Gen4

Applications Reference Manual

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TECH/OPS

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Partner with Performance™

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Chapter 1: Introduction

About Gen4 documentation

This version of the manual

This version of the Gen4 manual replaces all previous versions. Sevcon has made every effort to ensure this document is complete and accurate at the time of printing. In accordance with our policy of continuing product improvement, all data in this document is subject to change or correction without prior notice.

Copyright

Scope of this manual

The Application Reference Manual provides important information on configuring lift and traction drive systems using Gen4 controllers as well as details on sizing and selecting system components, options and accessories.

The manual also presents important information about the Gen4 product range.

Related documents

The following documents are available from Sevcon:

- The Object Dictionary providing important information about CANopen communication with Gen4.
- Device Configuration Files (DCF) and Electronic Data Sheets (EDS) for each Gen4 model and revision.

Drawings and units

Orthographic illustrations in this manual are drawn in Third Angle Projection. SI units are used throughout this manual.

Warnings, cautions and notes

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:

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 Sevcon product.

Product identification label

If you have a customized product your unique identifier will appear at the end of the Type number. When discussing technical issues with Sevcon always have your product's Type number, Part number and Serial number available. Figure 1 shows a typical product identification label.

Figure 1 Product identification label

Technical support

For technical queries and application engineering support on this or any other Sevcon product please contact your nearest Sevcon sales office listed on the inside front cover of this manual. Alternatively you can submit enquiries and find the details of the nearest support center through the Sevcon website, www.sevcon.com.

Product warranty

Please refer to the terms and conditions of sale or contract under which the Gen4 was purchased for full details of the applicable warranty.

Chapter 2: About the Gen4

Introduction

Sevcon Gen4 controllers are designed to control 3-phase AC induction motors and Permanent Magnet AC (PMAC) motors in battery powered traction and pump applications. A range of models is available to suit a wide number of applications and cooling regimes.

The controller adapts its output current to suit the loading conditions and the ambient in which it is operating (temporarily shutting down if necessary). It will also protect itself if incorrectly wired.

Signal wiring and power connections have been designed to be as simple and straight forward as possible. Analog and digital signal inputs and outputs are provided for switches, sensors, contactors, hydraulic valves and CAN communications. These electrical signals can be mapped to Gen4's software functions to suit a wide range of traction and pump applications.

Given Gen4's mapping versatility it is important to ensure you map your application signals to the correct software functions (see 'Manual object mapping' on page 6-11). A common configuration is supplied by default which may suit your needs or act as a starting point for further configuration.

Configuration and control of Gen4 is fully customizable using Sevcon's Calibrator handset or DriveWizard, an intuitive Windows based configuration software tool.

A single green LED is provided to give a visual indication of the state of the controller. This signal can be replicated on a dashboard mounted light for example.

Standard features and capabilities

Available options

There are two mechanical package options (Figure 2) for the Gen4 controller at each voltage and current rating.

Frame size 4

Frame size 6

Figure 2 Mechanical package options

Intended use of the Gen4

The Gen4 motor controller can be used in any of these main applications for both pump and traction control:

- Counterbalanced, warehouse and pedestrian fork lift trucks
  (Classes 1 to 3, FLT1, 2 & 3)
- Airport ground support (AGS), including tow tractors
- Utility vehicles
- Burden carriers
- Sweepers and scrubbers
- Golf buggies/carts
- Neighborhood electric vehicles (NEV)
- Scooters
- Marine

Available accessories

The following accessories are available from Sevcon

- Loose equipment kit (connectors and pins) for Gen4
- Gen4 cooling kit
- CANopen Calibrator Handset

- SmartView™ display
- ClearView™display
- Hourmeters
- Contactors
- Fuses
- Drive Wizard - PC based configuration tool
- SCWiz – PC based motor characterisation tool

Overview of a truck drive system

Each traction or pump application requires a number of system components. The main components (excluding control inputs such as throttle and seat switch) are shown in Figure 3. In this example there are two controllers, a traction motor and a hydraulic pump, however all the main components would be the same if controller 2 was also powering a traction motor.

Communication between the controllers is achieved using the CANopen protocol. This protocol also allows Gen4 to communicate with other non-Sevcon, CANopen compliant devices.

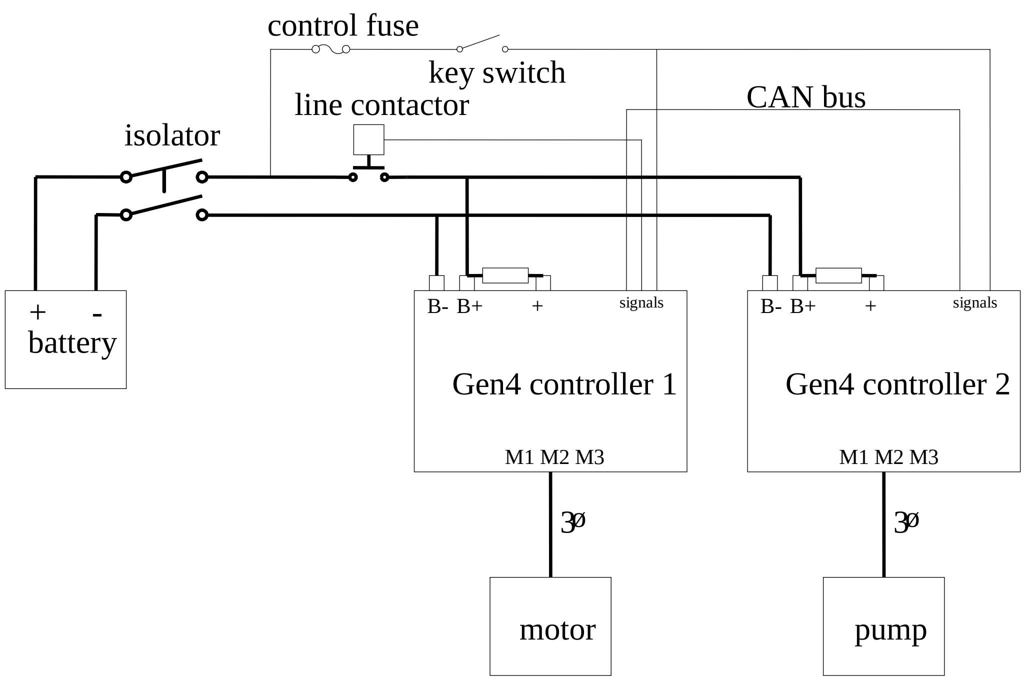


Figure 3 Truck system components

Signal power for the internal control circuits and software is derived from the battery via the control fuse and key switch as shown. No external in-rush current limiting is needed as long as Gen4 is used to control the line contactor and hence the timing of its closure. The software controls the start up sequence in this order:

1. Charge the input capacitors to within 10V of battery voltage (via the key switch signal line).
2. Close line contactor.

3. Generate output to the motor as demanded.

A line input fuse can be mounted on the body of the controller. The 'B+' terminal is a dummy terminal. If the fuse is mounted elsewhere, connections from the battery positive are made to the controller '+' terminal.

Principles of operation

FUNCTIONAL DESCRIPTION

The main function of Gen4 is to control the power to 3-phase squirrel-cage AC induction or PMAC motors in electric vehicles. Four-quadrant control of motor torque and speed (driving and braking torque in the forward and reverse directions) is allowed without the need for directional contactors. Regenerative braking is used to recover kinetic energy which is converted into electrical energy for storage in the battery.

In a traction application control commands are made by the driver using a combination of digital controls (direction, foot switch, seat switch, etc.) and analog controls (throttle and foot brake). The controller provides all the functions necessary to validate the driver's commands and to profile the demand for speed and torque according to stored parameters.

Throttle inputs can be configured as speed or torque-speed demands with throttle-dependent speed limits: in either case, a torque demand is continually calculated to take account of pre-set limits on the level and rate-of-change of torque. The torque demand is used to calculate current demands; that is, the controller calculates what currents will be required within the motor to generate the required torque.

There are two distinct components of the current, known as the d-q axis currents, which control current flow in the motor. The d-axis current is responsible for producing magnetic flux, but does not by itself produce torque. The q-axis current represents the torque-producing current.

When a vehicle is ready to drive, but no torque is being demanded by the driver, the d-axis or magnetizing current will be present in the motor so that the vehicle will respond immediately to a torque demand. To save energy the magnetizing current is removed if the vehicle is stationary and no torque has been demanded after a set period.

Measured phase currents and current demands i_d and i_q, the d-q axis currents, are used as part of a closed-loop control system to calculate the necessary voltage demands for each phase of the motor. Voltage demands are then turned into PWM demands for each phase using the Space Vector Modulation (SVM) technique. SVM ensures optimum use of the power semiconductors.

Power conversion section

The power conversion section of Gen4 employs a 6-switch MOSFET bridge operating at an effective frequency of 16 kHz. Excellent electrical and thermal efficiency is achieved by:

- Minimization of thermal resistances.
- Use of the latest MOSFET technology
- Internal thermal protection (if temperatures are excessive, output torque is reduced).
- Overcurrent protection using device characteristics.
- Internal measurement of output current.
- Overvoltage trip in the event of regenerative braking raising battery voltage to unsafe levels.

Dual traction motor

In the case of dual traction motors, there is additional processing of the associated steering signal (from a potentiometer or switches) in order to generate separate torque demands for the left and right motors of the vehicle. This allows the two motors to be operated at different speeds, which greatly assists in turning the vehicle and prevents wheel scrub. After the torque demands have been generated, the operation of each motor control system is as described in the case of a single traction motor.

Pump motors

Pump motor control is similar to traction motor control, although motion is requested using a different combination of switches.

Interfaces

In addition to its motor control functions, Gen4 offers many other functions designed to interface with electric vehicles. A variety of digital and analog input sources are supported, as listed in 'Signal connections' on page 3-10.

Voltage and current control of up to three contactors or proportional valves is provided by Gen4, and includes built-in freewheeling diodes for spike suppression. All I/O on the Gen4 controller is protected against short-circuit to the battery positive and negative terminals.

Connectivity and interoperability with other system devices (for example another Gen4 controller) using a CANbus and the CANopen protocol is provided. In addition to in-service operation, the CANopen protocol allows the controller to be commissioned using the Calibrator handset or Sevcon's DriveWizard tool. In addition Sevcon's SCWiz PC based tool provides the function to self-characterise most induction motors and hence simplify the process of putting a new motor into service.

For simple visual diagnosis of system faults and to monitor system status, a green LED is provided on the body of the controller. It is continuously lit when there is no fault but flashes a different number of times, in a repeated pattern, when there is a fault. The number of flashes indicates the type of fault (see 'LED flashes' on page 6).

Master-slave operation

The Gen4 controller contains both master and slave functions as shown in Figure 4. They operate as follows:

- **Slave function:** implements the CANopen Generic I/O Profile (DS402) and the Drives and Motion Control Profile (DSP401).
- **Master function:** implements vehicle functionality (traction and pump control) and CANopen network management.

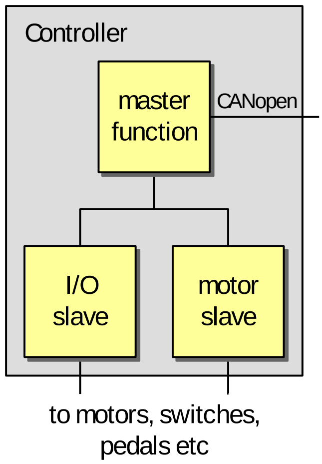


Figure 4 Single controller

Torque mode

In this mode Gen4 maintains the motor torque output at a constant value for a given throttle position. This is similar to DC motors (in particular, series wound DC motors) and provides a driving experience like a car. To prevent excessive speed when the load torque is low, for example when driving down hill, a maximum vehicle speed can be set.

Speed mode

In this mode Gen4 maintains the motor at a constant speed for a given throttle position as long as sufficient torque is available. Speed mode differs from torque mode in that the torque value applied to the motor is calculated by the controller based on the operator's requested speed (determined by throttle position) and the vehicle's actual speed. This mode is useful where accurate speed control is required irrespective of the motor torque.

Safety and protective functions

GENERAL

Electric vehicles can be dangerous. All testing, fault-finding and adjustment should be carried out by competent personnel. The drive wheels should be off the floor and free to rotate during the following procedures. The vehicle manufacturer's manual should be consulted before any operation is attempted.

The battery must be disconnected before replacing the controller or one of its fans. After the battery has been disconnected wait 30 seconds for the internal capacitors to discharge before handling the controller.

Never connect the controller to a battery with vent caps removed as an arc may occur due to the controller's internal capacitance when it is first connected.

As blow-out magnets are fitted to contactors (except 24V) ensure that no magnetic particles can accumulate in the contact gaps and cause malfunction. Ensure that contactors are wired with the correct polarity to their power terminals as indicated by the + sign on the top molding.

Do not attempt to open the controller as there are no serviceable components. Opening the controller will invalidate the warranty.

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

Where appropriate use of a suitable line contactor should be considered.

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 Gen4 motor controller should be carefully considered and relevant safety precautions taken. The Gen4 has several features which can be configured to help the system integrator to meet vehicle safety standards. Sevcon accepts no responsibility for incorrect application of their products.

Fault detection and handling

There are five categories of faults as described in Table 1. For a detailed list of faults see 'Fault identification' on page 6.

Fault severity	Controller latched off until	Consequences
Return to base (RTB)	Cleared by Sevcon personnel	Immediate shut down of the system with the exception of the power steering if needed. Power is removed to nearly all external components.
Very severe (VS)	Cleared by authorized service personnel	Immediate shut down of the system with the exception of the power steering if needed. Power is removed to nearly all external components.
Severe (S)	Keyswitch recycled (turned off then on)	Immediate shut down of the system with the exception of the power steering if needed. Power is removed to nearly all external components.
Drive-inhibit (DI)	User deselects all drive switches before reselecting	Neutral brakes or coasts the traction motor(s) to a stop. The fault prevents the operator initiating drive, but does not inhibit braking function, in particular, controlled roll-off braking.
Information (I)	Not latched	Information faults do not require immediate action, although some cutback of power or speed may occur.

