTION The vehicle manufacturer must ensure that an appropriate controller configuration is set to ensure the vehicle remains in a safe condition, even in the event of a fault.

5.2 DC Link Supply

The DC supply is connected through a main contactor to the terminals on the controller.

The Gen5-S9 inverter does not have high voltage pre-charge circuitry built in. Pre-charge must therefore be provided externally, on a system level. This is most typically provided by a battery pack and it's Battery Management System.

Nominal working voltage	350V
Operating voltage range	50-400V max output, 400-450V reduced output
Over-voltage hardware trip level	>475V, Software over-voltage trip level 460V. Permanent damage to the unit may occur above these voltages.
Current measurement accuracy	5%
DC link capacitance	640 μ F
Polarity protection	You must ensure that reverse polarity protection is provided external to the controller. For example, by control of the main line contractor.
Pre-charge	Must be controlled externally.
Ground fault protection	You must ensure that ground fault protection is provided externally to the controller. For example, by control of the main line contractor.

Table 2 – DC link



CAUTION You must provide reverse polarity protection externally to the controller, for example, by control of the main contractor. Reverse polarity connection of the DC link will permanently damage the controller.



WARNING You must provide ground fault protection externally to the controller. If you fail to do this, dangerous voltages may be present that could lead to injury or death

5.3 Wire Size



When deciding on power cable diameter, consider cable length, grouping of cables, the maximum allowable temperature rise, and the temperature rating of the chosen cable.

Cable sizes between 35mm² and 70mm²:

Average current (rms)	Cable size	
175A	35mm ²	AWG2
200A	70mm ²	AWG0

Table 3 – cable size

See figure 4 for more information. Consider cable temperature rises/ambient, based on your current.

5.4 Fuse Size

The DC Link supply must be fused to protect the vehicle wiring and the controller in the event of a fault. Use fast-blow fuses, rated appropriately.

For more information, refer to manufacturer's datasheets.

5.5 Inverter (Motor Output)

The inverter connects to the motor. For example, on a motor with UVW terminals labelled, the terminals M1, M2, M3 on the controller would be connected to the terminals U, V, W(respectively).

Switching Frequency	Range configurable between 2kHz and 12kHz range. We recommend 8kHz for most applications as it offers good thermal performance where high RPM is not required. Note that frequency can be set to adjust automatically based on the thermal requirements of the controller.
Protection output current	Gradual reduction from peak to continuous rating over time, based on temperature.
Protection short-circuit	- Protected against any motor phase to B- or B+ during power-up. - Protected against motor phase to phase short circuits during operation. - On power-up and with drive current applied, the controller automatically detects that valid output loads are present. For example, an open/short circuit motor phase.

Table 4 – motor output



CAUTION Repetitive short circuits may damage the controller.

5.5.1 Rating Conditions

For each test, four of the following five conditions are held at their nominal value and the remaining condition is varied. The conditions are:

- DC link voltage: 300 volts DC
- PWM switching frequency: 8kHz
- Motor voltage: 65%
- Ambient temperature: 45°C
- Coolant: 45°C input temperature, 50/50 glycol/water mixture at 10L/min flow rate

All tests use a 50Hz AC waveform. Wire size is 50mm².

5.5.2 Continuous Rating

Many external parameters effect the electrical rating of the controller, including the coolant temperature, ambient air temperature, the battery voltage, cable sizes and switching frequency.

These parameters feed into a complex algorithm used to deliver the maximum performance, while ensuring long-term reliability of the product. Below are a series of graphs designed to show how each of these parameters in isolation can cause de-rating to the electrical performance of the product.

In real life, the controller will be operating under a combination of these parameters, and it may be necessary to combine the information provided to understand the expected performance under your specific conditions.

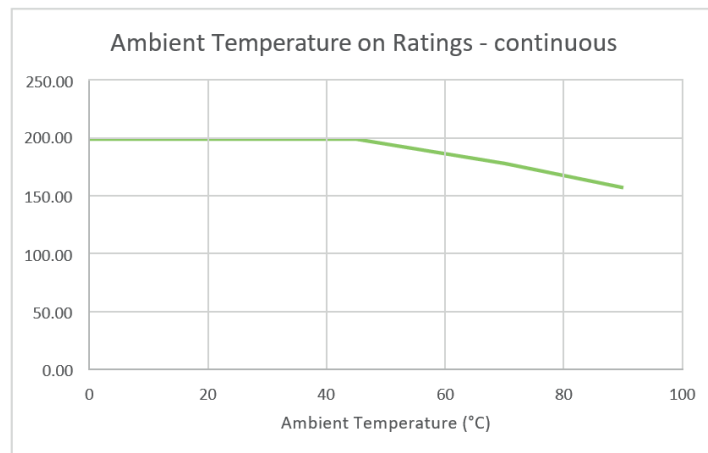


Figure 1 how ambient temperature affects ratings

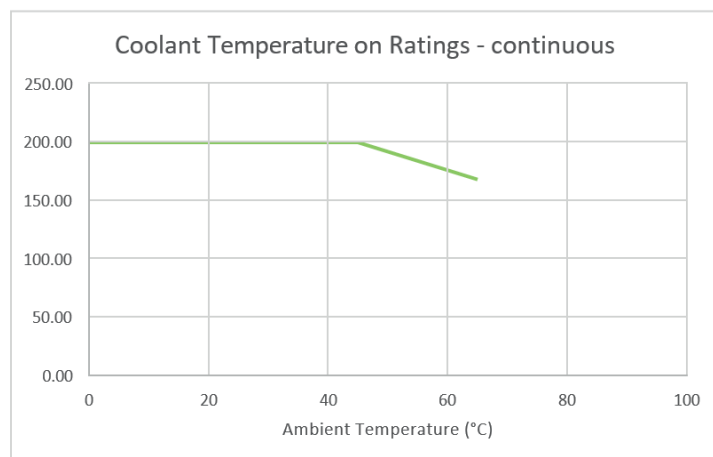


Figure 2 how coolant temperature affects ratings

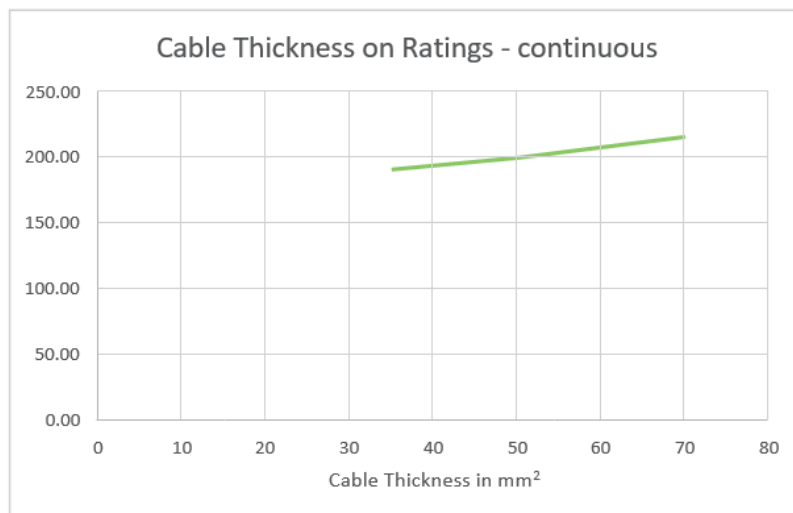


Figure 3 how cable thickness affects ratings



When deciding on power cable diameter, consider the cable length, grouping of cables, the maximum allowable temperature rise, and the temperature rating of the chosen cable.

5.5.3 Short-term Overload

Short-term overload is affected by switching frequency, coolant flow rate and temperature and DC Link. The following graphs outline how these factors affect ratings.