Table 1 Fault categories

Chapter 3: Installation

Mounting Gen4

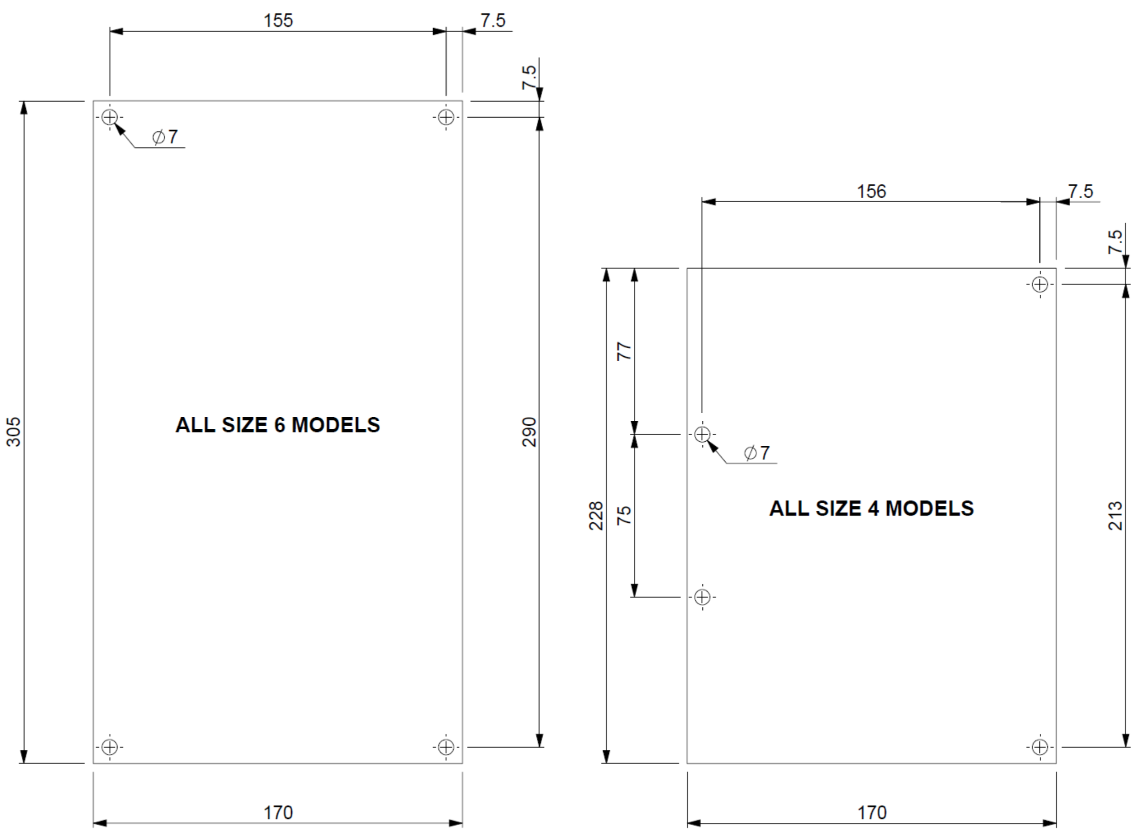
Orientation

The controller can be mounted in any orientation.

Clearance for LED access

If you want an operator of your vehicle to be able to view the onboard LED, it is advisable to consider the line of sight to the LED at this time.

Mounting hole pattern



Flatness of mounting surfaces: 0.2mm

⚠ Failure to comply with this flatness specification can cause deformation of the frame and damage to the product.

EQUIPMENT REQUIRED:

- 4 x M6 socket cap head bolts, nuts and spring washers. Bolts need to be long enough to pass through 12 mm of Gen4 baseplate and your mounting surface thickness.
- T hand-socket wrench or Allen key
- Thermal grease

Recommended torque setting: 10 Nm ± 2 Nm

Spread a layer of thermal grease, such as Dow Corning 340, on the Gen4 base plate before bolting to your mounting surface. Apply the grease at the minimum thickness sufficient to fill in the gaps due to non-flatness and follow the manufacturer's documentation.

Cooling requirements

To ensure you get the maximum performance from your Gen4 controller:

- Keep it away from other heat generating devices on the vehicle
- Maintain its ambient operating temperature below the specified maximum (see ‘Operating environment’ on page 4-6)

To obtain maximum performance it is important to keep Gen4’s base plate within the operating temperature range. To do this, mount Gen4 to a surface capable of conducting away the waste heat. A plate approximately 420 mm x 270 mm x 9.5 mm (thermal resistance 0.30°C/W) will give thermal performance as shown in Figure 9 on page 4-3.

Cooling performance is affected by mounting surface flatness and the thermal transfer between mounting surface and Gen4. Ensure you apply thermal grease and your mounting surface meets the flatness figures as described in the ‘Mounting’ section above.

EMC guidelines

The following guidelines are intended to help vehicle manufacturers to meet the requirements of the EC directive 89/336/EEC for Electromagnetic Compatibility. Any high speed switch is capable of generating harmonics at frequencies that are many multiples of its basic operating frequency. It is the objective of a good installation to contain or absorb the resultant emissions. All wiring is capable of acting as a receiving or transmitting antenna. Arrange wiring to take maximum advantage of the structural metal work inherent in most vehicles. Link vehicle metalwork with conductive braids.

Power cables

Route all cable within the vehicle framework and keep as low in the structure as is practical - a cable run within a main chassis member is better screened from the environment than one routed through or adjacent to an overhead guard. Keep cables short to minimize emitting and receiving surfaces. Shielding by the structure may not always be sufficient - cables run through metal shrouds may be required to contain emissions.

Parallel runs of cables in common circuits can serve to cancel emissions - the battery positive and negative cables following similar paths is an example. Tie all cables into a fixed layout and do not deviate from the approved layout in production vehicles. A re-routed battery cable could negate any approvals obtained.

Signal cables

Keep all wiring harnesses short and route wiring close to vehicle metalwork. Keep all signal wires clear of power cables and consider the use of screened cable. Keep control wiring clear of power cables when it carries analogue information - for example, accelerator wiring. Tie all wiring securely and ensure it always follows the same layout.

Controller

Thermal and EMC requirements tend to be in opposition. Additional insulation between the controller assembly and the vehicle frame work reduces capacitive coupling and hence emissions but tends to reduce thermal ratings. Establish a working balance by experiment. Document the complete installation, in detail, and faithfully reproduce on it all production vehicles. Before making changes, consider the effect on EMC compliance. A simple cost reduction change could have a significant negative effect on the EMC compliance of a vehicle.

Connecting power cables

See also 'EMC guidelines' on page 3-4.

Battery and motor connections

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

Equipment required:

- Cables sized to suit the controller and application (see table below)
- M8 crimp ring lugs
- Crimp tool
- M8 wrench

Torque setting: 11 Nm ± 2 Nm

Consider cable routing before making connections.

- Keep cable runs short
- Minimize current loops by keeping positive and negative cables as close together as possible.
- Route cables away from the LED if you intend to make this visible under normal operating conditions.

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 10 mm and the maximum penetration is 15 mm.

⚠ If you use a bolt which is too long, damage to the terminal and overheating of the connection may occur. If you use a bolt which is too short and there isn't enough thread engagement you may damage the threads.

CABLE SIZES

When deciding on power cable diameter, consideration must be given to cable length and temperature rating of the chosen cable.

Gen4 average (rms) current	Cable sizes	
	metric	US
150 A	35 mm^2	1 AWG
250 A	50 mm^2	1/0 AWG

On-board fuse mounting

You can mount your main input protection fuse directly onto the controller body as shown in Figure 6. Select the appropriate fuse from the table below. Connect the battery positive cable to the B+ terminal. The B+ terminal is a dummy terminal only and has no internal connection.

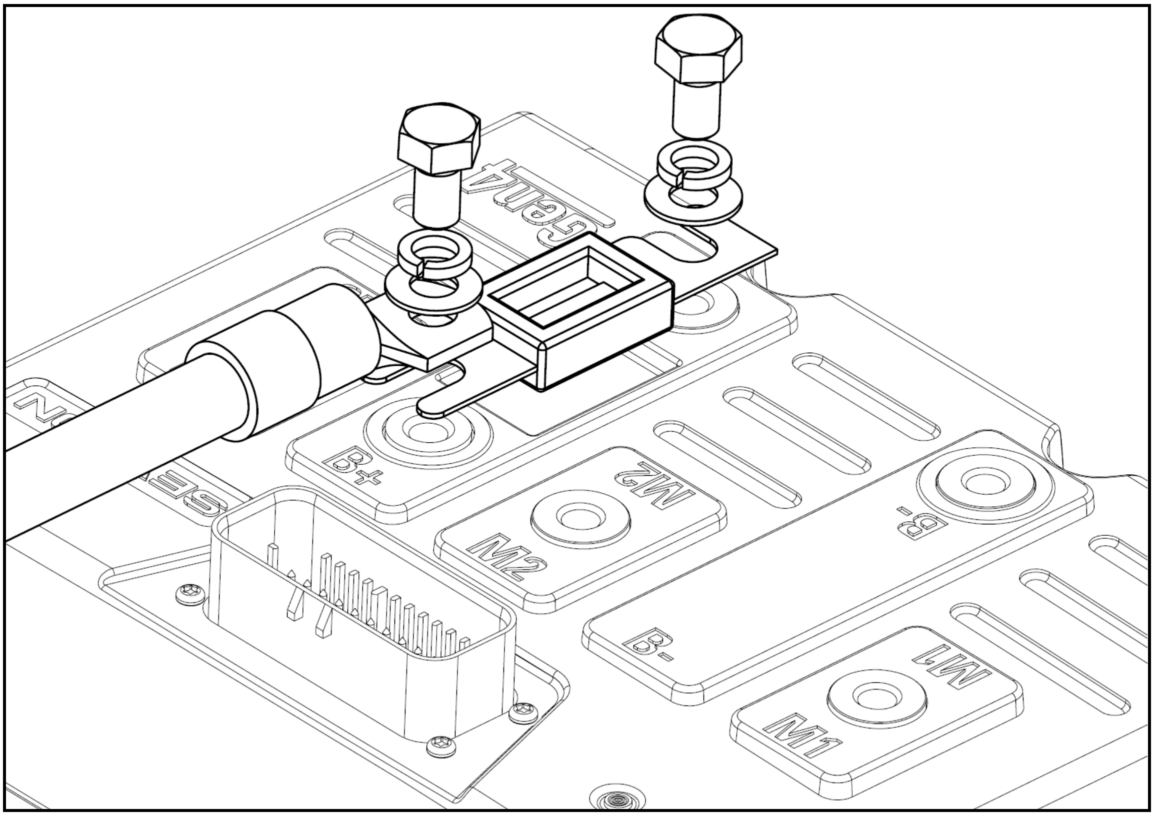


Figure 5 On-board fuse mounting – size 4 models

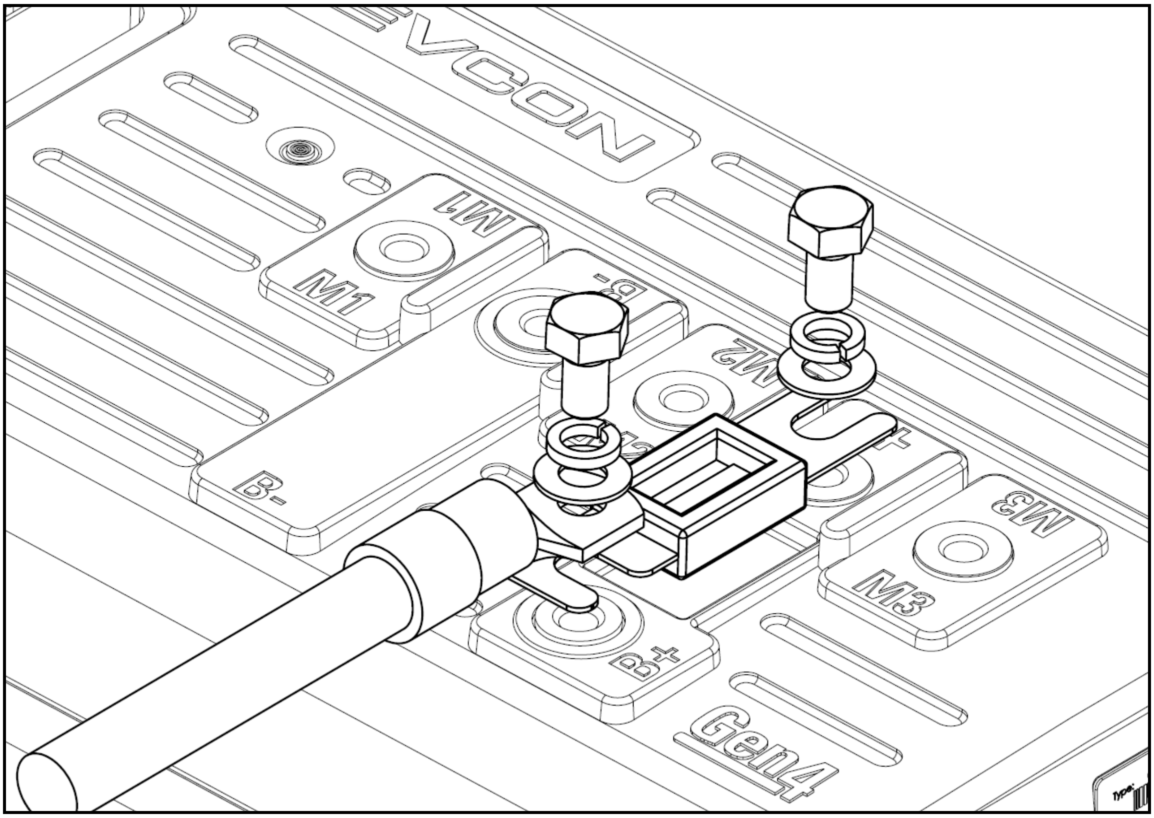


Figure 6 On-board fuse mounting – size 6 models

Fuse rating and selection

On-board fuse dimensions are in accordance with DIN43560/1

Gen4 input voltage	Gen4 peak output current	Fuse rating	Sevcon part number
24V/36 V	450 A	425 A	858/81990
	650 A	750 A	858/33021
36V/48 V	450 A	425 A	858/81990
	650 A	750 A	858/33021
72V/80 V	350 A	355 A	858/32045
	550 A	500 A	858/32043

Signal wiring

Assemble your wiring harness using wire of the sizes recommended below and the Sevcon loose connector kit (P/N 661/27091). The use of twisted pair and/or screened cables is recommended for the speed sensor and CANbus wiring.

To make a connection, gently push the connector housing onto the appropriate mating half on the Gen4. Never force a connector. Connectors are keyed to prevent incorrect insertion.

Shielded or twisted wire is recommended. Keep signals away from power cables to avoid interference. See also 'EMC guidelines' on page 3-4.

Signal wire sizes

Use wire between 0.5 mm² (20 AWG) and 1.5 mm² (16 AWG) for all signal wiring. Single twisted pair cable is readily available in 0.5 mm² (20 AWG).

CANbus termination

See also 'EMC guidelines' on page 3-4.

If your system has more than one CAN node, connect the nodes in a 'daisy chain' arrangement (Figure 7) and terminate the connections of the two end nodes with a 120 Ω resistor. If the end node is a Gen4, link pins 2 and 24 on the customer connector, a 120 Ω resistor is built into the controller. If you have a single node system the termination resistor should be connected so that the bus operates correctly when configuration tools are used.

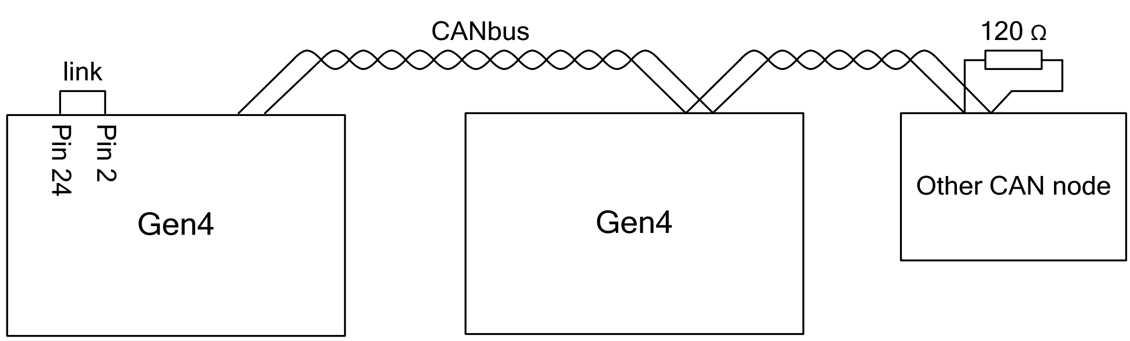


Figure 7 CAN node termination

Signal connections

Signal connections are made to Gen4 via a 35 way AMPSeal connector.

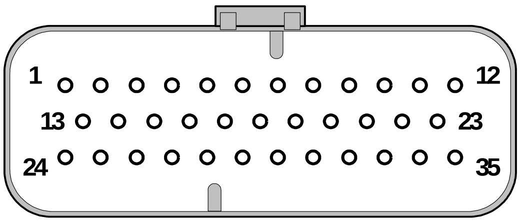


Figure 8 Customer Connector

Pins are protected against short-circuits to the battery positive or negative terminals.

Pin	Name	Type	What to connect	Maximum rating	Comment
1	Key switch in	Power	From 'dead' side of key switch via suitable fuse	7A (Total of all contactor output currents plus 1.0A)	This input supplies power from the battery for all the logic circuits. The unit cannot operate without "Key switch in" supply. Pins 1, 6 and 10 are connected together internally and can be used individually or in parallel.
2	CAN termination	Comms	To terminate a Gen4 CAN node link pin 2 to pin 24. This connects a 120Ω termination resistor, mounted inside the controller, across the CANbus.		Make the connection only if the Gen4 is physically at the end of the CANbus network (see 'CANbus termination' on page x-y.
3	Contactor out 1	Out	To the switched low side of contactor or valve coil. Contactor out 1 usually drives the line contactor.	2.0A per output, subject to a limit of 6A for the total of all the outputs. V = Vb	This output provides low side voltage or current control to the load depending on configuration. The output goes low or is chopped to activate the load. It goes high (to Vb) to de-activate the load.
4	Output 1 Supply +	Power	To one end (high side) of a contactor to be controlled by Contactor out 1	2A	This output feeds power to the contactors. The output is at battery voltage.

Pin	Name	Type	What to connect	Maximum rating	Comment
5	Encoder "U"	Digital pulse	Position encoder	10V	Use this in conjunction with "V" and "W" for PMAC motors.
6	Key-switch in	Power	From 'dead' side of key switch via suitable fuse	7A (Total of all contactor output currents plus 1.0A)	This input supplies power from the battery for all the logic circuits. The unit cannot operate without "Key switch in" supply. Pins 1, 6 and 10 are connected together internally and can be used individually or in parallel.
7	Contactor out 2	Out	To the switched low side of contactor or valve coil.	2.0A per output, subject to a limit of 6A for the total of all the outputs. V = Vb	This output provides low side voltage or current control to the load depending on configuration. The output goes low or is chopped to activate the load. It goes high (to Vb) to de-activate the load.
8	Output 2 Supply +	Power	To one end (high side) of a contactor to be controlled by Contactor out 2	2A	This output feeds power to the contactors. The output is at battery voltage.
9	Digital Input 6	Digital	From digital switch input 6.	Type B V = Vb See Table 3	See note to Table 3
10	Key switch in	Power	From 'dead' side of key switch via suitable fuse	7A (Total of all contactor output currents plus 1.0A)	This input supplies power from the battery for all the logic circuits. The unit cannot operate without "Key switch in" supply. Pins 1, 6 and 10 are connected together internally and can be used individually or in parallel.
11	Contactor out 3	Out	To the switched low side of contactor or valve coil.	2.0A per output, subject to a limit of 6A for the total of all the outputs. V = Vb	This output provides low side voltage or current control to the load depending on configuration. The output goes low or is chopped to activate the load. It goes high (to Vb) to de-activate the load.

Pin	Name	Type	What to connect	Maximum rating	Comment
12	Output 3 Supply +	Power	To one end (high side) of a contactor to be controlled by Contactor out 3	2A	This output feeds power to the contactors. The output is at battery voltage.
13	CAN High	Comms	CANbus High signal	V = 5 V	Maximum bus speed 1 Mbits/sec Alternative connection to pin 16
14	Encoder A Input	Digital pulse	From the speed encoder A channel	I = 25 mA (internally limited) V = 8 V (for current-source encoders) V = 2.5V or 5V (for open-collector encoders)	Check the speed encoder signals have the correct number of pulses per revolution. Check Gen4 is configured for the type of encoder you are using (open-collector or current-source)
15	Encoder power supply -	Power	To the negative supply input (0 V) of the speed encoder	I = 100 mA V = 0.5 V	We recommend the use of screened cable for the encoder wiring. Connect the screen to this pin only along with the negative supply.
16	CAN High	Comms	CANbus High signal	V = 5 V	Maximum bus speed 1 Mbits/s. Alternative connection to pin 13
17	Encoder "V"	Digital pulse	Position encoder	10V	Use this in conjunction with "U" and "W" for PMAC motors.
18	Digital Input 1	Digital	From digital switch input 1. In a basic configuration this is usually the forward switch.	Type A V = Vb See Table 3	See note to Table 3
19	Digital Input 3	Digital	From digital switch input 3. In a basic configuration this is usually the foot switch (FS1).	Type A V = Vb See Table 3	See note to Table 3
20	Digital Input 5	Digital	From digital switch input 5.	Type B V = Vb See Table 3	See note to Table 3

Pin	Name	Type	What to connect	Maximum rating	Comment
21	Digital Input 8	Digital	From digital switch input 8.	Type B V = Vb See Table 3	See note to Table 3
22	Pot. 1 wiper in	Analog	From potentiometer 1 wiper.	V = 10 V Zin = 82 kΩ (24V/36V and 36V/48V models) Zin = 100 kΩ (24V/36V and 36V/48V models)	Suitable for potentiometers in the range 500 Ω to 10 kΩ or Voltage-output device (e.g. Sevcon linear accelerator) 0 to 5 V or 0 to 10 V.
23	Pot. 2 wiper in	Analog	From potentiometer 2 wiper.	V = 10 V Zin = 82 kΩ (24V/36V and 36V/48V models) Zin = 100 kΩ (24V/36V and 36V/48V models)	
24	CAN Low	Comms	CANbus Low signal	V = 5 V	Maximum bus speed 1 Mbits/s. Alternative connection to pin 27
25	Encoder B Input	Digital pulse	From the speed encoder B channel	I = 25 mA (internally limited) V = 8 V (for current-source encoders) V = 2.5V or 5V (for open-collector encoders)	
26	Encoder power supply +	Power	To the positive supply input of the speed encoder	I = 100 mA V = 5V or 10V software selectable	Check the speed encoder you use is compatible with Gen4. See page 6-14 for configuration details.
27	CAN Low	Comms	CANbus Low signal	V = 5 V	Maximum bus speed 1 Mbits/s. Alternative connection to pin 24

Pin	Name	Type	What to connect	Maximum rating	Comment
28	CAN power supply +	Power	To CAN device requiring external supply	V = 24 V I = 100 mA	Check that the CAN device power supply requirement is suitable for Gen4.
29	Encoder "W"	Digital pulse	Position encoder	10V	Use this in conjunction with "U" and "V" for PMAC motors.
30	Digital Input 2	Digital	From digital switch input 2. In a basic configuration this is usually the reverse switch.	Type A V = Vb See Table 3	See note to Table 3
31	Digital Input 4	Digital	From digital switch input 4. In a basic configuration this is usually the seat switch.	Type A V = Vb See Table 3	See note to Table 3
32	Digital Input 7	Digital	From digital switch input 7.	Type B V = Vb See Table 3	See note to Table 3
33	Motor thermistor in	Analog	From a thermistor device mounted inside the motor	V = 5 V (via 2.2 kΩ internal pull-up resistor)	A NTC thermistor having a resistance of approximately 2.2 kΩ at 100°C will give best sensitivity. Connect the other lead of the thermistor to the B- terminal of the Gen4 controller. Can also be used as an additional analog input
34	Pot. 1 power supply +	Power	Supply feed to potentiometer 1. In a basic configuration this is the throttle.	V = 10 V I = 15 mA	Suitable for potentiometers in the range 500 Ω to 10 kΩ
35	Pot. 2 power supply +	Power	Supply feed to potentiometer 2.	V = 10 V I = 15 mA	Suitable for potentiometers in the range 500 Ω to 10 kΩ

Table 2 Connector A pin out and wiring information

Controller voltage	Digital Input Type	Impedance to B+	Impedance to B-
24V/36V	A	9k	9k
	B	13k	9k
36V/48V	A	16k	16k
	B	24k	16k
72V/80V	A	44k	44k
	B	66k	44k

Table 3: Impedance at Digital Input Pins

Note to Table 3:

Configure the digital input switches as active-high (switched to Vb) or active-low (switched to battery negative).

Configuration applies to all digital input switches (1 to 8) i.e. they are all active-high or all active-low.

When a switch is open the digital input pin sits at 0.5 x Vb. The input sinks current in active-high configurations and sources current in active-low configurations.

Wire-off protection is possible by combining a type A digital input with a type B digital input.

Chapter 4: Specification

Electrical

Input voltage

	24/36V controllers	36/48V controllers	72/80V controllers
Working voltage limits:	12.7V to 52.2V	25.9 V to 69.6 V	43.5 V to 116 V
Non-operational overvoltage limits:	59.4V	79.2 V	132 V
Battery voltage droop:	Vnom to 0.5 x Vnom for 100 ms Vnom to 0 V for 50 ms		
Input protection:	Input protected against reverse connection of battery		

Output protection

Output current:	Reduced automatically from peak to continuous rating depending on the time a peak load is applied to the controller (see Figure 9 on page4-3). Reduced automatically if operated outside normal temperature range.
Short-circuit:	Protected against any motor phase to B- or B+ at power-up. Protected against any motor phase to another motor phase at any time during operation. At switch-on Gen4 detects valid output loads are present before applying drive current.

⚠ Repetitive short circuits may damage the controller.