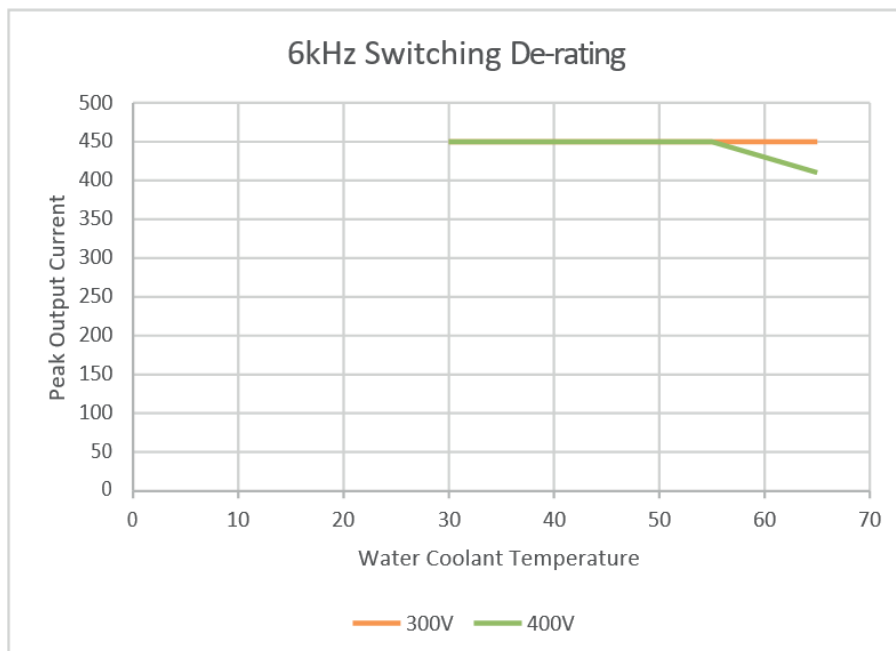


Figure 4 6kHz switching de-rating

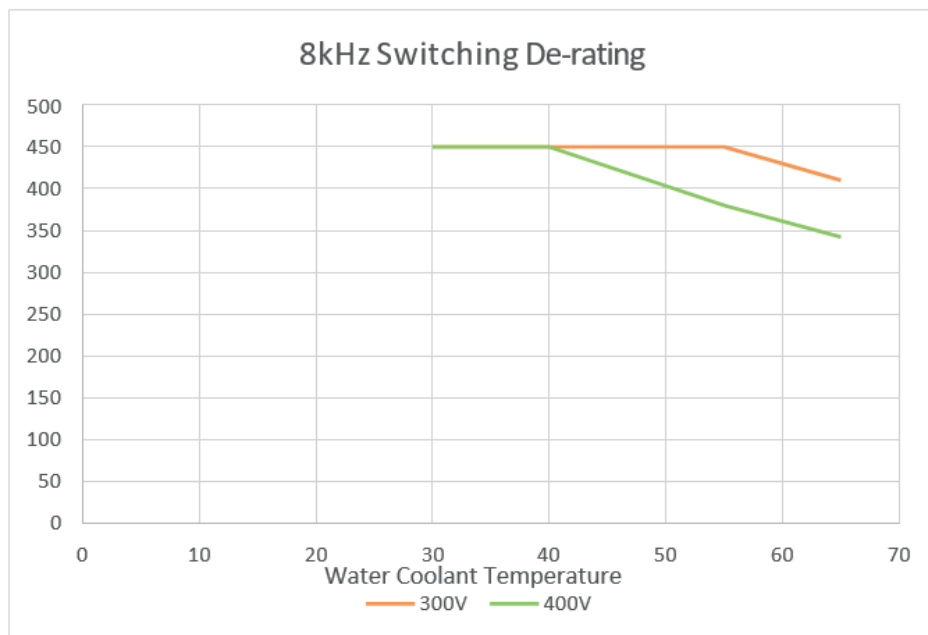


Figure 5 8kHz switching de-rating

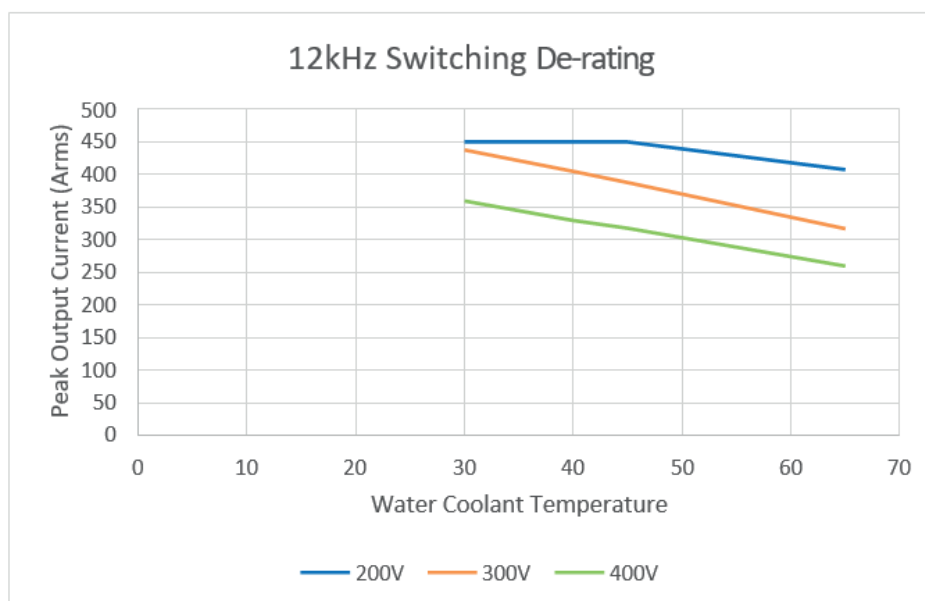


Figure 6 12kHz switching de-rating

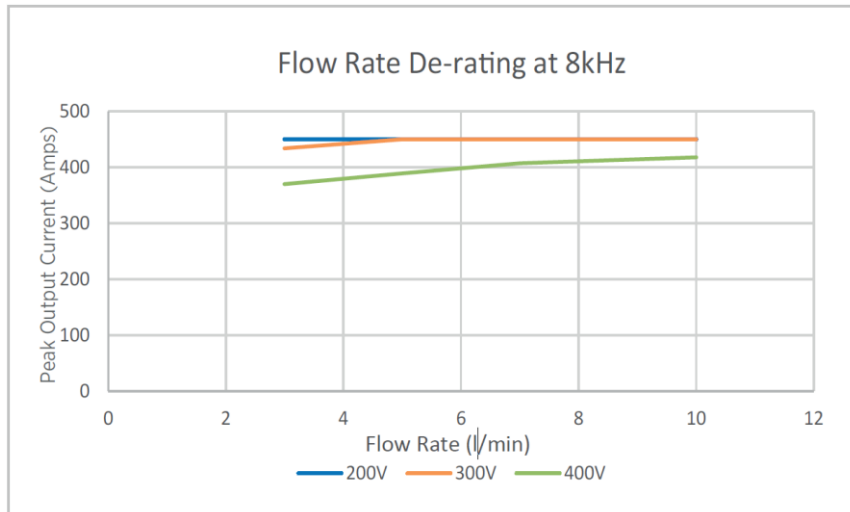


Figure 7 8kHz how flow rate affects ratings

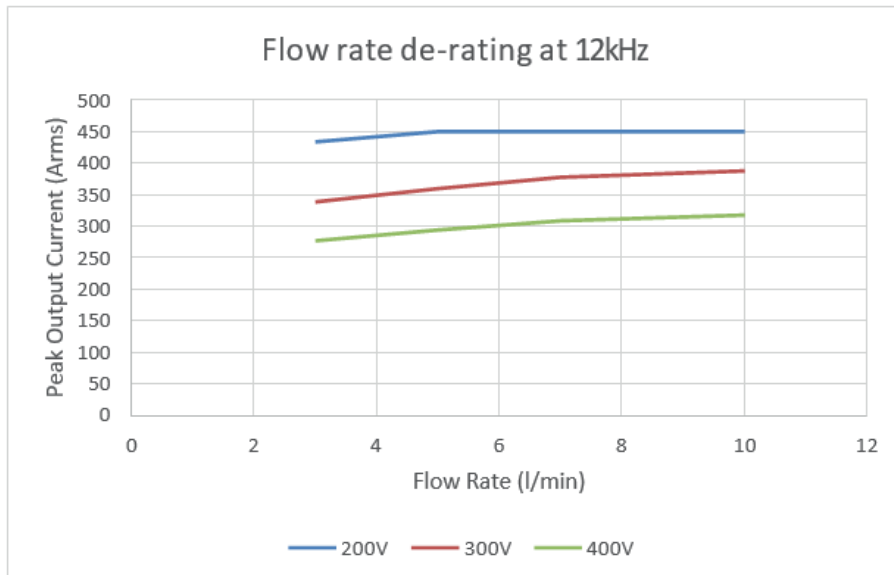


Figure 8 12kHz how flow rate affects ratings

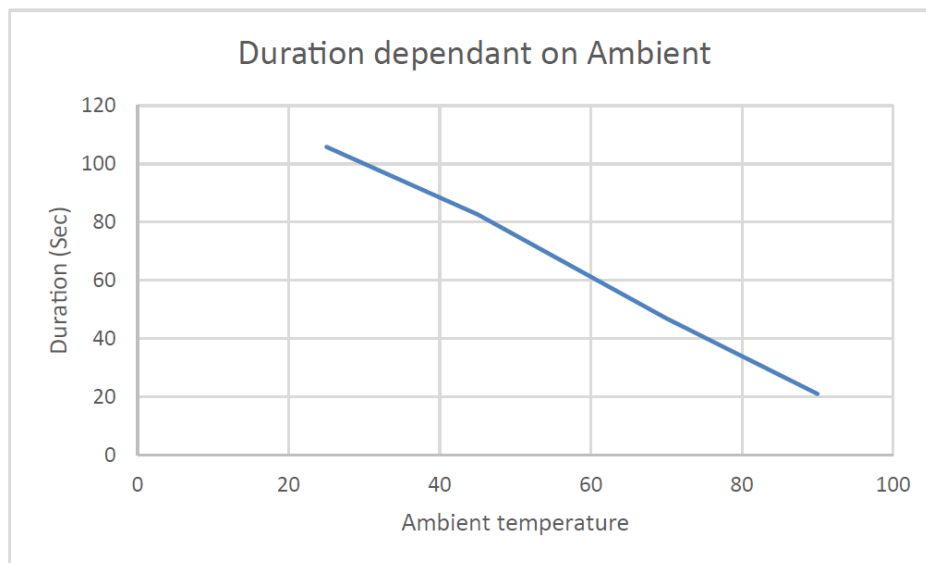


Figure 9 Duration dependent on ambient

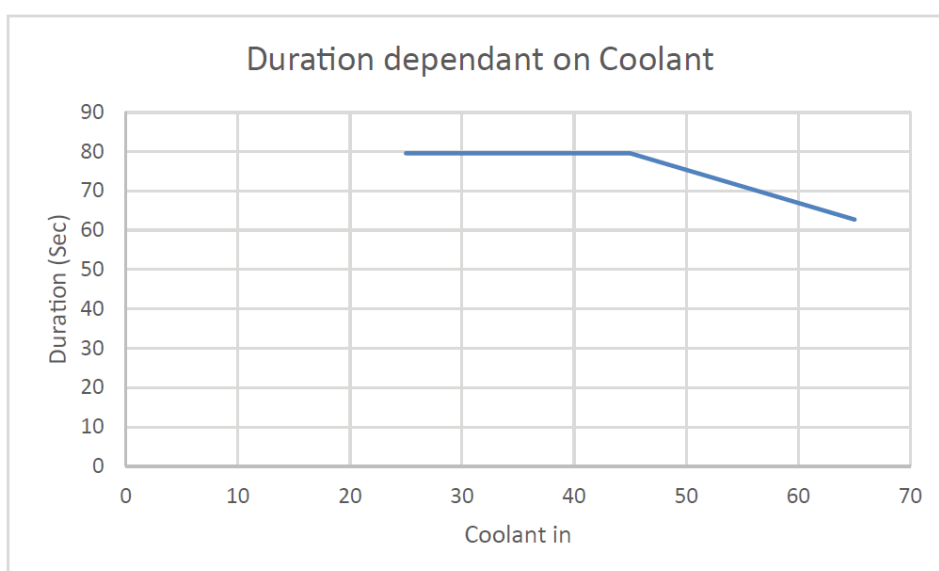


Figure 10 Duration dependent on coolant

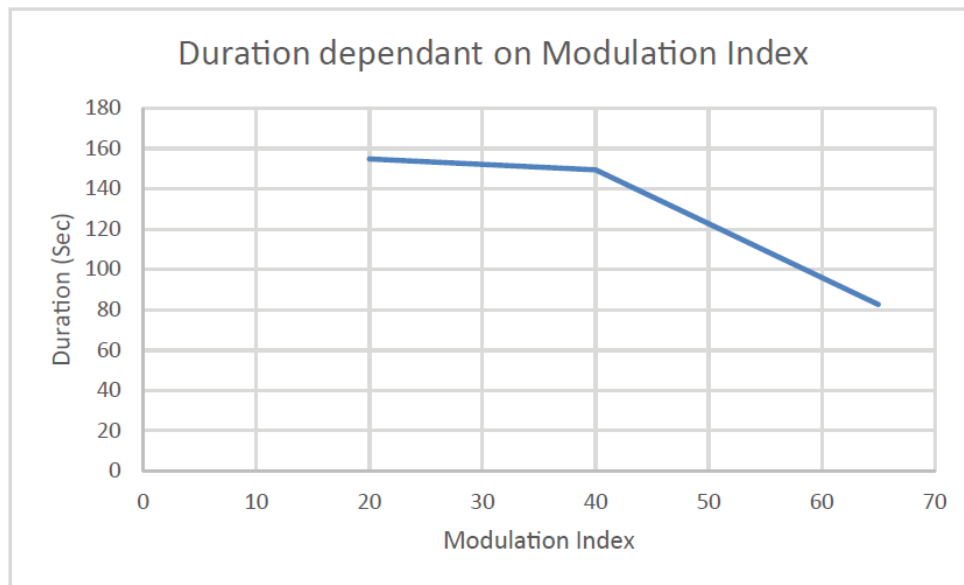


Figure 11 Duration dependent on modulation index

5.6 Overload Duration

When running from cold (at the respective ambient and coolant temperatures), the times highlighted in the graphs above represents the duration at 450A - before the inverter cuts back.

In some cases, to achieve the 450A, the switching frequency is reduced due to junction temperature limits.

5.7 Effect of Multiple Conditions on Ratings

It can be difficult to determine the effect of multiple conditions varying from nominal. One approach is to use the minimum of each condition. This can work reasonably well when operating at conditions more limiting than nominal, but tends to be more pessimistic than necessary when operating at conditions less limiting than normal.

Chapter 6: Wiring

Chapter 6 - Wiring

6.1 Signal Connector

Mating connector	Molex CMC P/N 64320-1311 (left) or P/N 64320-3311 (right)
Integrity	IP67/IP6K9K. IP6K9K can only be guaranteed when terminal cavity seal plugs are used.
Pin labels	A1 to M4 and are marked on the connector: • 40 smaller pins A to K, 0.635mm cavity • 8 larger pins L and M, 1.50mm cavity
Required pins	40 smaller pins, 0.635mm cavity: • Molex CMC Sq Crimp Terminal P/N 64323-1029 (0.75mm² wire size) 8 larger pins, 1.50mm cavity: • Molex CMC Sq Crimp Terminal P/N 64322-1039 (1mm² – 2mm² wire size) Please refer to the Molex website to select the most up-to-date and appropriate pins.

Table 5 – Logic connector

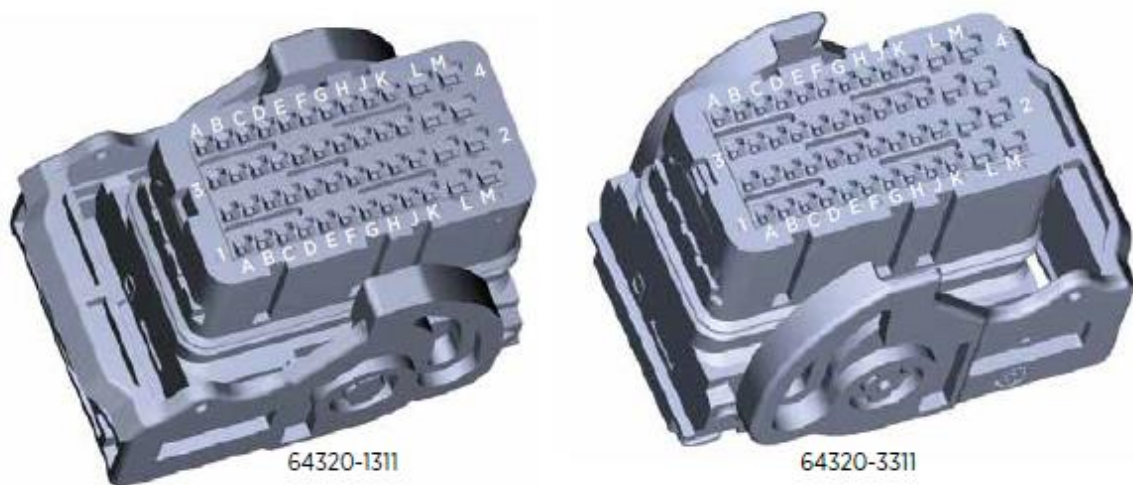


Figure 12 – Mating connector

6.1.1 Logic Pinout

	4	3	2	1
A	CAN2 H (Not currently functional)	Digital Input 1 (Din 1)	CAN1 H	Encoder Supply (Enc Supply)
B	Encoder Ground (Enc-Gnd)	Resolver Excitation– (Res Exc-)	Digital Input 2 (Din 2)	ResolverExcitation+ (Res Exc+)
C	CAN2 L (Not currently functional)	CAN Ground (CAN Gnd)	CAN1 L	CAN1 Termination Resistor (CAN1 Res)
D	CAN2 Termination Resistor (Not currently functional)	Digital Input 4 (Din 4)	Digital Input 3 (Din 3)	User Supply 1
E	User Supply 2	Resolver Cos+ (Res Cos)	Encoder U (Enc U)	Analogue Input 1 (Ain 1)
F	Analogue Input 2 (Ain 2)	Resolver Cos Low (Res CosLo)	UART Tx (Not currently functional)	Encoder A (Enc A) Encoder Sin (Enc Sin)
G	HVIL A	Thermistor TH2	Analogue input Ground (Ain Gnd)	Thermistor TH1
H	HVIL B	Resolver Sin+ (Res Sin)	UART Rx (Not currently functional)	Encoder V (Enc V)
J	Analog Input 3 (Ain 3)	Resolver Sin Low (Res SinLo)	Encoder B (Enc B) Encoder Cos (Enc Cos)	Ignition Switch (KL15)
K	Digital out 4 Source High side switch 2A (Dout4 +)	Digital out 3 Source High side switch 2A (Dout3 +)	Analog In 4 (Ain 4)	Encoder W (Enc W)
L	Control 0V (KL31)	Analogue out 1 Sink Low side PWM 1A (Aout1 -)	Analogue out Source (Aout Supply +)	12-24V supply (KL30)
M	Control 0V (KL31)	No connection	Analogue out 2 Sink Low side PWM 3A (Aout2 -)	12-24V supply (KL30)

Table 6 – Signal Connector

6.2 KL30 Control Supply

The controller has one logic power input. The figure shows a suggested schematic connection.