Output ratings

Input (Vdc)	Function	Short term rating* (A rms)	Continuous current (A rms)
24/36	Single traction	450	180
	Single traction	650	260
36/48	Single traction	450	180
	Single traction	650	260
72/80	Single traction	350	140
	Single traction	550	220

*2 minute rating (lower ratings are possible for longer periods; see example in Figure 9)

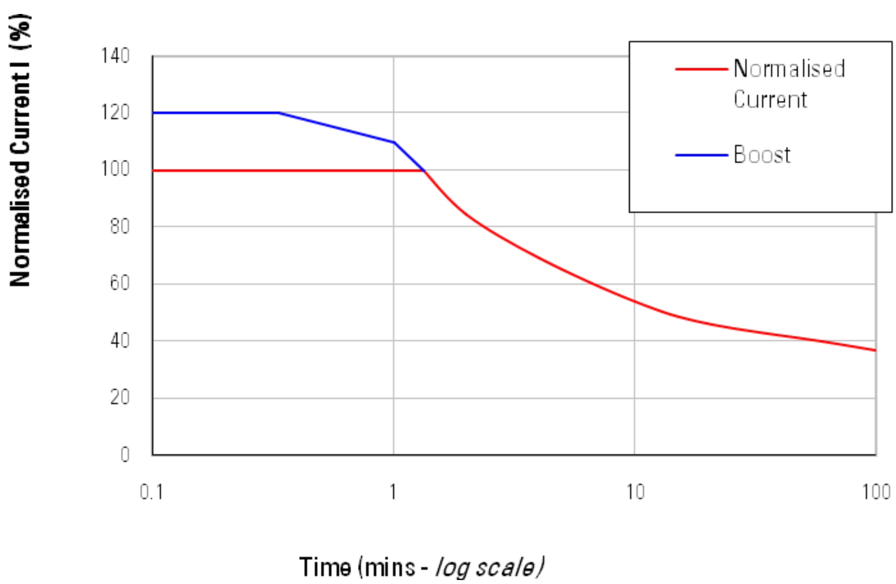


Figure 9 Output reduction over time with sustained peak demand

CAN interface

CAN protocol:	CANopen profiles DS301, DS401 and DS402 are supported. Physical layer uses ISO11898-2.
Baud rates supported:	1 Mbits/s (default), 500 kbits/s, 250 kbits/s, 125 kbits/s, 100 kbits/s, 50 kbits/s, 20 kbits/s and 10 kbits/s.

Control inputs and outputs

Digital inputs:	8 digital switch inputs (software configurable polarity). Can be wire-off protected. Active low inputs < 1.8 V: active high inputs > Vb - 1.8 V
Analog inputs:	2 general purpose inputs which can be used for 2-wire potentiometers (software configurable). They can also be configured as digital inputs. Motor thermistor input
Potentiometer inputs:	Two 3-wire protected inputs (software configurable).
Inductive drive outputs:	3 configurable PWM outputs. Use in voltage or current control mode. Voltage-controlled: Continuous sink current = 2A Peak current limited to < 2.5A Open-circuit detection (Iout < 0.1 A) is a configurable option Voltage-controlled (PWM) mode allows contactors with a rating less than Vnom to be used (range 24 V to Vnom). Current-controlled: Current output configurable between 0 and 2A

Isolation

Any terminal to the case:	Withstands 2 kV d.c. Meets EN1175-1:1998 and ISO3691 Complies with IEC-60664

EMC

Radiated emissions:	EN12895 (Industrial Trucks – Electromagnetic Compatibility) EN 55022:1998, 6, class B EN 12895:2000, 4.1 Emissions. When part of a system with a motor operating, FCC Part 15, Radiated Emissions. Meets the standards given in FCC Part 15, Section 15.109:
Conducted emissions:	No mains port, therefore not required
Susceptibility:	Performance level A (no degradation of performance) or level B (degradation of performance which is self-recoverable) subject to the additional requirement that the disturbances produced do not: • affect the driver's direct control of the truck • affect the performance of safety related parts of the truck or system • produce any incorrect signal that may cause the driver to perform hazardous operations • cause speed changes outside limits specified in the standard • cause a change of operating state • cause a change of stored data
Radiated RF field:	EN 61000-4-3, 5.1 Test Level: user-defined test level of 12 V/m EN 12895:2000, 4.2 Immunity EN 61000-4-6, Table 1 - Test Levels
Electrical fast transient:	EN 61000-4-4, Table 1 - Test Levels, Level 2
Electrostatic discharge:	EN 12895:2000, 4.2 Electrostatic Discharge 4 kV contact discharge 8 kV air discharge
Electrical surge:	EN 61000-4-5:1995, Table A.1 – Selection of Test Levels, Class 3

Regulatory compliance

Designed to meet:	EN1175-1:1998 (which covers EN1726 for the controller) ISO 3691 UL583 ASME/ANSI B56.1:1993

Mechanical

Operating environment

Operating temperature:	-30°C to +25°C (no current or time derating) +25°C to +80°C (no current derating, but reduced time at rated operating point) +80°C to +90°C and -40°C to -30°C (with derating)
Non-operation temperature:	-40°C to +85°C (can be stored for up to 12 months in this ambient range)
Humidity:	95% at 40°C and 3% at 40°C
Ingress of dust and water:	IP66 rated

Shock and vibration

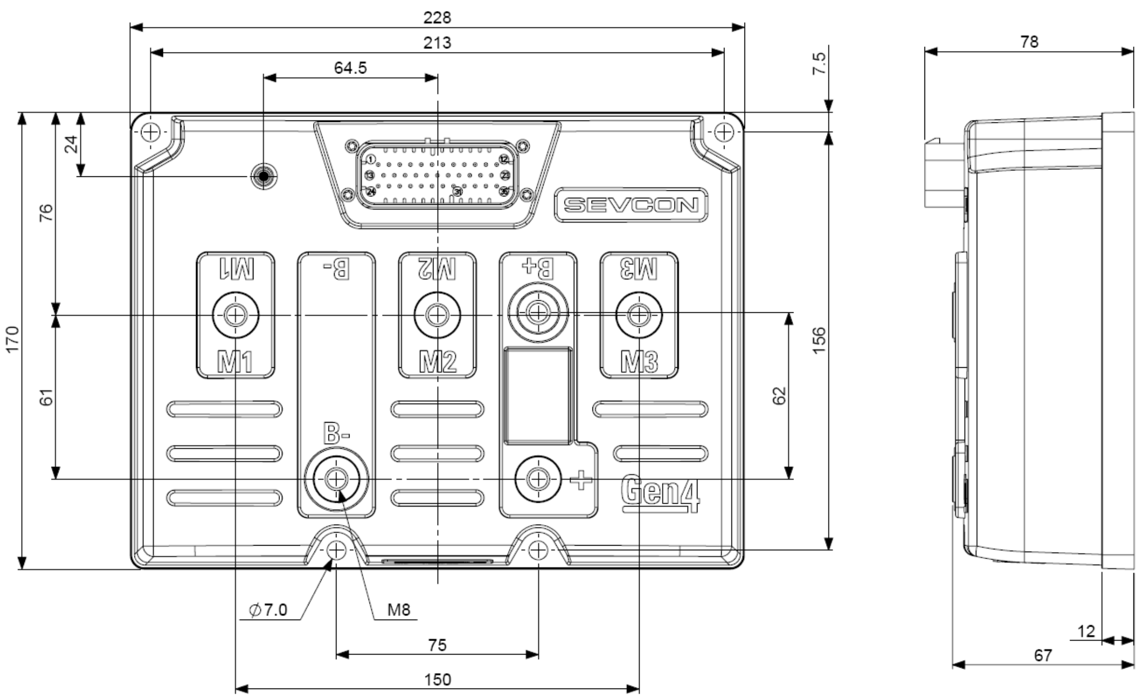
Thermal shock:	EN60068-2-14, Test Na
Repetitive shock:	50 g peak 3 orthogonal axes, 3+ and 3– in each axis, 11 ms pulse width
Drop test:	BS EN 60068-2-32:1993 Test Ed: Free fall, appendix B, Table 1
Bump:	40 g peak, 6 ms, 1000 bumps in each direction repetition rate 1 to 3 Hz.
Vibration:	3 g, 5 Hz to 500 Hz
Random vibration:	20 Hz to 500 Hz, acceleration spectral density 0.05 g^2/Hz (equivalent to 4.9 g_{rms})

Weight

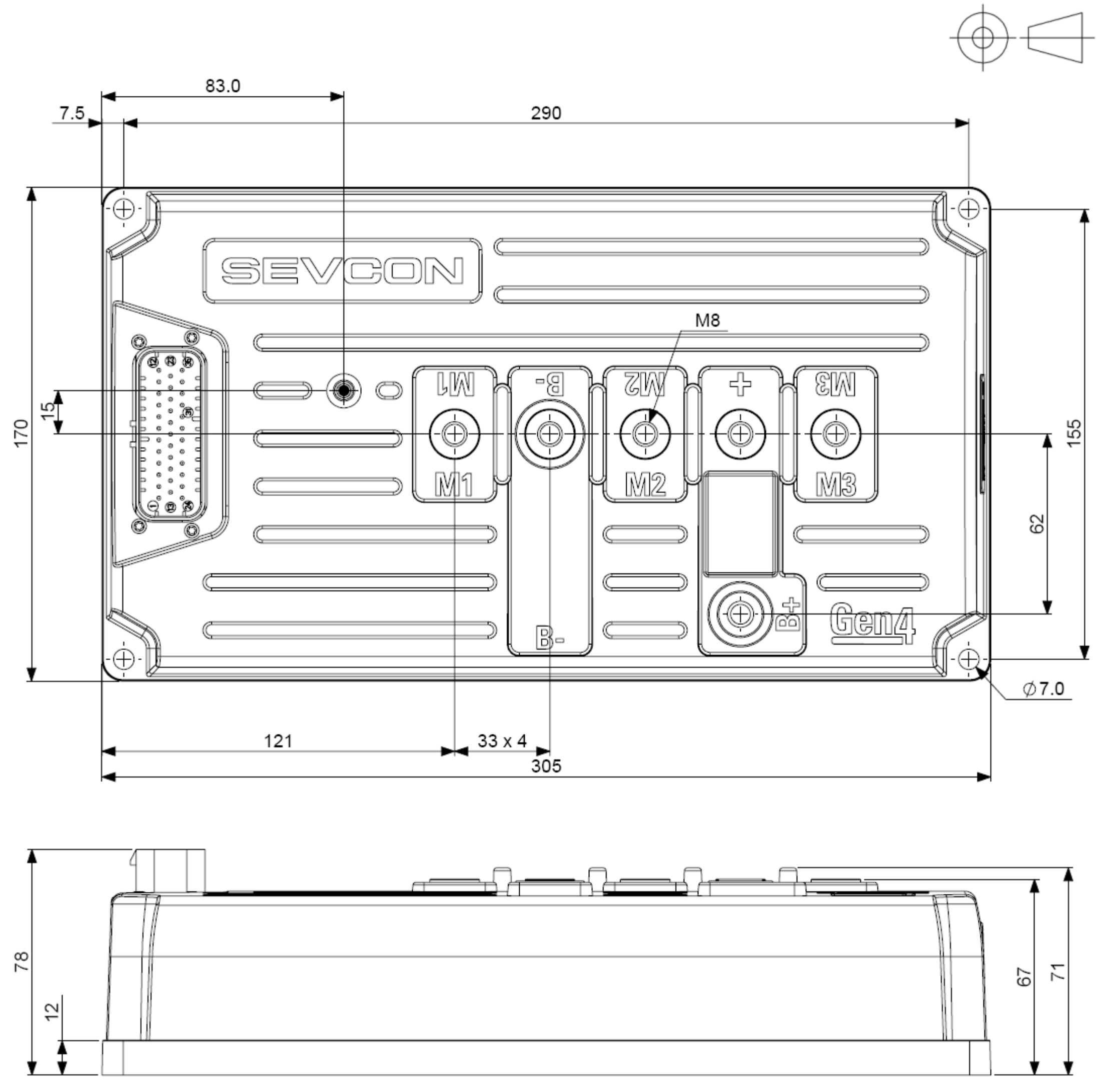
	Controller weight
Case size 4:	2.7kg
Case size 6:	3.8kg

Dimensions

Size 4 models



Size 6 models



Chapter 5: System design

Sizing a motor

Information required about the application

To select an appropriate induction motor for an application find or estimate the following information:

- Minimum battery voltage
- Maximum motor speed required
- Peak torque required at base speed
- Peak torque required at maximum motor speed
- Continuous (average) motor power output required to perform the work cycle
- Peak motor power output required and duration

Include inertia and friction contributed by the motor, as well as any gearing in the drive chain, when calculating torque and load requirements. If replacing a DC motor with an AC motor in an existing application, the DC motor torque vs. speed curve is a good starting point to determine the required ratings.

Motor maximum speed

Determine the maximum motor speed using the required vehicle or pump maximum speeds and the ratio of any gear box or chain between the motor and the load. Most motor manufacturer rate induction motors at synchronous speed which is 1,500 and 1,800 rpm for a 4-pole motor when operated from 50 Hz and 60 Hz line frequencies respectively.

The maximum speed an induction motor can be used at is determined by the limit of the mechanical speed, typically 4,000 to 6,000 rpm, and the reduction in useful torque at higher speeds. Increasing losses in the iron of the motor at higher speeds may further limit the maximum speed. Always check the maximum speed with the motor manufacturer. Check also any limitations imposed by the maximum frequency of the encoder input signal (see 'Motor speed sensor (encoder)' on page 5-11).

Torque required between zero and base speed

Calculate the torque required by the application. Use figures for the work that needs to be done against friction and gravity, plus those required to accelerate the load inertia and momentum. Up to rated speed the peak torque that can be supplied when using a correctly specified Gen4 is equal to the breakdown torque. Select a motor with a breakdown torque rating greater than the peak torque required.

Torque required at maximum speed

Calculate the torque as above. As speed increases beyond base speed the maximum torque an induction motor can supply falls as defined by the following two equations:

In the constant power region;

$$T = \frac{T_{\max}}{\left(\frac{\omega}{\omega_{rated}}\right)}$$

In the high speed region;

$$T = \frac{T_{\max}}{\left(\frac{\omega}{\omega_{rated}}\right)^2}$$

This is shown in Figure 10. Select a motor with a torque rating greater than the peak torque required.

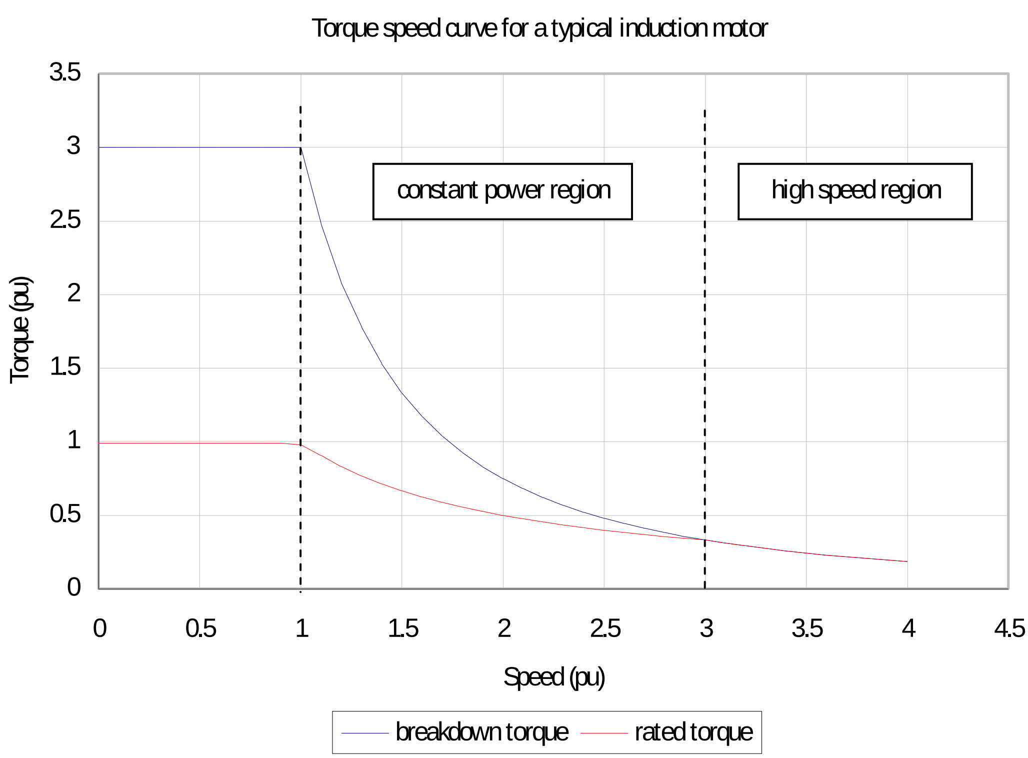


Figure 10 Torque speed curve

Continuous power rating

The required continuous power rating of the motor is governed by the application load cycle over a shift. Use the maximum RMS current over a period of one hour to determine the motor rating required. The motor manufacturer will typically specify a 1 hour or continuous rating. Select a motor whose ratings are equal to or greater than your calculated load over 1 hour.

Peak power rating

The peak power rating required for the application is actually determined by the peak torque required, as this determines the motor current required. Motor manufacturers will provide S1, S2 or S3 duty cycle ratings for the motors.

Selecting the Gen4 model

Matching motor and controller ratings is not an exact exercise and therefore you may need to perform iterative calculations. The main considerations when choosing an appropriate Gen4 controller are described below.

Current and power ratings considerations

Consider the following when choosing the appropriate Gen4 controller:

- Ensure the controller chosen matches or exceeds the peak current and average current requirements of the motor(s) in the application.
- Ensure the application can dissipate the waste heat generated by the controller. If the controller gets too hot it reduces its output, limiting vehicle performance.

Power output restrictions at motor and drive operating temperature limits

A controller protects itself by reducing the current and hence torque available when its temperature limit is reached (Figure 11).

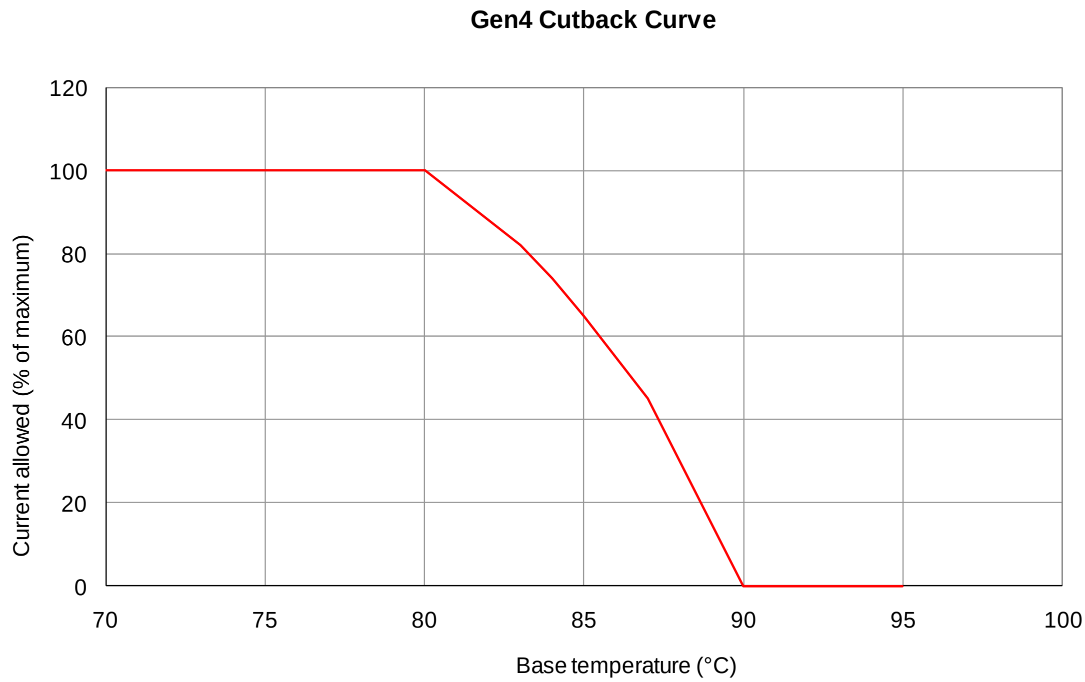


Figure 11 Current allowed vs. controller base temperature

Circuit configuration

Once motor size is determined the application circuit configuration can be defined. A basic single traction configuration (Figure 12) is provided as a starting point for new designs. Given the flexibility of the I/O it is possible to configure a wide range of systems. Refer to 'Signal connections' on page 3-10 to see what each I/O signal is capable of doing as you design your system. For pump applications a basic single pump system is shown in Figure 13. **Error! Reference source not found.**.

Single traction wiring diagram

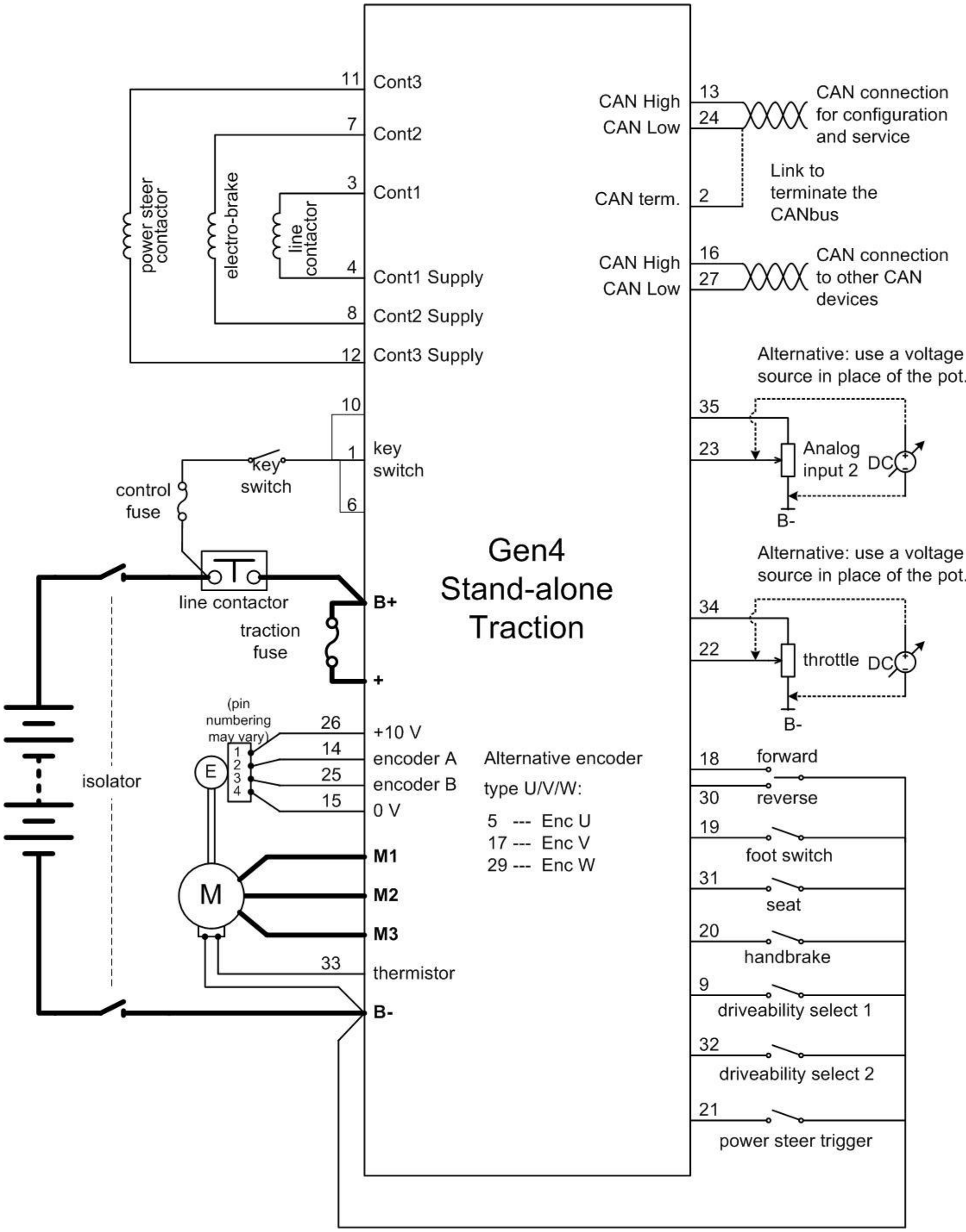


Figure 12 Single traction wiring diagram

Single pump wiring diagram

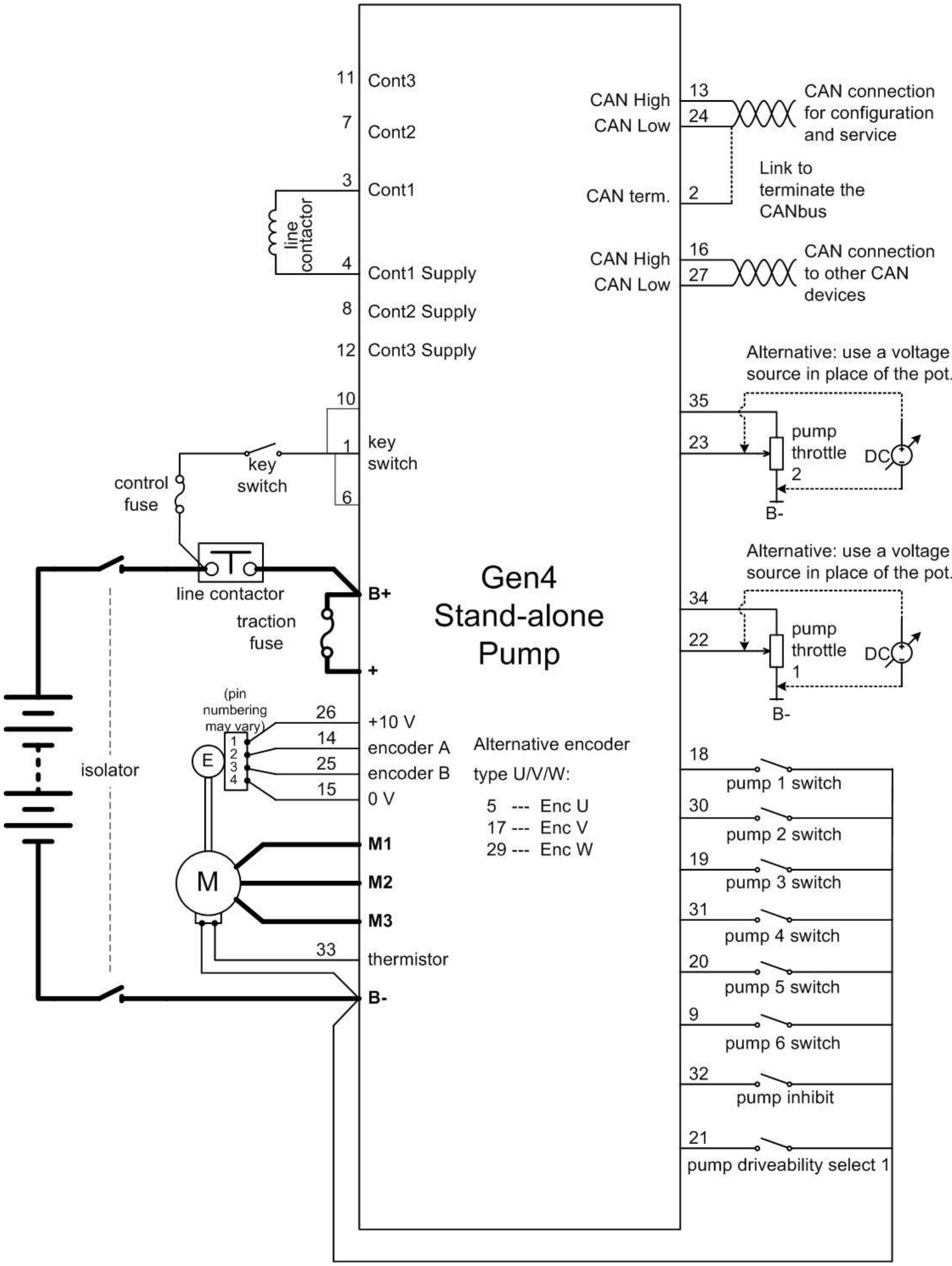


Figure 13 Stand-alone pump wiring diagram

Twin motor systems

A twin motor system may be powered by two Gen4 controllers operating in master–slave configuration. In this case the necessary commands are transmitted by the master node to the slave node via the CANbus.