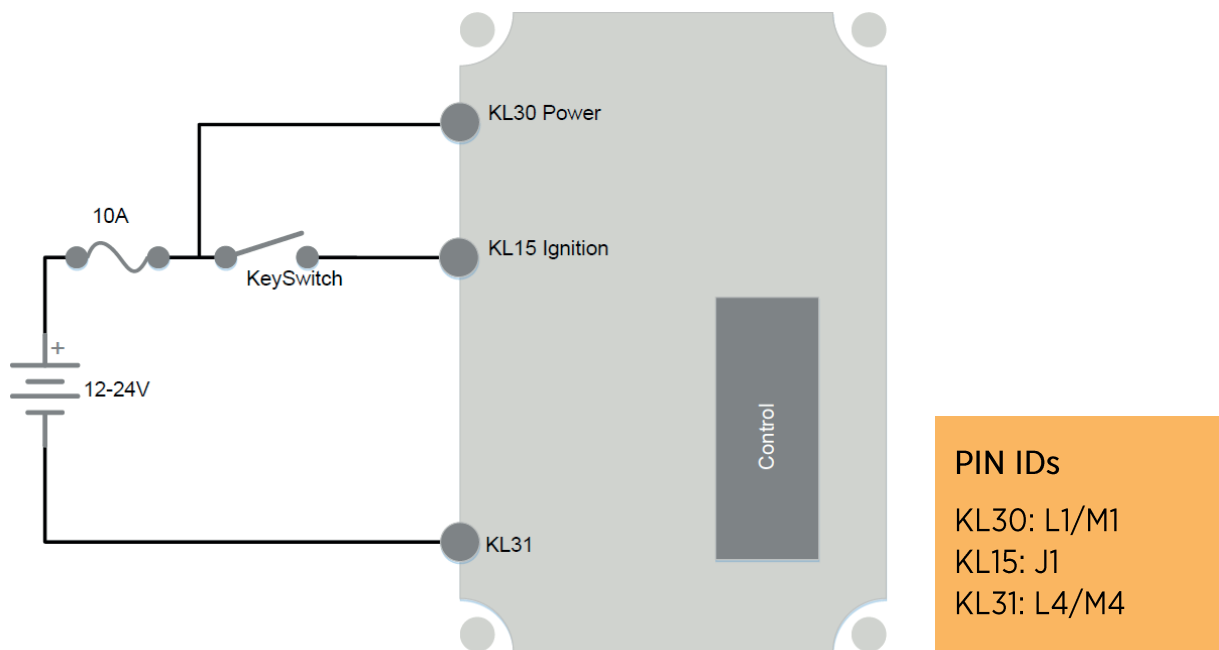


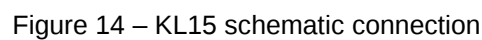
Figure 13 – KL30 schematic connection

KL30 is connected directly to the power supply.

Absolute maximum voltage	36V
Capacitance	10 μF (before inrush)
Peak inrush current	< 10A @ 25°C
Protected against reverse voltage connection	Yes
Nominal working voltage	12V - 24V
Signal power	Supplied between KL30 and KL31 (the signal ground)
Standby power consumption	12V <150 μA. 24V < 450 μA
Wire size, recommended	0.5mm² / AWG20
Working voltage limits	8V - 32V ISO16750-2 Class B (12V System) / Class F (24V System)

Table 7 – KL30 rating

The figure shows a suggested schematic connection. The key switch provides voltage to KL15.

Table 8 – KL15 rating

6.4 CAN Interface

CAN channels are used to communicate with the controller.

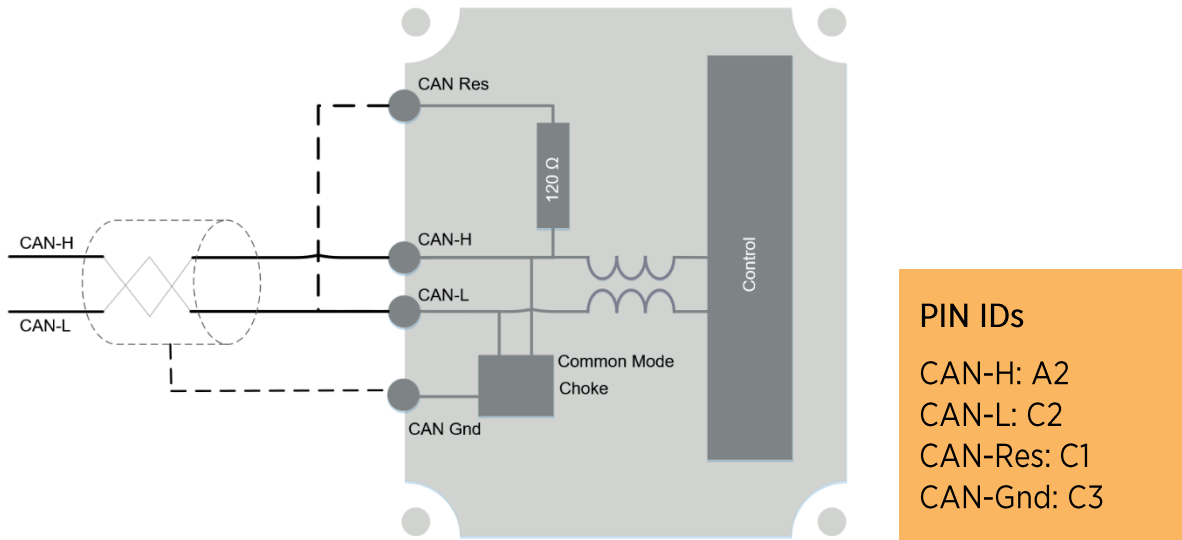


Figure 15 – CAN1 connection

Absolute maximum voltage	36V transient, 24V continuous
Built-in 120Ω termination resistor, selectable through wiring	See CAN schematic connection diagram
CAN Revision	Support for both standard (2.0A and 2.0B compatible) and extended CAN frames (2.0B compatible) Configuration is via CANopen, while H-protocol and ProCAN supports J1939 message semantics. Bitrates up to 1Mbit are supported.
ESD protected	Yes
Maximum common mode signal	± 40V
Wire size, recommended	0.5mm ² / AWG20

Table 9 – CAN details

6.5 Input-Digital

The controller has four identical digital inputs - these can only be accessed by custom code, or I-protocol.

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The digital signal is connected between Din1/Din2/Din3/Din4 and KL31 (the signal ground / active low) or KL30 (signal power / active high) depending on desired configuration.

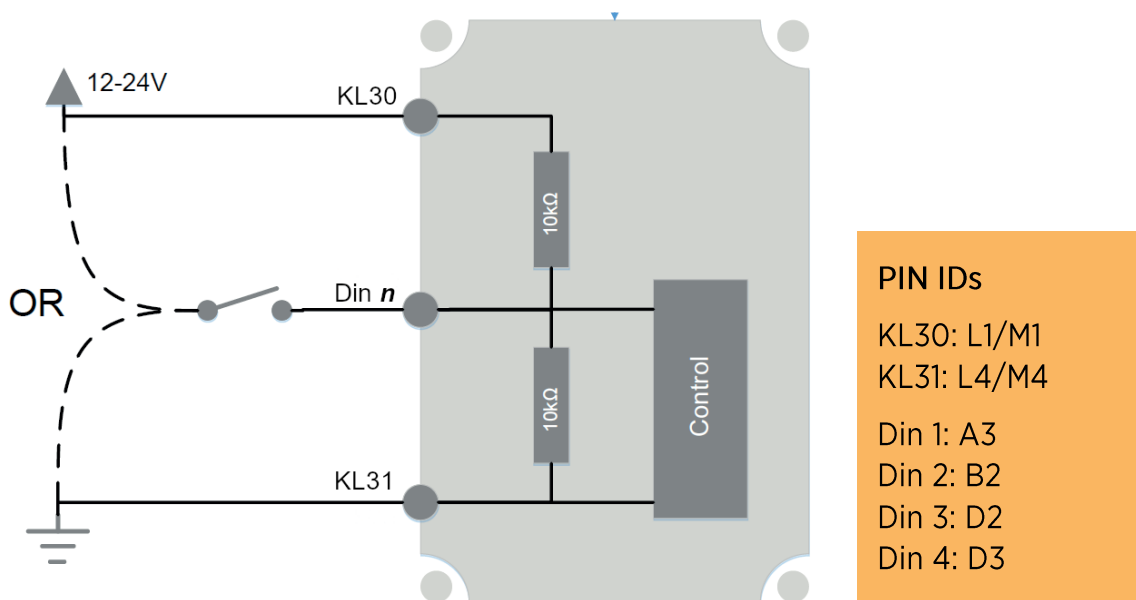


Figure 16 – Digital input connection

Absolute maximum input voltage	36V (continuous)
Configurable to be active hi or active low	Yes
Input impedance	5kΩ
Quiescent level	50% of KL30
Threshold level	User configurable up to 36V
Wire size, recommended	0.5mm ² / AWG20

Table 10 – Digital Inputs

6.6 Input – Analogue

The controller has four identical analogue inputs.

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The analog signal is connected between Ain1 /Ain2 (the analog input) and Ain Gnd (the signal ground).

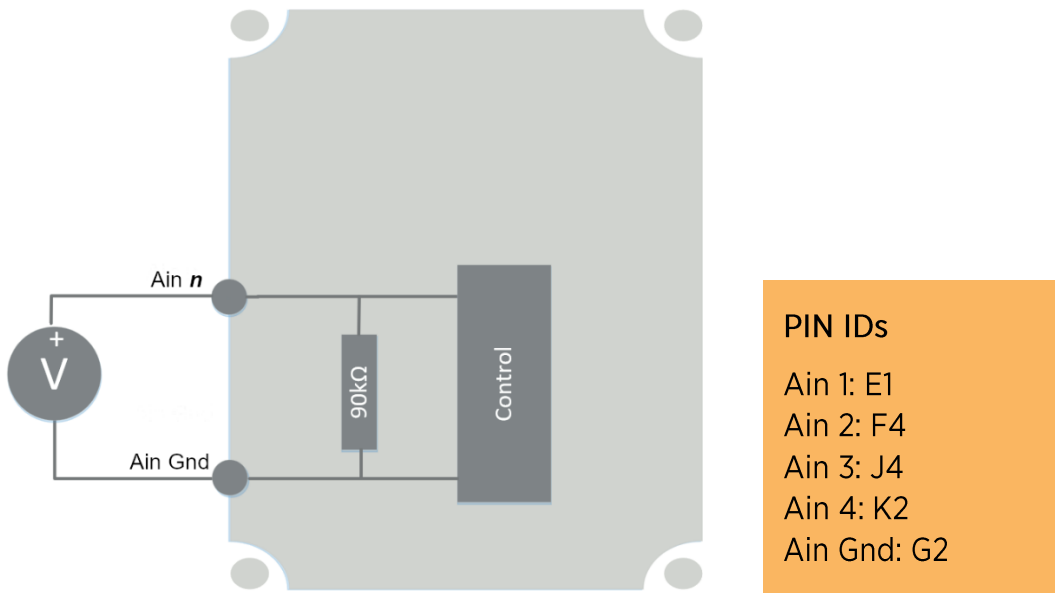


Figure 17 – Analogue input connection

Absolute maximum input voltage	36V (continuous)
Accuracy	5%
Bandwidth	127Hz
Input resistance	90kΩ
Input voltage	0V to 10V
Resolution	10 bit
Wire size, recommended	0.5mm ² / AWG20

Table 11 – Analogue inputs



To preserve analog signal accuracy, use good wiring practice, especially to the Ain Gnd signal. This ground is also used for the sourcing digital out.

6.7 Input – Temperature

The controller has two identical temperature sensor inputs, typically used for motor temperature measurement, and can be used to ensure improved reliability and operation of the motor and controller.

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The temperature sensor is connected between TH1 / TH2 (the sensor input) and KL31 0V (the signal ground).

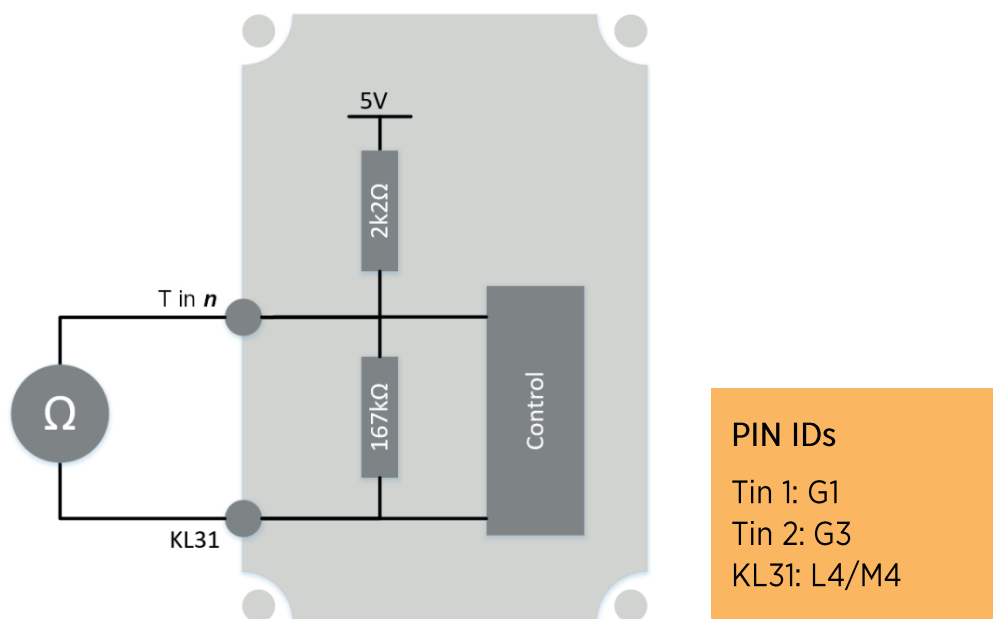


Figure 18 – Temperature sensor connection

Absolute maximum input voltage	36V (continuous)
Accuracy: 10% from 330Ω to 1000Ω	When configured with a KTY84: @20°C ± 5°C; @200°C ± 5°C, (typical) When configured with a PT1000: @20°C ± 6°C; @200°C ± 6°C, (typical)
Internal excitation for the thermistor	5V with 2.2kΩ pull-up resistor (the calibration takes into account the internal resistors)
Wire size, recommended	0.5mm ² / AWG20

Table 12 – Thermistor inputs

6.8 Input - Sin-Cos Encoder

The controller has one Sin-Cos encoder input. The pins are shared with the A-B encoder input. Sin-Cos encoders are one of several motor speed/position sensors supported by the controller.

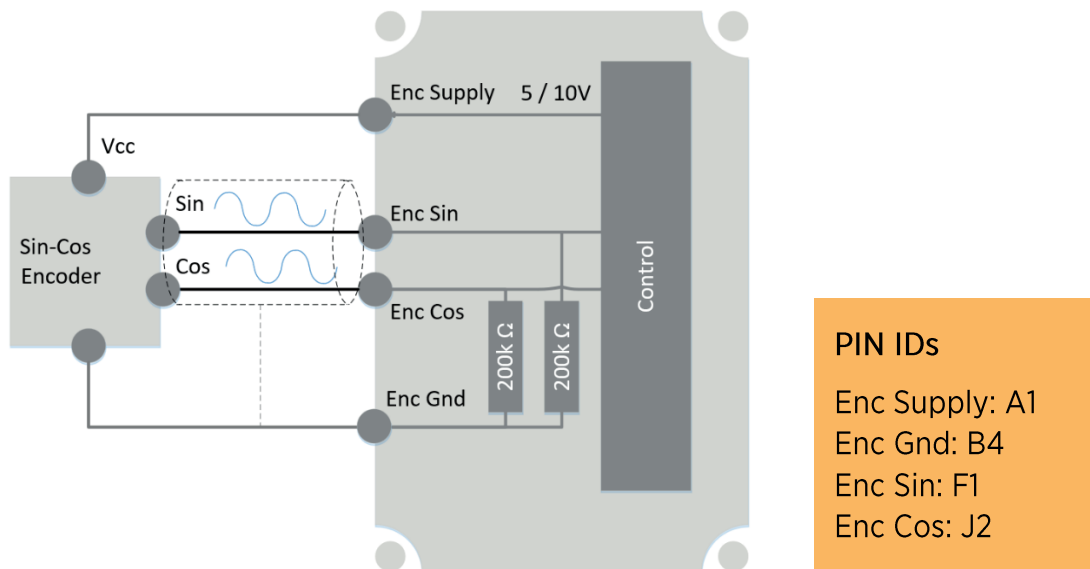


Figure 19 – Sin-cos speed sensor connection

Absolute maximum input voltage	36V (continuous)	
Current measurement accuracy	5%	
Input impedance	200kΩ	
Input pins	Shared with the A-B Encoder	
Input voltage	0V - 5V	
Maximum frequency	1.2kHz	
Voltage	Select 5V supply. Sin-cos encoder is supplied from a dedicated encoder supply. The 0V - 5V encoder output phases are connected to Enc-Sin and Enc-Cos and the ground to Encoder Gnd (the signal ground).	
		CAUTION To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor.
Wire size, recommended	0.5mm ² / AWG20 screened cable	

Table 13 – Sin/Cos

Pole Pairs

The controller can control motors with sin-cos sensors that produce multiple sin and cosine waves per mechanical rotation. However, the number of pole pairs in the motor must be an integer multiple of the number of sin-cos waves per rotation (itself an integer only).

Examples:

An encoder that produces	Can be used with motors with
1 wave per rotation	1 pole pair, 2 pole pairs, 3 pole pairs, etc.
3 waves per rotation	3 pole pairs, 6 pole pairs, 9 pole pairs, etc.
5 waves per rotation	5 pole pairs, 10 pole pairs, 15 pole pairs, etc.

Table 14 – Sin/Cos waves per revolution

6.9 Input - AB Encoder

The controller has one AB encoder input. The pins are shared with the Sin-Cos encoder input. The AB Encoder is one of several motor speed/position sensors supported by the controller.

Four-wire connection provided for open-collector quadrature pulse encoder devices.

Supplied from a dedicated encoder with a selectable 5/10V supply. Phases are connected to Enc-A and Enc-B and the ground to Enc-Gnd (the signal ground).

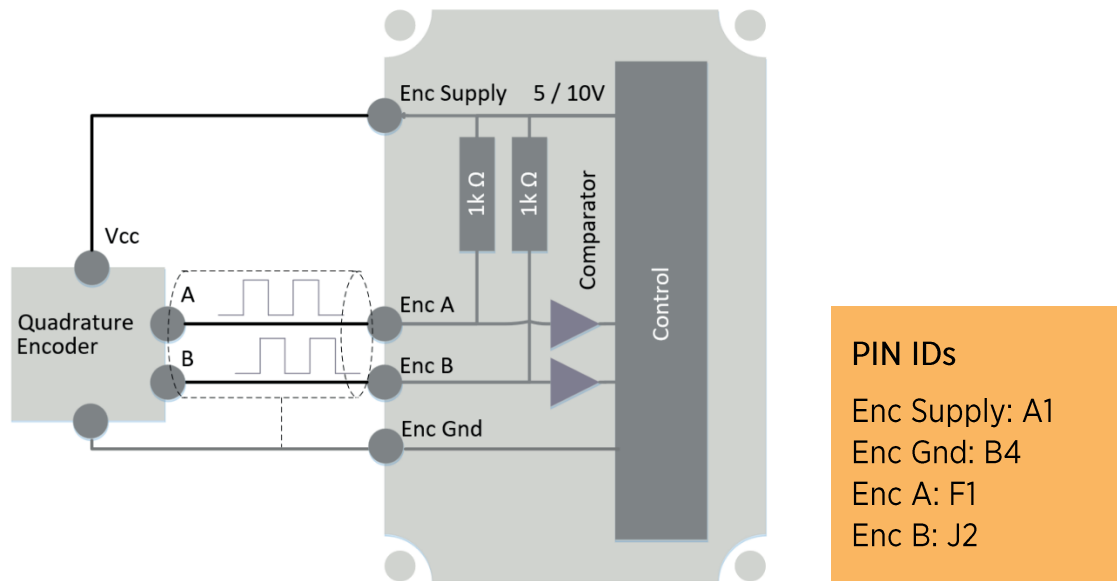


Figure 20 – AB Encoder sensor connection

Absolute maximum input voltage	36V
Filter	<5us A hardware circuit cleans the signal: a glitch filter removes very short pulses and a comparator with hysteresis provides a definite hi & low. The inputs are shared with the Sin-Cos Encoder
Hi/Low threshold	50% of Encoder supply (2.5 or 5V)
Hysteresis	300mV
Maximum Frequency	50kHz. For a pulses per revolution (ppr) encoder, the maximum readable motor speed is $50,000 \times 60 / (\text{ppr}/2)$. For example: 256 pulses per evolution, maximum readable speed is ~11,700 RPM
Voltage	Selectable 5V / 10V  CAUTION To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor
Wire size, recommended	0.5mm ² / AWG20 screened cable

Table 15 – AB encoder

6.10 Input - UVW Encoder

The controller has one set of U-V-W Hall sensor inputs.

The UVW encoder is one of several motor speed/position sensors supported by the controller. A UVW input (Hall Sensors in diagram) is supplied from a dedicated encoder with a selectable 5/10V supply. The UVW input (Hall Sensors in diagram) signals to Enc-U, Enc-V and Enc-W and the ground to Encoder Gnd (the signal ground).

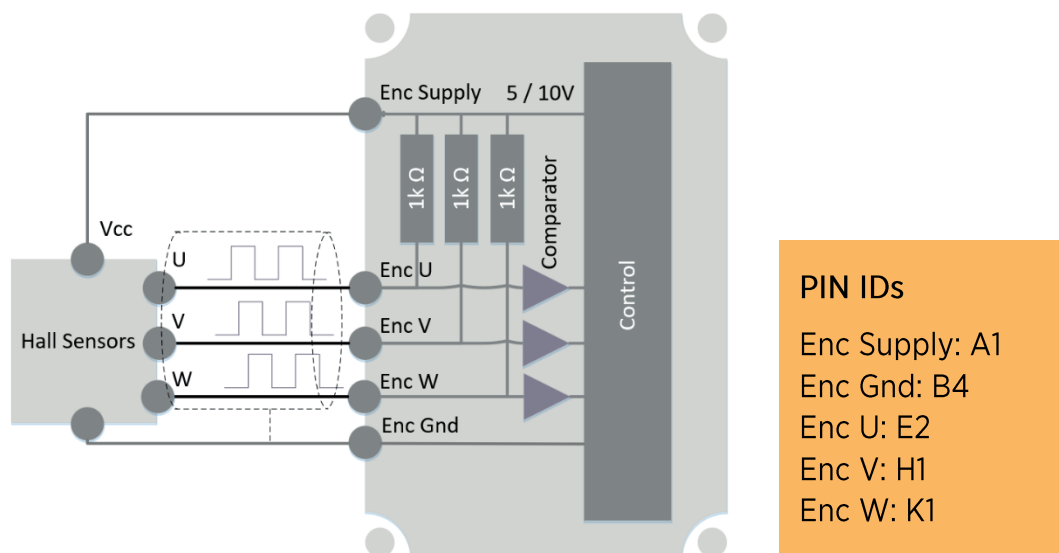


Figure 21 – UVW speed sensor connection

Absolute maximum input voltage	36V	
Filter	< 5us. A hardware circuit cleans the signal: a glitch filter removes very short pulses and a comparator with hysteresis provides a definite hi & low.	
Hi/low threshold	50% of Encoder supply (2.5 or 5V)	
Hysteresis	300mV	
Maximum frequency	1.2kHz	
Selectable voltage	Selectable 5V / 10V	
		CAUTION To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor
Wire size, recommended	0.5mm ² / AWG20 screened cable	

Table 16 – UVW encoder

6.11 Input – Resolver

The controller supports one resolver. The resolver is one of several motor speed/position sensors supported by the controller.