Motors may be operated independently in a combined traction-pump application or operated in tandem where each motor drives a separate wheel. In this latter case the controller (where there are two controllers, the controller configured as master):

- Assists in the steering of a vehicle by adjusting the torque of each motor dependent on the steering angle.
- Reverses the direction of the inner wheel in order to provide a smaller turning circle. The speed of the outer wheel is also limited during a turn.

An example of possible wiring for Gen4 traction controllers operating in master-slave configuration is shown in Figure 14.

Auxiliary components

Main contactor

Select the appropriate contactor line contactor from Table 4. A line contactor used at its rated coil voltage must be rated 'continuous'. Contactor coil voltage chopping allows the use of coils rated 'intermittent', provided the manufacturer's conditions are met.

Gen4 peak output current	Coil	Sevcon P/N	Manufacturer	Notes
Up to 450 A	24 V	828/37024	Albright SW200-29	See paragraph below
	48 V	828/57026	Albright SW200-20	
	80 V	828/67010	Albright SW200-460	
Up to 650 A	24 V	828/39001	Albright SW200	Chop at 17 V (intermittent coil)

Table 4 Main contactor rating

The controller can drive any contactor with coil voltages from 12 V to Vb. It is worth considering the use of 24 V contactors with the contactor drive output set to voltage-control mode. This allows you to use one type of contactor for any battery voltage (24 V to 80 V). Pull-in voltage, pull-in time and hold-in voltage values are all configurable.

35 Way AMPSeal Connector Kit

Kit consists of Gen4 mating 35 way AMPSeal connector and pins, Sevcon p/n 661/27901

Emergency stop switch

Refer to the appropriate truck standards.

On-board fuse

See 'On-board fuse mounting' on page 3-7.

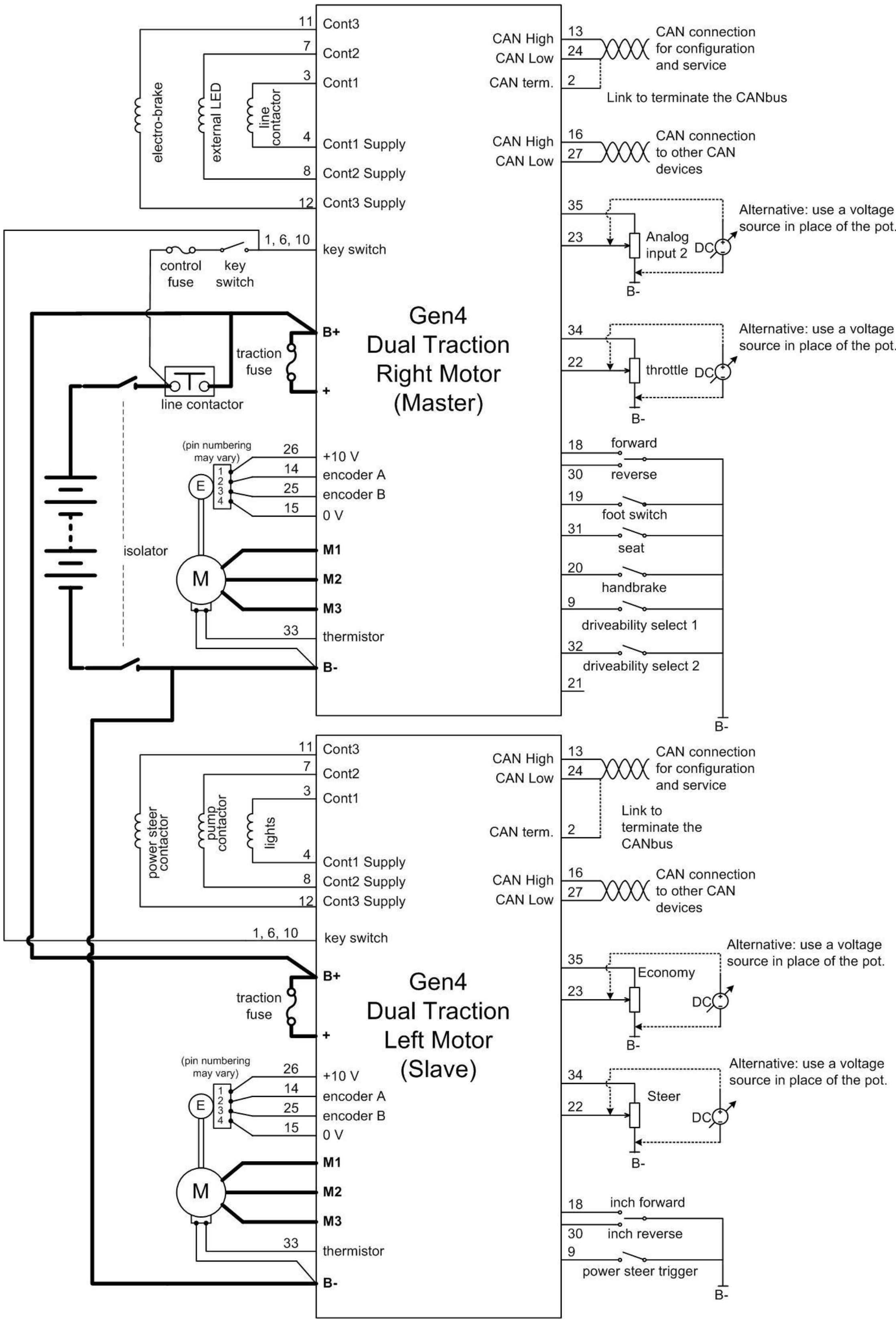


Figure 14 Dual traction wiring diagram

Key switch fuse F2

Use a fuse rated for the larger of: A) the sum of the drive currents plus 1A for internal circuits, and B) the capacitor pre-charge circuit. In the following example there are two contactors each drawing 2 A:

	Device	Current
A	Line contactor	2 A
	Pump contactor	2 A
	Gen4 control circuits	1 A
B	Pre-charge circuit	7 A

Fuse choice: 7A.

Motor speed sensor (encoder)

A 4-wire connection is provided for open-collector or current-source encoder devices (software configurable). You can use the following types of encoder, or equivalents:

Type	Output	Supply	Specification
Bearing Type (SKF and FAG)	Open collector	5 to 24 V DC	64 and 80 pulses per revolution Dual quadrature outputs Output low = 0 V (nominal)
HED Type (Thalheim)	Constant current	10 V nominal	80 pulses per revolution Dual quadrature outputs Output low = 7 mA Output high = 14 mA

The number of encoder pulses per revolutions (**n**) and the maximum motor speed (**N**) are related to, and limited by, the maximum frequency of the encoder signal ($\mathbf{f}_{max}$). The following table shows the maximum motor speed for a given encoder on a 4-pole motor.

Encoder ppr	Maximum motor speed (rpm)
128	6000
80	10000
64	10000

For other types of encoder and motor use the formulae:

$$f_{\max}(Hz) = \frac{n(per\,revolution) \times N(rpm)}{60}$$

with $\mathbf{f}_{max}$ limited to 13.3 kHz.

and

$$N_{\max}(rpm) = \frac{20000(rpm)}{(p/2)}$$

Motor commutation sensor (U, V, W)

A 3-wire connection is provided for open-collector phase commutation sensors.

The sensor must provide one cycle per electrical cycle. The signals may be used for angle and speed information

Initial power up sequence

Incorrectly wired or configured vehicles may behave in unexpected ways. At the end of the following procedure, only lower the drive wheels to the ground after correct operation of the motor and encoder has been confirmed.

Checks prior to power up

Follow this checklist prior to applying power to your system:

- Jack up the vehicle so that the drive wheels are clear of the ground.
- Confirm all connections are tightened to specified level.
- Ensure all plugs are fully inserted.
- Confirm power wiring connections are made to the correct terminals (B+, B-, +, M1, M2 and M3).
- Ensure the controller is securely mounted (from a mechanical and thermal perspective).
- Ensure there is adequate and correctly ducted airflow for the fan cooled version.
- Check the routing of cables is safe with no risk of short circuit, overheating or cable insulation wear due to rubbing.

Checks after power is applied

Apply power and do the following:

- Use DriveWizard (see page 6-2) or any configuration tool to complete the configuration process which starts on page 6-7.
- Using the drive controls ensure the wheels rotate in the expected direction. If they do not, check the motor wiring, encoder wiring and encoder configuration (page 6-14).

It should now be safe to lower the vehicle to the ground and test drive. Proceed with caution.

Chapter 6: Configuration

Introduction

This section covers what you need to do to configure Gen4's software once you have designed and installed your hardware. All of Gen4's parameters have a default value and the amount of configuration needed is dependent on your particular system.

The main topics are:

- DriveWizard configuration tool: installation and use
- CANopen: an introduction to the protocol and its use in Sevcon products
- An overview of the configuration process outlining what needs to be done and the order in which it must be done
- The configuration steps

DriveWizard configuration tool

DriveWizard (Figure 15) is Sevcon's proprietary configuration tool. It allows the user, subject to a secure login process, to monitor, configure and duplicate the parameters of any Sevcon CANopen node such as the Gen4 controller. DriveWizard can also be used to monitor and configure the parameters of any 3rd party CANopen node. The information presented here is an overview only. For more information see DriveWizard's on-screen help system.

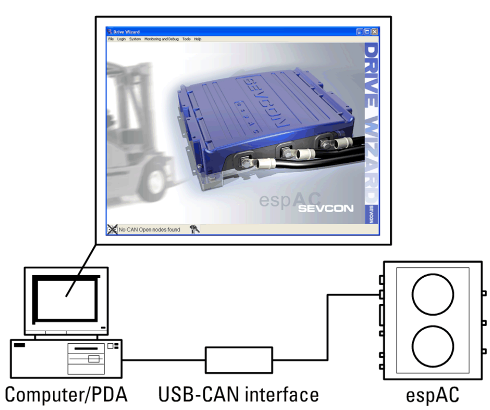


Figure 15 DriveWizard and hardware

DriveWizard functionality with lowest access level

The lowest access level allows you to review or monitor:

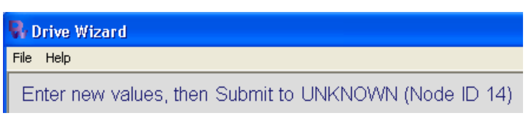
- DCF files on disk
- the contents of the Object Dictionary (applies also to 3rd party nodes)
- the mapping of CANopen PDO communication objects
- system logs
- fault logs
- counters
- operational logs
- real time data (applies also to 3rd party nodes).

You can also change the baud rate and Node ID of a connected node. To write information to a Sevcon CANopen node you will need a higher level of access.

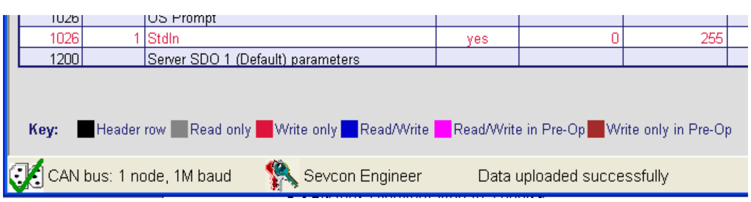
Status bars

User controls are invisible when DriveWizard is busy reading/writing.

User prompts are displayed in the top left of the screen as shown below:



The bottom right area of the status bar shows what DriveWizard is doing if busy and sometimes the result of DriveWizard's action if this is not clear from the main display area.



The bottom left status bar in the above example shows how many CAN nodes are connected and the access level of the person using DriveWizard.

When viewing the Object Dictionary in DriveWizard, parameters are color coded and the key is shown in the lower portion of the screen.

Saving, duplicating and restoring a node's configuration

You can use DriveWizard to:

- Save a node's configuration. This can be used at some later date to clone the node's configuration.
- Duplicate a node's configuration, in real time, to another node on the CANbus.
- Restore a configuration to a node.

DATA MONITORING

You can use DriveWizard to monitor data or parameters of a Sevcon or 3rd party node in real time and graph the data.

CANopen

This section assumes you have an understanding of CAN and are familiar with its use. If you are new to CAN or CANopen please refer to the CiA (CAN in Automation) website, www.can-cia.org for further information.

The following information provides an introduction to the important CANopen terminology used in this manual and how it relates to the configuration of your Gen4 controller.

CANOPEN PROTOCOL

CANopen is a CAN higher layer protocol and is defined in the DS301 'Application Layer and Communication Profile' specification. All CANopen devices must adhere to this standard. To provide greater standardization and interoperability with 3rd party devices, Gen4 is designed to use the CANopen protocol for communication on its CANbus and meets V4.02 of DS301.

CANopen also supports standardized profiles, which extend the functionality of a device. The controller supports the following CANopen standardized profiles:

- DS401 (V2.1) – Device Profile for Generic I/O Modules
- DSP402 (V2.X) – Device Profile for Drives and Motion Control

COMMUNICATION MODELS

In any CANopen system, there are three communication models in use. These are Master-Slave, Client-Server and Producer-Consumer. The function of each is explained below.

OBJECT DICTIONARY

Any device connected to the CANopen network is entirely described by its Object Dictionary. The Object Dictionary defines the interface to a device. You setup, configure and monitor your Gen4 controller by reading and writing values in its Object Dictionary, using a configuration tool such as Sevcon's DriveWizard (see page 6-2).

There are two important text files associated with the Object Dictionary. These are:

EDS (ELECTRONIC DATA SHEET)

An EDS is a text file representation of the Object Dictionary structure only. It contains no data values. The EDS is used by configuration software such as Sevcon's DriveWizard to describe the structure of a node's Object Dictionary. An EDS for each Gen4 model and software version, is available from Sevcon. The EDS file format is described in the DSP306 – Electronic Data Sheet Specification.