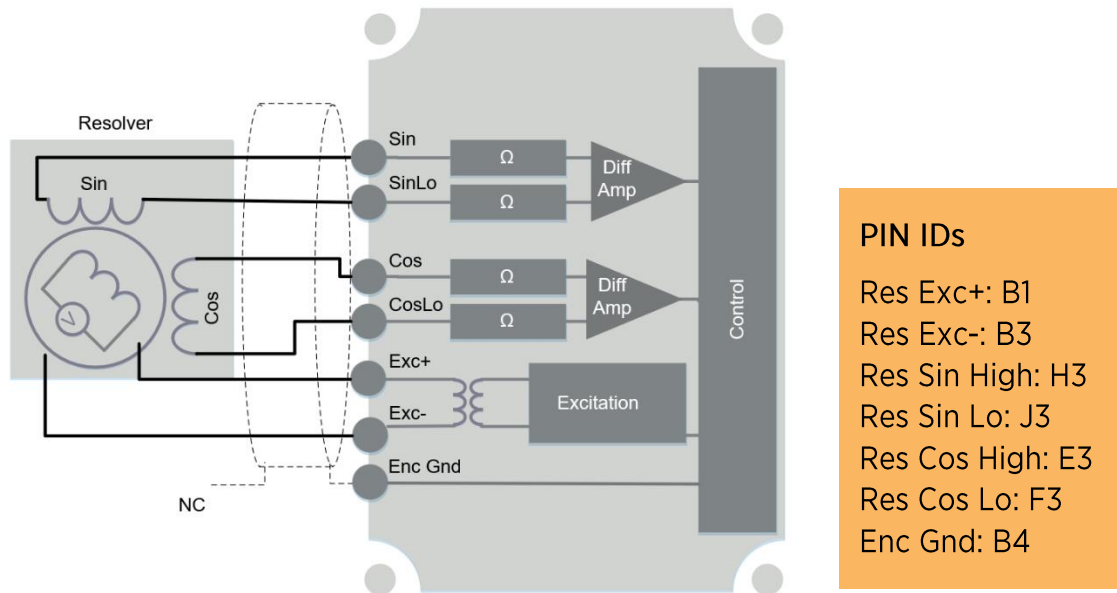


Figure 22 – Resolver wiring connection

Common mode impedance	21k Ω
Differential mode impedance	24k Ω
Excitation	- Excitation frequency: 10kHz - Maximum output voltage: 3.5Vrms - Maximum output current: 50mA - Isolated
Resolver gain range	0.2 to 0.7
Resolver voltage input	1.5Vp-p
Wire size, recommended	0.5mm ² / AWG20. Differential pairs should be twisted-pair with the shield connected to encoder ground.

Table 17 – Resolver

Pole Pairs

The controller can control motors with multiple pole-pair resolvers, that is, returning multiple sine and cosine waves per mechanical rotation. However, the number of pole pairs in the motor must be an integer multiple of the number of resolver pole pairs.

Example:

Encoder	Can be used with motors with
Single pole pair	1 pole pair, 2 pole pairs, 3 pole pairs, etc.
3 pole pair	3 pole pairs, 6 pole pairs, 9 pole pairs, etc.
5 pole pair	5 pole pairs, 10 pole pairs, 15 pole pairs, etc.

Table 18 – Resolver pole pairs

6.12 Output - Low Side Driver (1A PWM capable)

The PWM output pins on this module are capable of sinking a maximum of 1A.

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The load is connected between Aout Supply (positive supply) and Aout 1 (low side PWM).

Connecting directly to KL30 is not recommended. Inductive loads may incorporate a recirculating diode, although it is not required when connected as recommended. (Note the internal controller diode.)

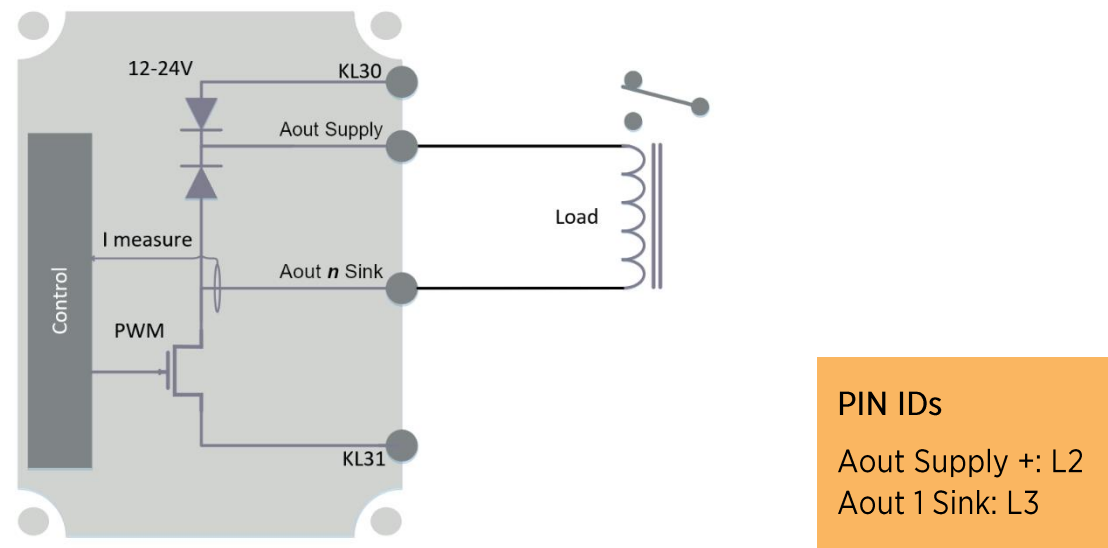


Figure 23 – Low Side PWM output (1A PWM capable)

Current measurement accuracy	± 0.2A
Maximum capacitive load	100nF
Maximum output current	1A continuous
Maximum output voltage	KL30
Protected against	Battery reverse polarity connection and overload
PWM frequency	16kHz (fixed)
Wire size, recommended	1mm ² / AWG17

Table 19 – Analogue output low side PWM



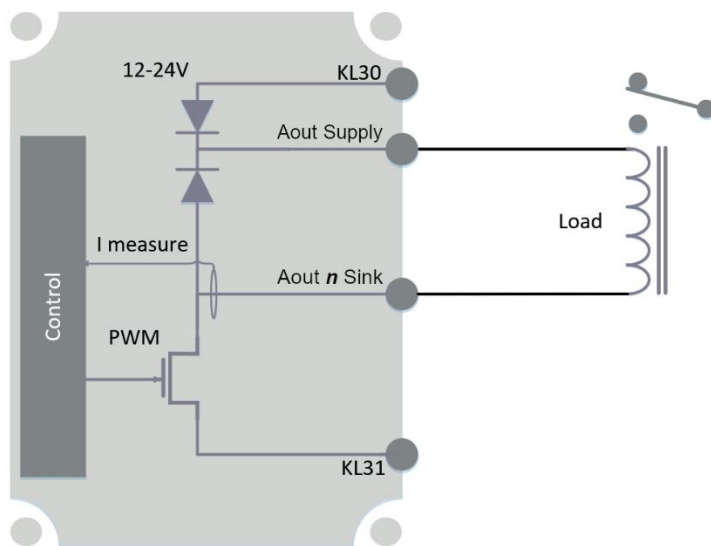
CAUTION Do not use contactors that have built-in economizer circuits. The internal circuits are not compatible with the controller and may cause a malfunction or damage. The current software has limited protection of low side drivers. Use the over-current trip with caution as it is slow to prevent damage in all cases.

6.13 Output - Low Side Driver (3A PWM capable)

The PWM output pins on this module are capable of sinking a maximum of 3A

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The load is connected between Aout Supply (positive supply) and Aout 2 (low side PWM).

Connecting directly to KL30 is not recommended. Inductive loads may incorporate a recirculating diode, although it is not required when connected as recommended. (Note the internal controller diode.)



PIN IDs

Aout Supply +: L2
Aout 2 Sink: M2

Figure 24 – Low side PWM output (3A PWM capable)

Current measurement accuracy	± 0.2A
Maximum capacitive load	100nF
Maximum output current	3A continuous
Maximum output voltage	KL30
Protected against	Battery reverse polarity connection and overload
PWM frequency	16kHz
Wire size, recommended	1mm ² / AWG17

Table 20 – Analogue Output low side PWM



CAUTION Do not use contactors which have built-in economizer circuits. The internal circuits are not compatible with the controller and may cause malfunction or damage. The current

software has limited protection of low side drivers. Use the over-current trip with caution as it is slow to prevent damage in all cases.

6.14 Output - High Side Driver (2A capable)

The controller has two identical digital outputs which source current. The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used.

- The load is connected between KL31 0V (ground reference for signals) and Dout Source 3 or Dout Source 4.
- Inductive loads should incorporate a recirculating diode, although it is not required with low inductance loads, such as a signal relay.

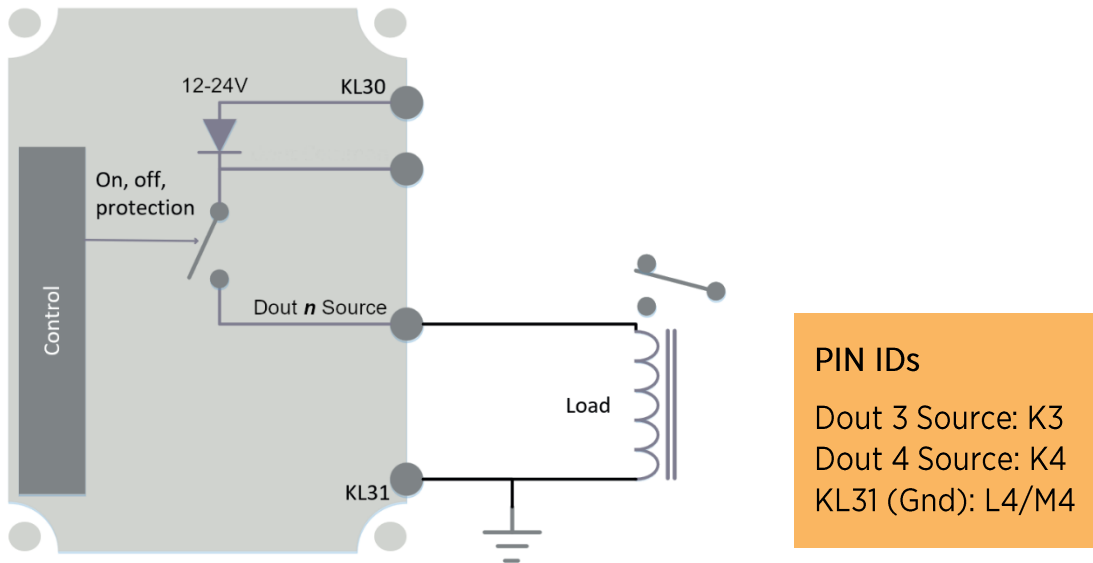


Figure 25 – High side digital driver connection

Maximum capacitive load	1uF
Maximum output current	2A continuous
Maximum output voltage	KL30
Protected against	Battery reverse polarity connection and overload
Wire size, recommended	1mm ² / AWG17

Table 21 – Digital Outputs

6.15 HVIL

The controller has a High Voltage Interlock (HVIL) circuit, which becomes effective when housed in a vehicle system.

The High Voltage Interlock Circuit (HVIL) protects against exposed high voltage. HVIL-A and HVIL-B form a loop. The HVIL is an internally monitored electrical loop that detects when the cable cover is removed. To detect the loop status change, you can use one of the following methods:

- Use an external device to independently monitor the electrical HVIL status
- Configure Gen5-S9 to report on the status of the HVIL over CAN

The software will report the status of the current (flowing or not), but no action will be taken by the inverter.



WARNING All work must be carried out by a competent, qualified engineer, and failure to comply with this advice may lead to risk of high voltage exposure and associated risks, including death.

If action is required when the cover is removed, then this action must be triggered externally to the Gen5-S9 controller. The external system can intervene either physically (for example, by opening line contactors feeding power to the Gen5-S9), or by sending an appropriate CAN message to the Gen5-S9 (for example, by requesting a reduction of torque to 0, or by requesting the disabling of the power frame).

For other HVIL status change action using the Gen5-S9 Custom Code feature, consult Custom-code help pages in the Gen5-S9 interface Documentation Drawer. This loop should be part of the high voltage enable in the DC supply circuit.

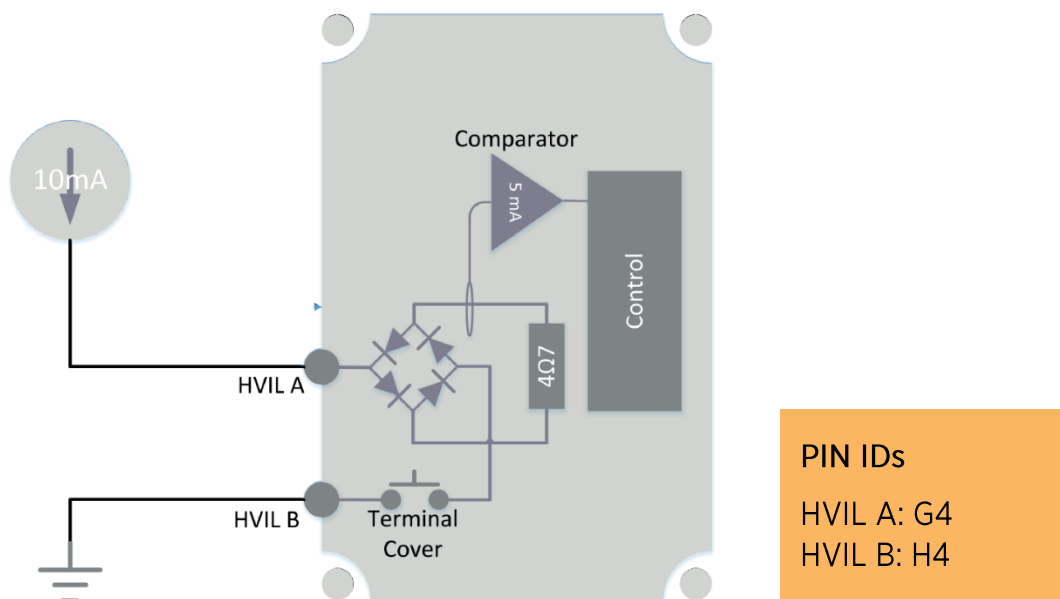


Figure 26 – HVIL schematic connection

Absolute maximum input current	100mA
Galvanic isolation from other circuits	Yes

Maximum voltage drop at 100mA	2.5V
Maximum common mode input voltage	100V
Maximum current guaranteed to be detected as off	3mA
Minimum current guaranteed to be detected as on	5mA
Wire size, recommended	0.5mm ² / AWG20

Table 22 – HVIL

6.16 Supply – Encoder

The controller has a single supply to be used with encoders. The figure shows a simplified schematic of the internal controller circuit and an example of how another circuit can be used. The encoder is connected between Enc-Supply (5V or 10V configurable) and Enc-Gnd.

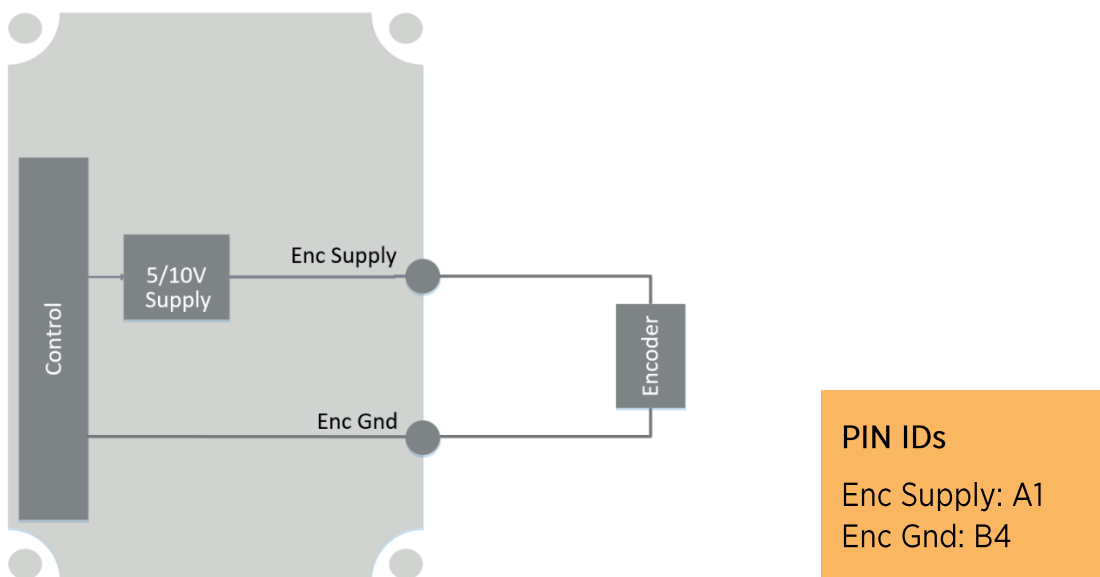


Figure 27 – Encoder supply connection

Voltage output accuracy	5%
Deviation over temperature	1%
Droop overload	1%
Dynamic response	<10% deviation, 10-90% load
Maximum capacitive load	100uF
Maximum output current	200mA continuous
Protected against	Reverse battery connection and overload
Voltage	Either 5V out or 10V out. Configured via a parameter in 0x4631
	 CAUTION To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor.
Wire size, recommended	0.5mm ² / AWG20

Table 23 – Encoder supply

6.17 Supply – User / Sensors

The controller has two identical, independent user (sensor) output supplies. The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The sensor/load is connected between KL31 (ground reference for signals) and User Supply 1 or User Supply 2.

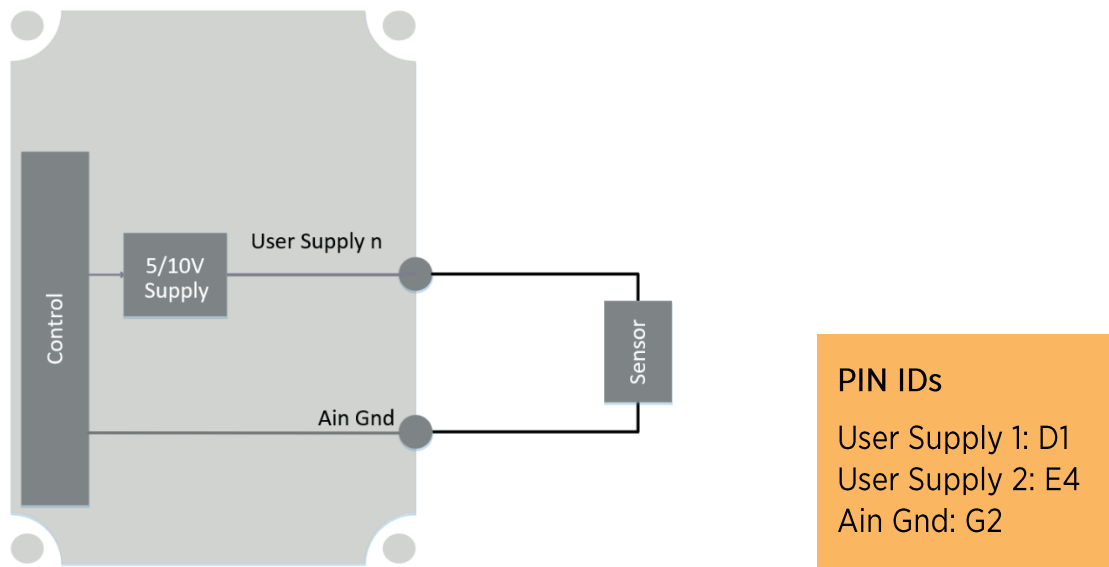


Figure 28 – User supply connection

Voltage output accuracy	5%	
Deviation over temperature	1%	
Droop overload	1%	
Maximum capacitive load	100uF	
Maximum output current	100mA continuous	
Protected against	Reverse battery connection and overload	
Voltage	Either 5V out or 10V out. Configured via a voltage current unit message.	
		CAUTION To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor.
Wire size, recommended	0.5mm ² / AWG20	

Table 24 – Supplies

6.18 Isolation

The Gen5-S9 comprises logic circuits (12V or 24V) and the high voltage circuits connected to B+/B-. These two circuit blocks are galvanically isolated from each other, and from the chassis.

As defined by ISO 6469-3, the logic circuits are class A, and the power circuits class B. There is a reinforced safety barrier between the power circuits and the logic circuits, and basic insulation between the power circuits and the enclosure. See figure 29 below.

The unit is not designed for direct grid connection. As is typical for an electric vehicle the high voltage battery and inverter must be galvanically isolated from the mains supply. Creepage and clearance is sufficient for operation up to a maximum altitude of 4000m.

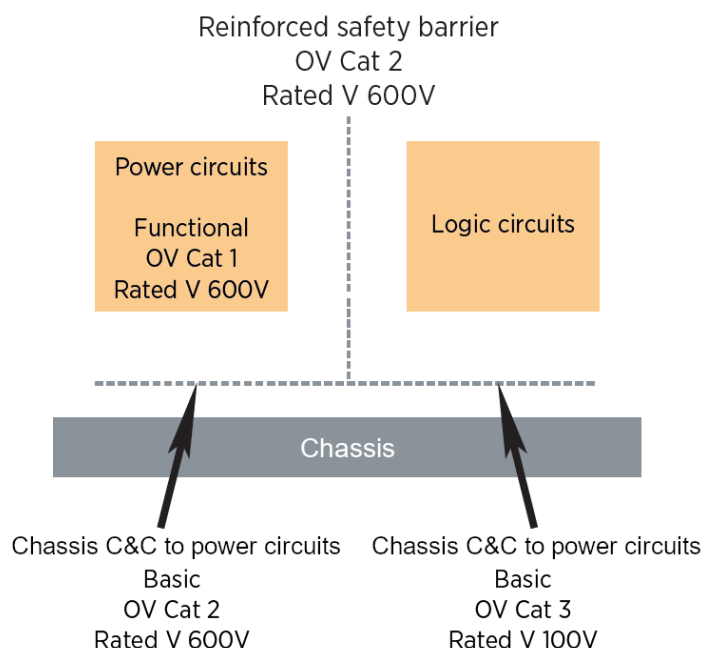


Figure 29 – Isolation diagram

Power terminals to the case:	Withstands 2300 V dc ³
Power terminals to control terminals ²	Withstands 4500 V dc ¹
Control terminals and CAN bus to the case	Withstands 100 V DC

Table 25 – Isolation

Notes:

1. Type test only
2. Removal of case is required to test barrier
3. Production test

Chapter 7: How to Install the Controller

Chapter 7 - How to Install the Controller

7.1 Mounting

This section assumes you are familiar with the EMC guidelines.

7.1.1 Mounting Hole Pattern

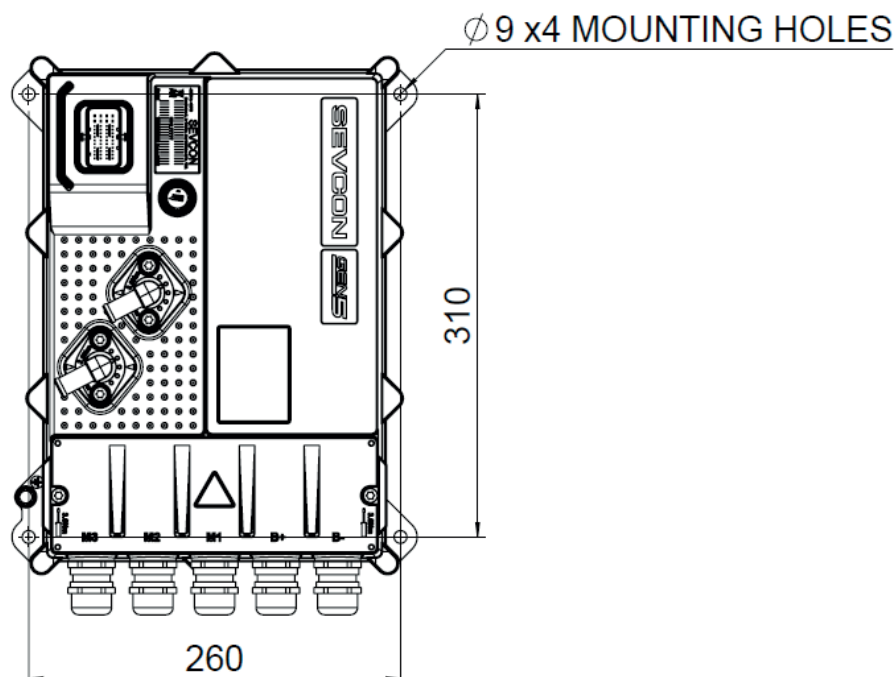


Figure 30 – Mounting hole pattern

Mounting procedure:

1. Position the controller over the mounting surface and ensure the mounting holes are aligned.
1. Fit spring washers over the bolts.
2. Utilizing the spring washers prepared in step 2, insert bolts through the mounting holes and loosely secure the nuts.
3. Firstly, fasten one of the numb and bolt pairs to the recommended torque.
4. Fasten the nut and bolt pair that is diagonally opposite to the pair in step 4 - to the recommended torque.
5. Fasten the remaining nut and bolt pairs to the recommended torque.

*Note: If an alternative mounting method is adopted, for example using screws and threaded holes, please adjust the mounting procedure and torque value accordingly.

7.1.2 Mounting Location



WARNING Electrical power terminals under the terminal cover on the controller present an electric shock hazard. All work must be carried out by a competent, qualified engineer, and failure to comply with this advice may lead to risk of high voltage exposure and associated risks, including death. High currents can also present a burn hazard. You must ensure that the electrical terminals of the controller are protected against access by unauthorized personnel.

When choosing the mounting location for the controller, consider the following guidelines:

1. Do not mount the controller on the outside of a vehicle where it would be assessable to unauthorized personnel.
2. Do not mount the controller where it may be susceptible to damage due to minor collisions or impact from road debris.
3. Although the controller has a high degree of ingress protection, avoid mounting the controller in locations where it may be submerged in water or subjected to long term exposure to jets of water.
4. The controller can be mounted in any orientation.
5. The inverter should not be used as a stressed member.
6. Co-planarity of mounting points: <0.2mm. Failure to comply with this flatness specification can cause deformation of the enclosure and damage to the product.
7. Take note of thermal and EMC considerations.

7.1.3 Equipment Required for Mounting

- 4 x M8 socket cap head bolts, nuts and spring washers. Bolts need to be long enough to pass through 7mm of Gen5-S9 mounting lugs and your mounting surface thickness.
- T hand-socket wrench or Allen key.

Recommended torque setting for the above mounting arrangement: 11Nm

7.2 Cooling Requirements

7.2.1 Cooling Considerations

To get the maximum performance from the controller:

- Keep the controller away from other heat-generating devices on the vehicle.
- Maintain its ambient operating temperature below the specified maximum.
- Maximum allowable coolant pressure of 1.0bar.
- Published ratings are based on a 50/50 water-glycol mixture. The mix you use may vary, depending on the application you are working on.

For information about flow rate, see chapter 5.