Each Object Dictionary matches a particular Gen4 software revision, and its structure is hard coded into the controller software.

DCF (DEVICE CONFIGURATION FILE)

This is a text file similar to an EDS except that it contains data values as well as the Object Dictionary structure.

DCFs are used to:

- Download a complete pre-defined configuration to a node's Object Dictionary.
- Save the current configuration of a node's Object Dictionary for future use.

COMMUNICATION OBJECTS

These are SDO (service data object) and PDO (process data object) as described below. There is a third object, VPDO (virtual PDO), used by Gen4 which is not a CANopen object. It is described here because its function is important and similar to that of a PDO.

SDO (SERVICE DATA OBJECT)

SDOs allow access to a single entry in the Object Dictionary, specified by index and sub-index. They use the client–server communication model, where the client accesses the data and the server owns the target Object Dictionary.

SDOs are typically used for device configuration (e.g. via DriveWizard) or for accessing data at a very low rate. They can be used to transmit large amounts of data using one of these methods:

PDO (PROCESS DATA OBJECT)

PDOs are used by connected nodes (for example in a twin motor configuration) to exchange real time data during operation. PDOs allow up to 8 bytes of data to be transmitted in one CAN message.

They use the producer-consumer communication model, where one node (the producer) creates and transmits the PDO for any connected nodes (consumers) to receive. Transmitted PDOs are referred to as TPDOs and received PDOs as referred to as RPDOs.

VPDO (Virtual Process Data Object)

VPDOs do a similar job as PDOs for data exchange, but internal to a single Sevcon node. They are unique to Sevcon and are not part of CANopen.

Configuration process overview

Electric vehicles can be dangerous. All testing, fault-finding and adjustment should be carried out by competent personnel. The drive wheels should be off the floor and free to rotate during the following procedures.

We recommend saving parameter values by creating a DCF, before making any alterations so you can refer to, or restore the default values if necessary. Do this using DriveWizard.

This part of the manual assumes you have a vehicle designed and correctly wired up with a CANopen network setup. Before you can safely drive your vehicle it is necessary to go through the following process in the order presented:

Step	Stage	Page
1	Motor characterization	6-8
2	I/O configuration	6-10
3	Vehicle performance configuration	6-19
4	Vehicle features and functions	6-30

ACCESS AUTHORIZATION

To prevent unauthorized changes to the controller configuration there are 5 levels of accessibility: (1) User, (2) Service Engineer, (3) Dealer, (4) OEM Engineering and (5) Sevcon Engineering. The lowest level is (1), allowing read only access, and the highest level is (5) allowing authorization to change any parameter.

To login with DriveWizard, select User ID and password when prompted.

To login with other configuration tools write your password and, optionally, a user ID to object 5000_h sub-indices 2 and 3. The access level can be read back from sub-index 1. The password is verified by an encryption algorithm which is a function of the password, user ID and password key (5001_h).

The password key allows passwords to be made unique for different customers. The user ID also allows passwords to be made unique for individuals.

How NMT state affects access to parameters

Some important objects can only be written to when the controller is in the pre-operational state. DriveWizard takes Gen4 in and out of this state as required.

If you are not using DriveWizard you may need to request the CANopen network to enter pre-operational before all objects can be written to.

To enter pre-operational, write '1' to 2800_h on the master node.

To restore the CANopen network to operational, write '0' to 2800_h.

The controller may refuse to enter pre-operational if part of the system is active: for example, if the vehicle is being driven. The request is logged in the EEPROM however, so if power is recycled the system won't enter operational and remains in pre-operational after powering up.

The NMT state can be read at 5110_h where 05 = operational and 7F = pre-operational.

Motor characterization

Ensure you have completed the CANopen network setup process.

Determining motor parameters

To provide optimum motor performance Gen4 needs the basic motor information normally found on the name plate as well as the following information:

- A value for each of the electrical parameters of the induction motor as shown in Figure 16.
- The magnetic saturation characteristics of the motor in the constant power and high speed regions.
- Current and speed control gains.

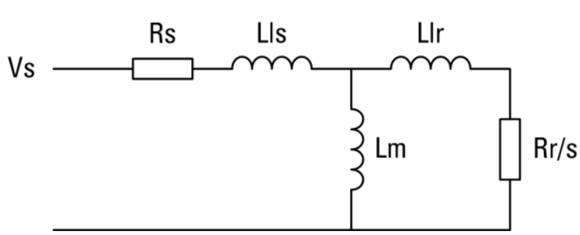


Figure 16 AC motor single-phase equivalent circuit

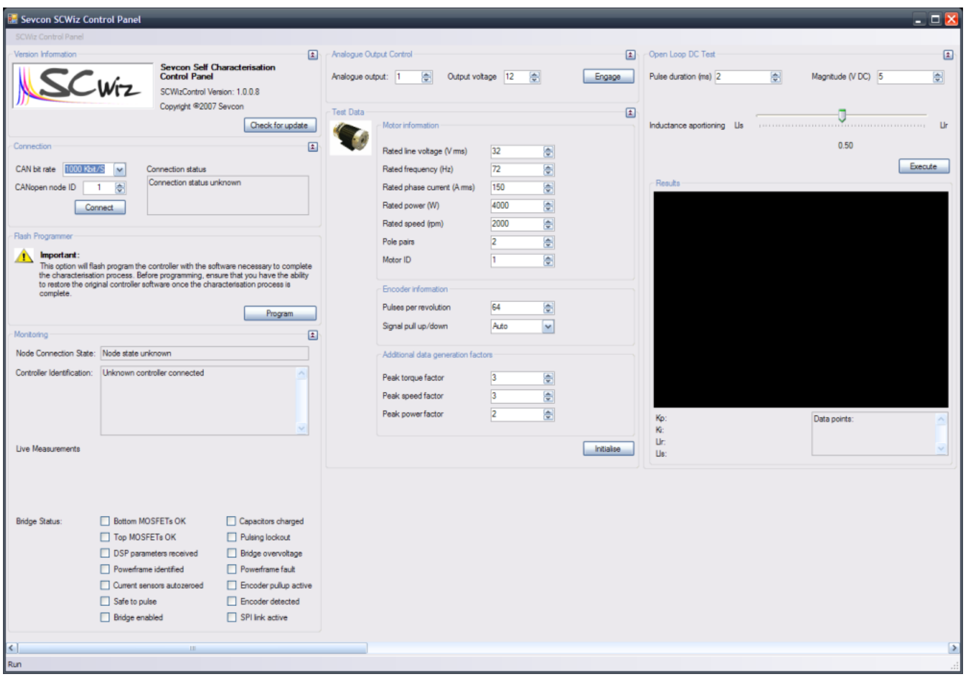
To determine these parameters use one of the following methods:

1. Ask the motor manufacturer to provide the data and enter it in the Object Dictionary at 6410_h. Also enter encoder data at 4630_h and 6090_h and motor maps at 4610_h to 4613_h.
2. Use the motor name plate data and the self characterization routine provided by Gen4 and DriveWizard (described below).

SELF CHARACTERIZATION

The self characterization function will cause the motor to operate. Ensure the vehicle is jacked up, with the driving wheels off the ground and free to turn, before starting the test.

The motor self-characterisation process allows a user to determine the electrical parameters required for efficient control of AC induction motors using a Gen4 controller connected to a PC or laptop running characterisation software. For further information, please contact your local Sevcon representative.



I/O configuration

Ensure you have completed the CANopen network setup and Motor Characterization processes described above.

The individual characteristics and mapping of the I/O in your application need to be setup. This can be done manually, or one of a selection of predefined setups can be selected. Predefines setups exist for many of the common vehicle functions such as standalone traction, standalone pump and twin traction.

For manual configuration, it is necessary to use PDOs and VPDOs to map application objects on the master node (2000_h to $25FF_h$) to the hardware I/O objects on all other nodes (6000_h to $6FFF_h$). Auto configurations will create the required PDO and VPDO mappings depending on which pre-defined I/O configuration has been selected, but additional PDO mappings can be added if desired.

To configure I/O:

- **Either** configure PDOs and VPDOs to map application objects on the vehicle master node to hardware I/O objects on other nodes, **or** select a pre-defined configuration and use auto-configuration to set up PDOs and VPDOs
- Setup each hardware I/O object, including wire-off protection.

Manual object mapping

To enable the controller to perform the functions required in your system it is necessary to map object to object (e.g. a measured input signal mapped to a steer operation).

This is achieved by setting up PDOs (node to node mapping) and VPDOs (internal mapping on each controller) as described below.

Apply mapping to Gen4 as follows:

- Standalone controllers: setup VPDOs only
- Networked controllers: setup VPDOs and PDOs

Before starting the mapping process it is a good idea to draw out a map of what you want to do. The amount of mapping required depends on the electrical wiring of your vehicle. Check to see if the default settings satisfy your needs before making changes.

VPDO MAPPING

VPDO mapping is defined by objects in the range 3000_h to $3FFF_h$ as shown in the table below. Use DriveWizard, or any other configuration tool, to access these objects.

Feature	Object indices	Notes
Motor	3000h	Used to map the master to the type of local motor
Input mapping	3300h	Used to map digital input signals to application inputs
	3400h	Used to map analog input signals to application inputs
Output mapping	3100h	Used to map application outputs to digital output signals
	3200h	Used to map application outputs to analog output signals

To help understand how to map internal objects an example VPDO mapping is shown in Figure 17. A digital switch input is mapped to the seat switch function to control the traction application, i.e. with no seat switch input the vehicle is prevented from moving.

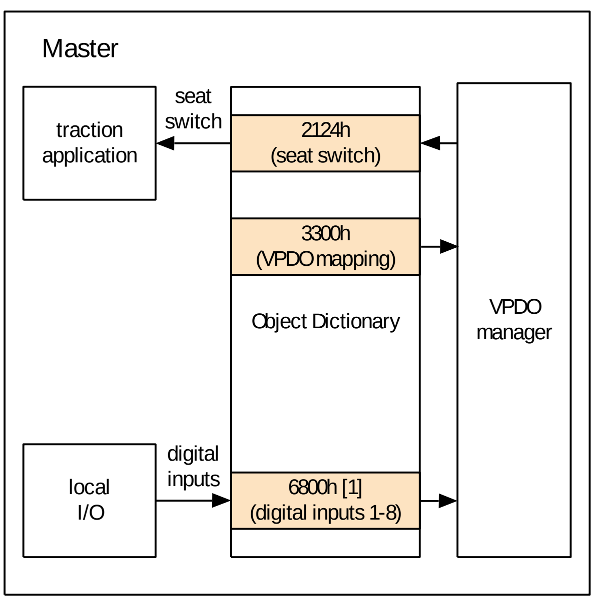


Figure 17 Example of a digital input mapped to the seat switch via VPDO

The number of sub-indices of each VPDO object depends on the amount of I/O on the device. For example, 3300_h has 9 sub-indices on a device with 8 digital inputs. Sub-index 0 gives the number of I/O channels in use. Sub-indices 1 to 8 correspond to the inputs.

To map the local I/O to an application signal object, set the appropriate VPDO sub-index to the application signal object index. If the seat switch shown in the above diagram was connected to digital input 4 (bit 3 in 6800_h,1), sub-index 4 of 3300_h would be set to 2124_h.

Some further examples are:

- Map FS1 to read the value of digital input 8 (connector A, pin 11): at 3300_h sub-index 8 enter the value 2123.
- Map the electromechanical brake signal to be applied to analog output 4 (connector C, pin 6): at 3200_h sub-index 4 enter the value 2420.

The data flow direction between the application signal objects and the local I/O objects depends on whether they are inputs or outputs. For inputs, the flow is from the local I/O to application objects, and vice versa for outputs.

Motor VPDOs are slightly different. There are six parameters for each motor, some of which flow from application to local I/O (controlword, target torque and target velocity) and some of which flow from local I/O to application (statusword, actual torque and actual velocity).

PDO MAPPING

The controller supports 9 RPDOs (receive PDOs) and 9 TPDOs (transmit PDOs). Up to 8 Object Dictionary entries can be mapped to each PDO. Every PDO must have a unique identifier (COB-ID).

Setup RPDOs and TPDOs to transmit and receive events between nodes, and map I/O from one node to applications in another node.

The easiest way to do this is using DriveWizard. If you are using a 3rd party configuration tool, the relevant Object Dictionary indices are listed in Table 5.

Feature	Object indices	Notes
Input mapping	1400h-15FFh	RPDO events
	1600h-17FFh	RPDO mapping
Output mapping	1800h-19FFh	TPDO events
	1A00h-1BFFh	TPDO mapping

Table 5 Objects associated with mapping

An example mapping (Figure 18) shows the movement of PDOs in a master-slave configuration in which a digital input to the slave has been mapped to the seat switch object in the master.