7.2.2 Connecting Coolant Hoses

To optimize coolant hose routing within the vehicle, you can adjust the coolant fitting's angle, to support a range of cable options:

1. Remove the X2 M5 screws.
2. Lift the spigot away from the seal.
3. Rotate the spigot to the desired angle.
4. Refit the spigot ensuring the seal is correctly located in the groove.
5. Tighten the X2 M5 screws. The torque setting is $3.0\text{Nm} \pm 0.2\text{Nm}$

Coolant spigot outer diameter: 13mm (14.2mm over lip/bulge).

Hoses should be provided with mechanical fixing within 200mm of the fitting.

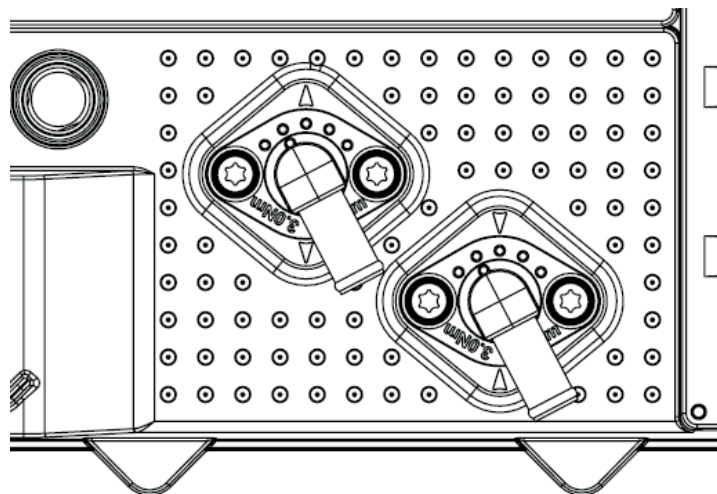


Figure 31 connecting coolant hoses



CAUTION Coolant flow direction is shown with arrow heads marked on the case (next to the coolant ports). Failure to comply with this will reduce performance and may damage the product.

7.3 Earth Connection

It is essential that the chassis earth connection on the enclosure is connected to the vehicle or machine chassis using a short cable.

- The controller is supplied with an M6 hex-head screw for this purpose.
- The protective chassis cable must be minimum 50% cross-sectional area of the power cables, terminated at the controller end with a suitable M6 ring terminal.
- The screw is supplied with a flat washer and spring washer, which should all be refitted, and the screw tightened to $5\text{Nm} \pm 0.5\text{Nm}$.
- The protective earth connection should have a maximum resistance of 0.1Ω when measured at 20A.

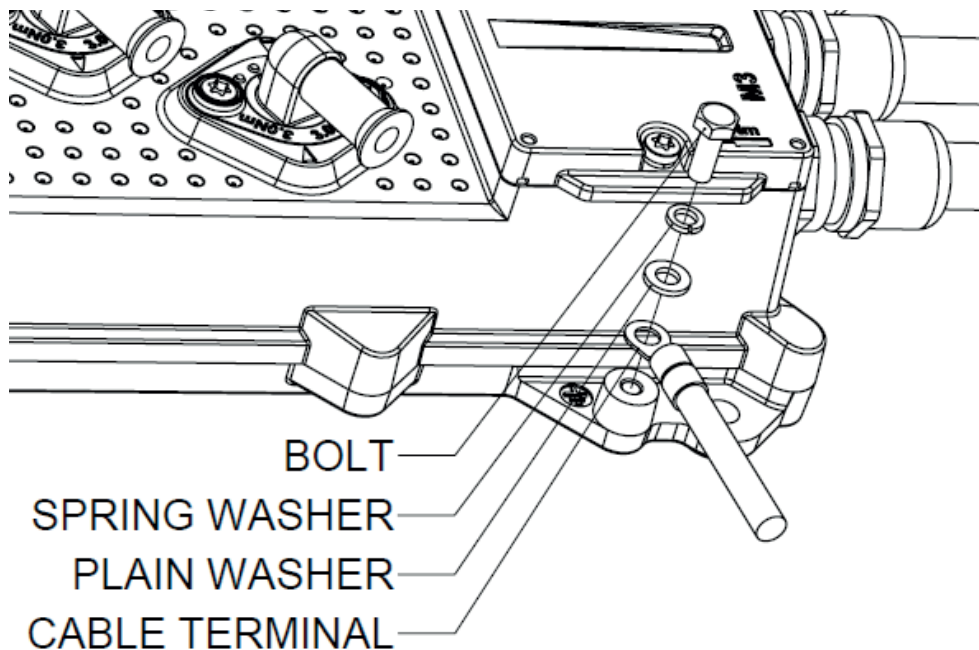


Figure 32 earth connection



WARNING Failure to provide a correctly sized protective earth connection may lead to risk of high voltage exposure and associated risks, including death, as well as non-compliance with international electrical safety regulations.



High voltage cable shields should be regarded as EMC shields and are not a substitute for the protective earth connection described above

7.4 Power Cables

Use the following tools and materials:

- Screened power cables sized to suit the controller and application
- Power cabling must have an orange colored outer sheath, to comply with automotive regulations
- M8 crimp ring lugs
- Heat-shrink sleeving
- Copper tape
- Crimp tool
- M8 wrench

Note: Cables carrying high AC currents are subject to alternating forces and may require support in the cable harness to avoid long-term fatigue.

7.4.1 Wire Size

When deciding on power cable diameter, consider cable length, grouping of cables, the maximum allowable temperature rise, and the temperature rating of the chosen cable.

7.4.2 Recommended Torque

Cable terminals should be secured by tightening the socket screws to $11\text{Nm} \pm 2\text{Nm}$.



CAUTION Coolant flow direction is shown with arrow heads marked on the case (next to the coolant ports). Failure to comply with this will reduce performance and may damage the product.

7.4.3 To Attach a Terminal Lug to the Power Cable



WARNING Ensure voltage is fully discharged, before removing cover. Failure to do so may lead to risk of high voltage exposure and associated risks, including death.

Procedure to connect a cable:

1. Ensure the chosen terminal lug will fit through the cable gland with an ID of approx. 18mm.
2. Cut back the outer sheath and screen 40mm.
3. Cut back the inner insulation 21mm.
4. Cut back the outer sheath 65mm.
5. Crimp the terminal lug.
6. Fit the copper tape over the screen.
7. Fit the heat shrink sleeve over the lug and inner insulation.

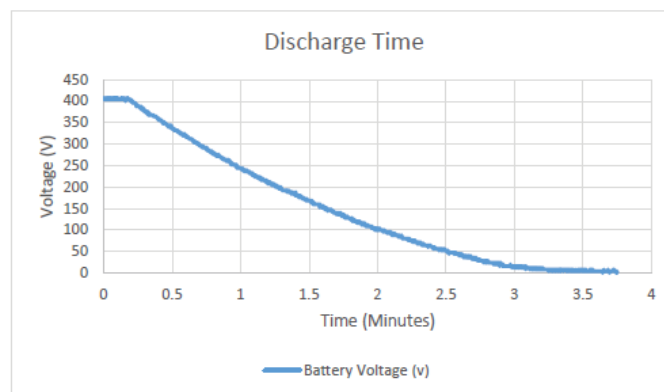


Figure 33 discharge time

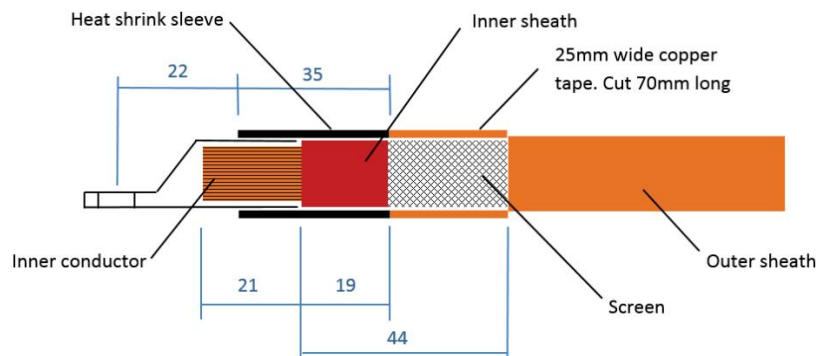


Figure 34 cable connection



WARNING Ensure there are no loose conductor strands or screen mesh braid exposed, as debris could fall into the unit and cause a PCB short circuit. The cable must be properly prepared with heat-shrink sleeve and copper tape, as instructed.

7.4.4 To Attach Cables

Keep the following in mind:

- The cable glands accept cables with outer diameters of Ø10mm ~ Ø18mm.
- Keep cable runs short.
- Minimize current loops by keeping positive and negative cables as close together as possible.
- Connect your power cables using the bolts supplied. They are sized to clamp one ring lug thickness. Use a longer bolt if you are fastening more than one ring lug. You need thread engagement of at least 10mm and the maximum penetration is 15mm.

To feed the cable through the cable gland:

1. While feeding a cable through a cable gland, loosen the cap first.
2. When it is completely undone, immediately tighten it back for about 1 or 2 threads engagement.
3. Then push the cable through the gland with the cap retained.
4. Once the terminal is secured, the cap can be tightened.
5. During the entire installation, DO NOT separate the cap from the rest of the gland structure.

This is to prevent any inner components dropping out. If inner components are missing or not aligned properly while reinserting, the gland could have a leaking problem.

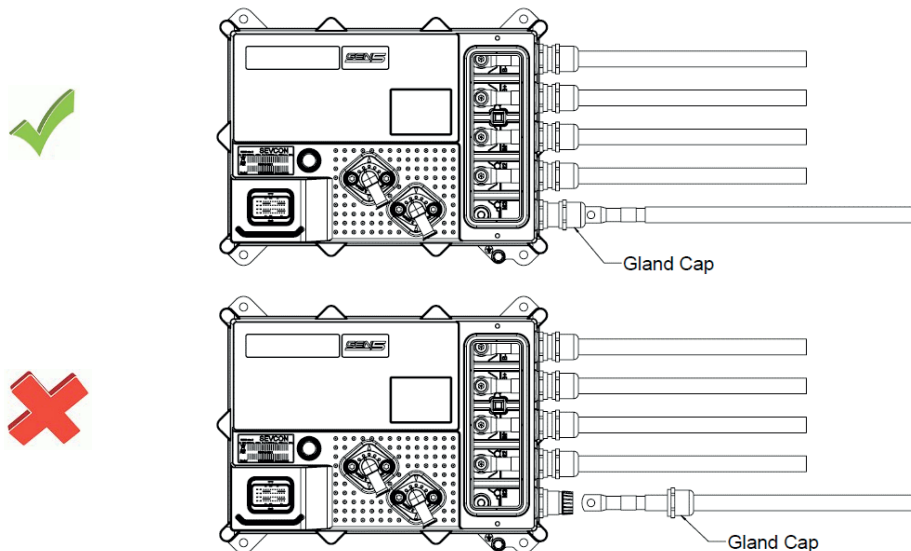


Figure 35 feeding cables



CAUTION If you use a bolt that is too long, damage to the terminal and overheating of the connection may occur. If you use a bolt that is too short and there is not enough thread engagement, you may damage the threads.

7.4.5 Using Screened Cables & Metal Screened Cable Glands

1. Ensure that all high voltage power cables are electrically isolated from the cable glands on the controller.
2. Ensure the cable screen is electrically isolated from the live inner conductor and the cable termination.
3. Under no circumstances should any of the cable screens be connected to any power terminal or live conductor.
4. The metal cable gland cap should be tightened to the gland body to a torque of $15\text{Nm} \pm 1.0\text{ Nm}$.
5. Once the unit is fitted, ensure the first 70mm exposed cables are straight, that is, no bending, and in line with the cable gland as much as possible. This is to achieve optimum sealing performance at the gland and cable interface.

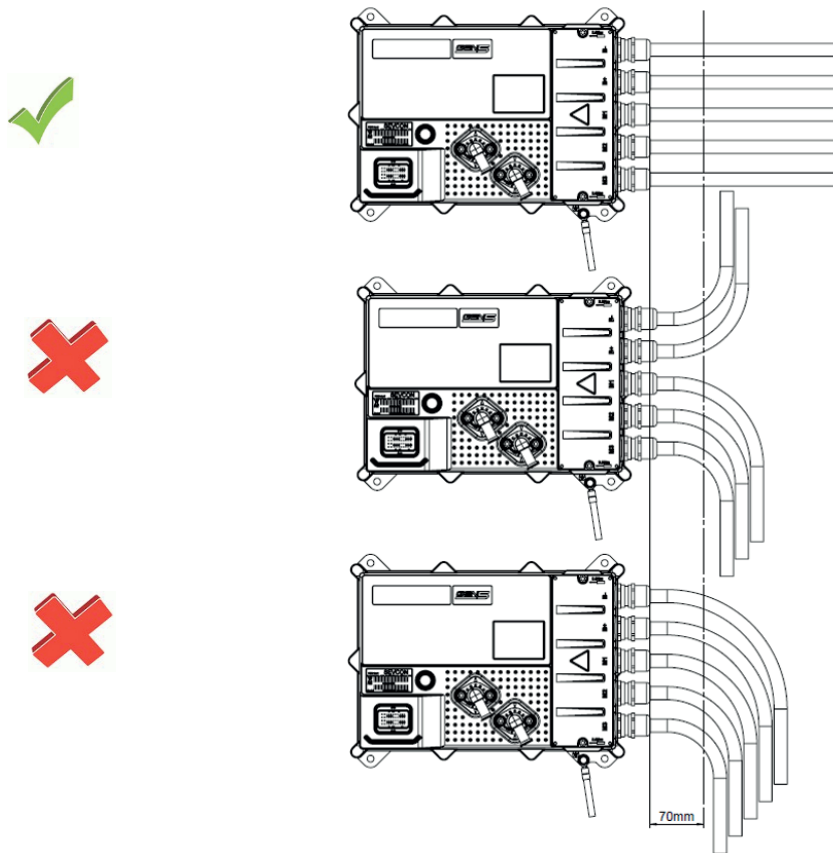


Figure 36 70mm of cables left straight



CAUTION When using metal cable glands, ensure that the spring contact fingers within the gland connect to the cable screen. There should be at least 8mm of inner insulator between the end of the screen and the cable lug.

7.4.6 Fitting the terminal cover

1. Ensure the lid seal is correctly positioned. The HVIL plug must be correctly aligned with the socket.
2. Position the cover ensuring it sits flat against the seal.
3. Fit the X2 M5 screws (provided) to a torque setting of $3.0\text{Nm} \pm 0.3\text{Nm}$.

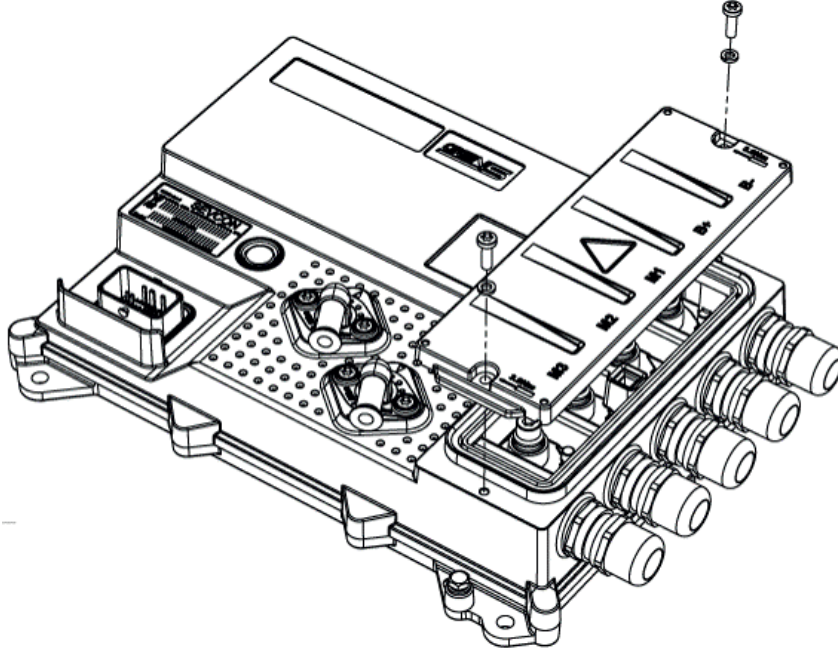


Figure 37 fitting terminal cover

7.5 Main Contactor and Pre-charge circuit

The Gen5 size9 controller does not offer any internal pre-charge function. Pre-charge must be done externally to the unit. If battery isolation is required for the application, an external device must be used to isolate the Gen5 size9 from the vehicle battery.

It is recommended that the pre-charge circuit is connected as shown in Figure 38. The circuit is intended to operate in the following manner: -

- At start-up K1 must be energized, the controller DC bus voltage should be monitored and should have reached 90% of the battery voltage within 5 seconds.
- If the DC bus voltage is more than 90% of battery voltage the main contactor K2 can now be closed. If the DC bus voltage is too low, this indicates a fault has occurred and K1 should be de-energized.

At shut-down K1 and K2 may be de-energized simultaneously.

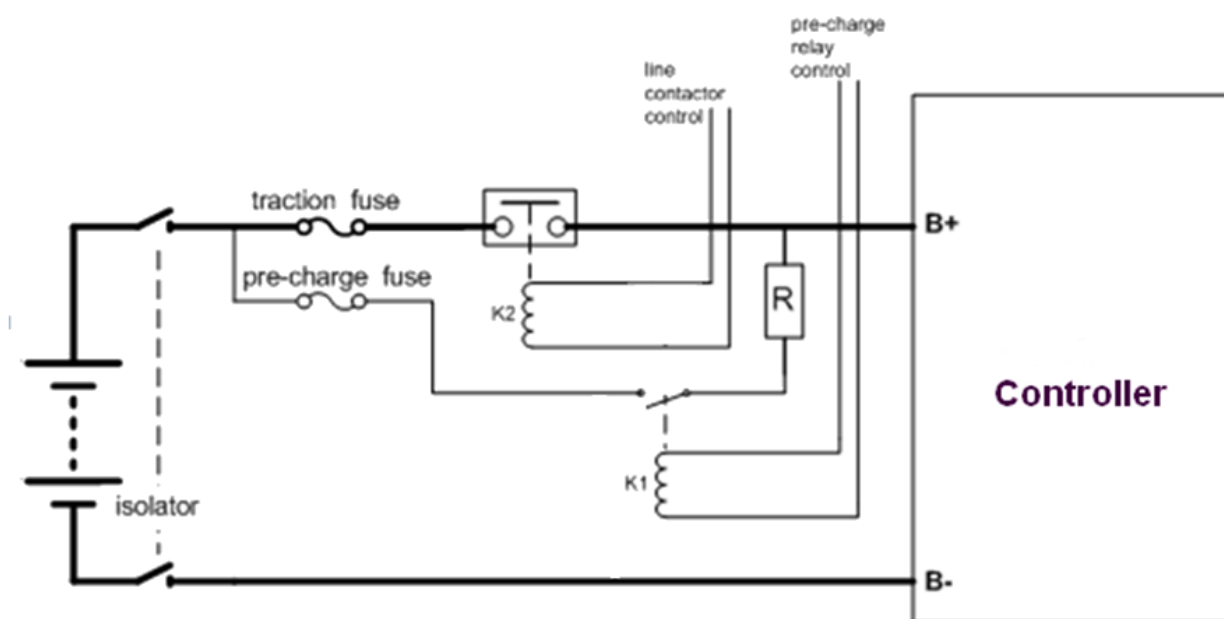


Figure 38 Line contactor and pre-charge wiring diagram

Components required for the pre-charge circuit are listed in Table 26.

Name	Function	Required specification	Comment
F1	Pre-charge fuse	500V DC 10A Slow blow preferred	
F2	Main traction fuse	500V DC 500A Semiconductor fuse	
K1	Pre-charge contactor / relay	Single pole 500V DC 10A	
K2	Main line contactor	>450V DC >500A	Must be interlocked so that K2 can only close if K1 is energized.
R1	Pre-charge resistor	Resistance 150Ω to 500Ω Pulse voltage 450V Energy pulse 100J Power 25W	Must be overload protected with thermal cut out and/or fuse

Table 26 - Pre-charge Components



WARNING Failure to use a capacitor pre-charge circuit may damage the controller and line contactor

A switchable resistor can be used to limit pre-charge inrush current. System voltage and other requirements should be used to determine the resistance and power values. The line contactor should close only after the controller has reached 90% of the battery voltage. The system should not remain in pre-charge for more than 5 seconds.



WARNING The internal DC capacitor bank will remain charged at a hazardous voltage for several minutes after power has been removed. If required a discharge circuit should also be integrated into the system.

Note that, if you use the built-in contactor drivers for the pre-charge relay and main line contactor, the coil specification must fall within the working limits of the Gen5 size9. Please refer to Sections 6.12, 6.13 and 6.14, starting from page 45.

Chapter 8: Safety, Regulation, and Standards

Chapter 8 - Safety, Regulations and Standards

8.1 Compliance

8.1.1 ISO 16750 Compliance Summary

For standards satisfied, please see below.

The coding system (B/E, L, H, I and Z) defines which parts/tests the MCU complies with, depending on the vehicle mounting location.

Standard section	ISO16750 code	Parameter	Description	Comments
ISO16750-2	B/E	US_MIN 8V/10V US_MAX 16V/32V	MCU supply voltage limits. The MCU must be able to perform in class A conditions and throughout the operating temperature range defined in ISO16750-4 within the supply voltage limits.	As the MCU is a dual 12V/24V product, code A (12V) and code E (24V) have been defined. The worst-case supply voltage will be used in tests.
ISO16750-3	L	See ISO16750-3 Table 25	Mechanical test requirements.	Mechanical tests conducted and their levels are determined by this code. For details, see ISO16750-3 Table 25.
ISO16750-4	H	TMIN -40°C TMAX 90°C	MCU operating temperature range. The MCU must be able to perform in class A conditions throughout this operating temperature range.	The MCU will operate in this range so long as the coolant is at a maximum temperature of 85°C. The MCU output capability will de-rate at higher temperatures; this is still deemed to be class A operation.
ISO16750-4	I	See ISO16750-4 Table 4	Climatic test requirements.	Climatic tests conducted and their levels are determined by this code. For details, see ISO16750-4 Table 4.
ISO16750-5	A/Z	See ISO16750-5 Table 1	Chemical test requirements.	Chemical tests conducted and their levels are determined by this code. For details, see ISO16750-5 Table 1.

Table 27

8.1.2 Test Requirements for the MCU and Compliance Status

Standard	Section	Test	Status
ISO 16750-2	4.2	DC Supply Voltage.	Compliant - Class A
ISO 16750-2	4.4	Over-voltage	Compliant - Class C
ISO 16750-2	4.2	Superimposed Alternating Voltage	Compliant - Class A
ISO 16750-2	4.5	Slow Decrease and Increase	Compliant - Class A/D
ISO 16750-2	4.6.1	Momentary Drop in Supply	Compliant - Class B
ISO 16750-2	4.6.2	Reset Behavior at Voltage Drop	Compliant - Class C
ISO 16750-2	4.6.3	Starting Profile	Compliant - Class A
ISO 16750-2	4.6.4	Load Dump	Compliant - Class C
ISO 16750-2	4.7	Reverse Voltage	Compliant - Class A
ISO 16750-2	4.9.1	OC Single Line Interruptions	Non-Compliant1
ISO 16750-2	4.9.2	OC Multiple Line Interruptions	Compliant - Class C
ISO 16750-2	4.10.2	SC Signal Circuits	Non-Compliant1
ISO 16750-2	4.10.3	SC Load Circuits	Non-Compliant1
ISO 16750-2	4.11	Withstand Voltage	Compliant - Class C
ISO 16750-2	4.12	Insulation Resistance	Compliant - >10MΩ
ISO 16750-3	4.1.2.7	Random Vibration - Test VII	Compliant - Class A
ISO 16750-3	4.2.2	Mechanical Shock - Rigid	Non-Compliant4
ISO 16750-3	4.3	Free-fall	Non-Compliant2
ISO 16750-4	5.1.1.1	Low Temperature Storage Test	Compliant - Class C
ISO 16750-4	5.1.1.2	Low Temperature Operation Test	Compliant - Class A
ISO 16750-4	5.1.2.1	High Temperature Storage Test	Compliant - Class C
ISO 16750-4	5.1.2.2	High Temperature Operation Test	Compliant - Class A
ISO 16750-4	5.2	Temperature Step Test	Compliant - Class A

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Standard	Section	Test	Status
ISO 16750-4	5.3.1	Temperature Cycling	Compliant - Class A
ISO 16750-4	5.3.2	Rapid Temperature Change	Compliant - Class C
ISO 16750-4	5.4.3	Submersion Test	Compliant - Class A
ISO 16750-4	5.6.2.3	Composite Temperature/Humidity Cyclic Test	Compliant - Class A
ISO 16750-4	5.6.2.4	Dewing Test	Compliant - Class B
ISO 16750-4	5.7	Damp Heat Steady State	Compliant - Class A
ISO 16750-4	5.5.1	Salt Spray Corrosion Test	Compliant - Class C
ISO 16750-4	5.5.2	Salt Leakage and Function Test	Compliant - Class A
ISO 16750-4	5.8	Corrosion Test with Flow of Mixed Gases	Compliant - Class C
ISO 16750-5	4	Chemicals - Various	TBC - Class3
Notes 1. MCU requires a user power recycle because current software does not allow recovery from certain faults. Additionally, the current software does not support protection of low side drivers. 2. DC link capacitor pins breaking; however, there was no significant indentation made to the MCU, hence the non-compliance result. 3. Chemical tests were successfully carried out on prototype units; however, these were machined and not of-tool. 4. Break in track near fastener, hence the non-compliance result.			

Table 28

8.1.3 REG10 Compliance Summary

For standards satisfied, please see below

Standard	Section	Test	Status
UNECE REG10	6.5 and 6.6	Radiated Emissions	Compliant
UNECE REG10	6.8	Radiated Immunity	Compliant
UNECE REG10	6.9	Transient Disturbances - Immunity	Compliant
UNECE REG10	6.7	Transient Disturbances - Conducted	Compliant

Table 29 – REG10 compliance

8.1.4 IP Compliance Summary

The motor controller has an IP rating of IP6K9K as well as IP67.

Standard	Test	Status
UNECE REG10	Submersion	Compliant
UNECE REG10	Steam	Compliant

Table 30 – IP compliance