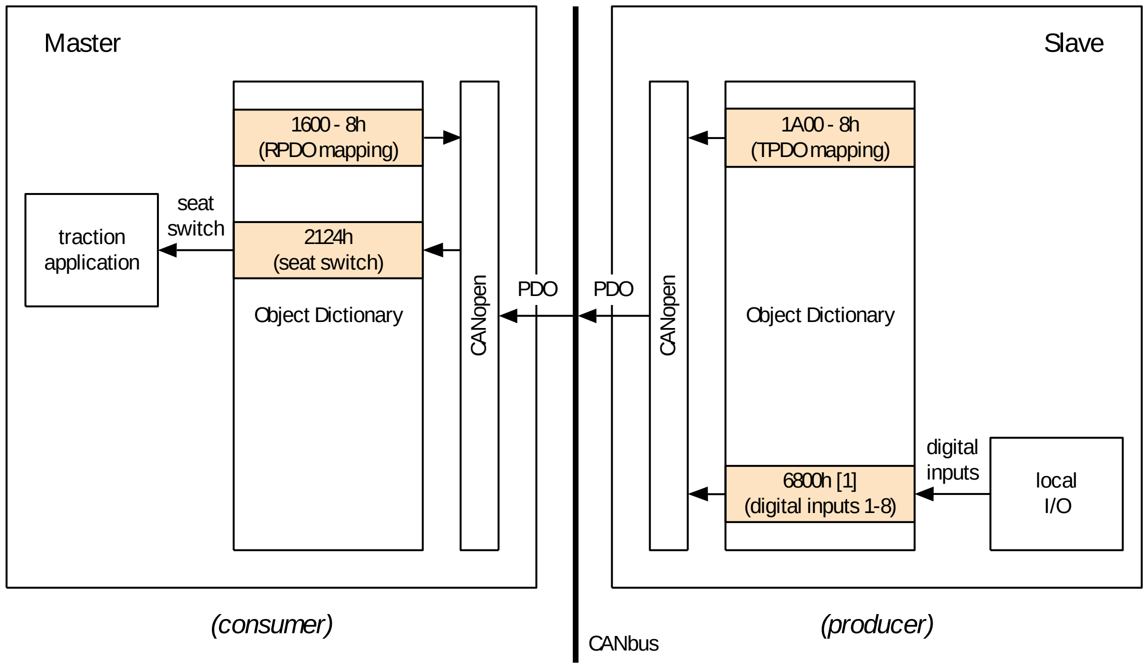


Figure 18 Example of a digital input mapped to the seat switch object via PDO and the CANbus

Automatic Configuration Mapping

The auto-configuration feature allows the user to select their vehicle I/O from a list of pre-defined configurations. The principle is identical to the manual process described above, but the PDO and VPDO mappings are created by each controller automatically at start up as well as CANopen network configuration settings. This feature provides an easy and reliable method of setting up both single and multi node systems, providing they match one of a selection of pre-defined setups (refer to page 1 for details on the available configurations).

To enable auto configuration on all nodes set 5810_h sub-index 1 to $0CFF_h$ (This corresponds to “Enabled”/”Both VPDO and PDO” for all IO auto configuration options in Drive Wizard). This enables the auto configuration of local and remote (via CANopen) analogue IO, digital IO and motor control. This is the default state for automatic configuration. It is possible to disable individual parts of the configuration to allow for user customization via the methods described above.

Digital input, analogue input and analogue output configurations can be selected from the predefined tables and their numbers entered into sub-indices 3, 5 and 6. This need only be set on the master controller if a multimode system is being configured.

CAN node function and configuration can also be defined via the auto configure feature. For each node the following should be specified:

- If it is Master or Slave in the CANBus system
- On the Master node, specify it's function, e.g. Traction, right side controller and also which other nodes are present as slaves, e.g. Pump, Power steer.
- On the Slave node, simply specify that it is a slave and which type of slave it is, e.g. Pump.

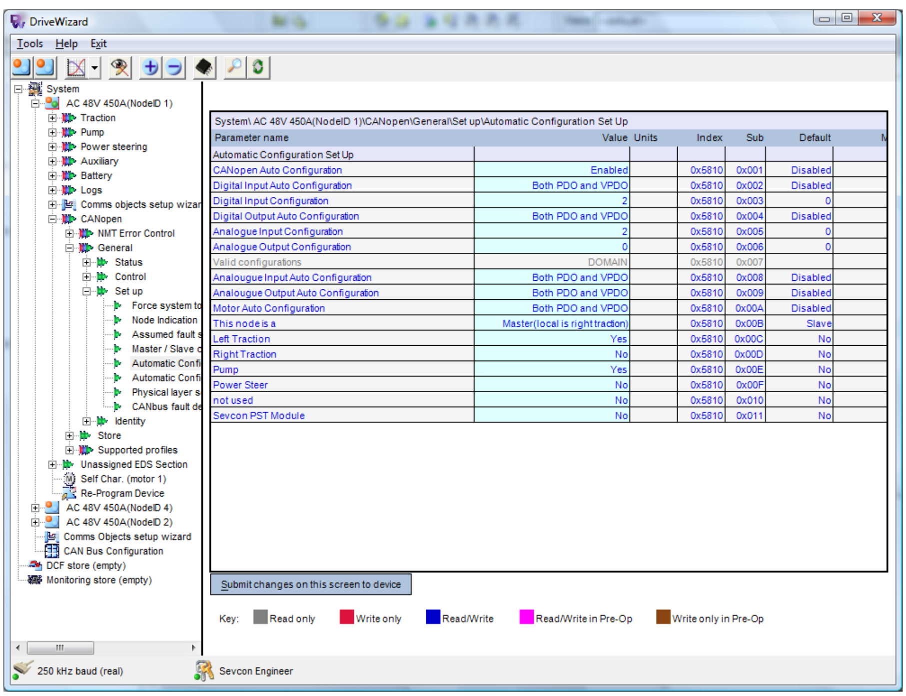


Figure 19 - DriveWizard screen showing automatic object mapping

ENCODER

It is important that the number of encoder pulses per revolution is entered correctly. If this information is not correct, the controller may not be able to brake the motor effectively.

To configure the encoder:

3. Enter the resolution pulses/rev at 6090_h.

4. Check the encoder pull up and change to voltage driver if needed at 4630_h. The default setting is current source.

To change the encoder polarity (if required) change the setting at $607E_h$ (reverses the forward and reverse speed measurements).

Digital inputs

The state of the digital inputs can be read at object 6800_h.

Digital inputs are either all active low (switch return to battery negative) or all active high (switch return to battery positive). A mixture of active low and active high inputs is not possible. The default setting is active low.

To configure digital inputs:

- Set active high/low logic at 4680_h.
- Set wire off protection at 4681_h. Any two digital inputs can be configured with wire-off protection. See Table 2 Connector A pin out and wiring information on page 3-14 (pins 14 and 15) for more details.
- Set digital input polarity at 6802_h. This is used to configure normally closed/open switches.

Analog inputs

The analog input voltages can be read at object $6C01_h$. Voltages are 16-bit integer values with a resolution of 1/256 V/bit.

Although each input is usually assigned a specific task by default, any of the inputs can be configured to accept a variable voltage or a potentiometer. Analog inputs can also be used as additional digital inputs.

3-wire inputs

To setup a 3-wire input:

- Enable wire-off protection if required at 4691_h
- If the wiper (connector A, pin 26 or 27) is connected to a voltage source, configure as a 2-wire input at 4692_h

2-wire inputs

There is no configuration for 2-wire inputs.

Motor thermistor input

You can connect a thermistor sensor to the Motor thermistor input or a switch to any digital input.

Type	Specification
PTC Silistor	Philips KTY84 or equivalent
Switch	Connected to a general purpose digital input

To setup go to object 4620_h:

- Configure as none, switch or PTC thermistor
- If you are using a PTC thermistor, set the high and low temperature voltages
- If you are using a switch select the digital input source

Read the measured motor temperature (PTC) or switch operation at object 4600_h.

Analog inputs configured as digital inputs

Each analog input can also be used as a digital input.

To configure an analog input as a digital input, set the high and low trigger voltages at object 4690_h.

The digital input status object, 6800_h, contains enough bits for the digital and analog inputs. The first n bits are the actual digital inputs (where n is the number of digital inputs) and the last 5 bits are from the analog inputs.

Analog (contactor) outputs

There are 3 analog outputs which you may have mapped to one or more contactor functions such as: line contactor, pump, power steer, electro-brake, external LED, traction motor cooling fan, alarm buzzer and horn.

Configure each of the outputs used in your system:

- Choose voltage control or current control for each analog output at $46A1_h$.
  (At the time of writing, current controlled devices can only be operated from Gen4 by mapping a signal input to the controller from an external 3rd party node).
- Set the frequency of each output to a fixed value of 16 kHz or any value between 40 Hz and 1 kHz at $46A2_h$ and $46A3_h$. You can have only one low frequency setting per controller. Low frequencies are normally used with current-controlled outputs.

- Set the analog output values at object $6C11_h$. The value is either a voltage or current depending on whether the output is voltage controlled or current controlled. Values are 16-bit integers with a resolution of 1/256 V/bit or A/bit.

Error control

In a CANopen network, the slave node on which the analog (contactor) outputs reside can be different to the master node which calculates the output value. If the CANbus fails, the master node is no longer able to control the slave outputs. In this situation, the outputs may need to change to a safe value. This is achieved with error control.

To configure error control:

- Set each output at object $6C43_h$ to use its last set value or the value at $6C44_h$ if the CANbus fails.
- Set values if needed at $6C44_h$ for each output. These values are 32-bit integers, in which the bottom 16-bits are ignored.

Vehicle performance configuration

Ensure you have completed the CANopen network setup, Motor Characterization and I/O Configuration processes described above.

Safety Interlocks

FS1

The FS1 switch is normally part of the throttle assembly. It closes when the throttle is pressed. The throttle voltage is ignored until FS1 is closed.

FS1 features are configured at 2914_h:

- SRO (static return to off): inhibits drive if FS1 is closed for the SRO delay without any direction (forward or reverse) being selected.
- FS1 recycle: forces the operator to lift their foot off the throttle before allowing drive after a direction change.

Deadman

The deadman switch operates similar to the FS1 switch, whereby, it inhibits drive until it is active. However, the deadman switch applies the electro-mechanical brake immediately on deactivation, whereas FS1 waits for the vehicle to stop before applying the brake.

Seat

The seat switch indicates operator presence on the vehicle. Drive is not allowed if this switch is open. If the seat switch opens during drive for a period longer than the seat switch delay, a fault is set, disabling drive. To clear a seat fault, close the seat switch, open FS1 and deselect the forward/reverse switch.

Set the seat switch delay at object 2902_h.

Handbrake

If mapped to a digital input, the handbrake switch inhibits drive if the vehicle handbrake is applied. Controlled roll-off detection is still active when the handbrake is applied in case the brake fails.

Torque mode/speed mode

The Gen4 controller provides both torque and speed control modes. Object 2900_h is used to set which mode to use. The default setting is torque mode.

This setting affects how driver demands are interpreted by the controller. In torque mode, the throttle push translates into a torque demand, which is applied to the traction motor. In speed mode, the throttle push translates to a speed demand. The controller then calculates the torque required to maintain this speed.

The difference between these control methods is most apparent when driving on an incline. In torque mode, when the vehicle is driven uphill, the vehicle speed will decrease due to the increased load. The operator must apply more throttle demand in order to maintain speed. In speed mode, the controller will apply additional torque in order to maintain the operator's speed demand, without the operator having to increase throttle demand.

Throttle

The controller can use 2 or 3 wire throttle inputs of the following types:

- Linear potentiometer in the range 470 Ω to 10 kΩ
- Voltage source in the range 0V to 10V: compliant with the standard 0..5 V, 0..10 V or 3.5..0 V ranges

To setup throttle inputs see 'Analog inputs' on page 6-16. The throttle voltage (2220_h) must be mapped to an analog input.

It is recommended that inputs with wire-off detection are used for the throttle input to detect wiring faults. This is especially important if a wire-off sets maximum throttle.

Setup the characteristics of the throttle at 2910_h:

- Enable/disable proportional braking. If enabled, the braking torque during direction braking is proportional to the throttle.
- Enable/disable directional throttle. If configured as a directional throttle, the throttle voltage indicates the direction as well as the speed demand. This removes the need for forward and reverse direction switches.
- Proportional speed limit enable/disable. Only used in torque mode. If enabled, speed limit is proportional to the throttle, otherwise speed limit is fixed at the forward or reverse maximum speed.

- Braking directional throttle enable/disable. Only used in torque mode. If enabled, a directional throttle can be used to demand a drive or braking torque in conjunction with the direction switches.
- Define the throttle voltage input: this is the relationship between the throttle voltage and the throttle value. Separate relationships can be specified for forward and reverse. Each relationship has two points, a start and an end. The points are configured differently for standard and directional throttles as shown in Figure 20 and Figure 21 respectively.

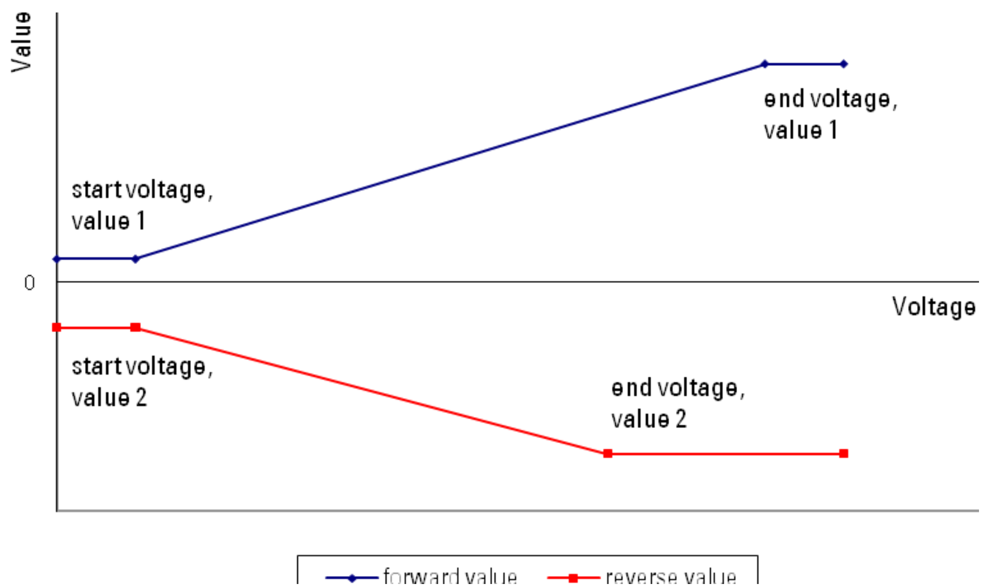


Figure 20 Standard throttle configuration

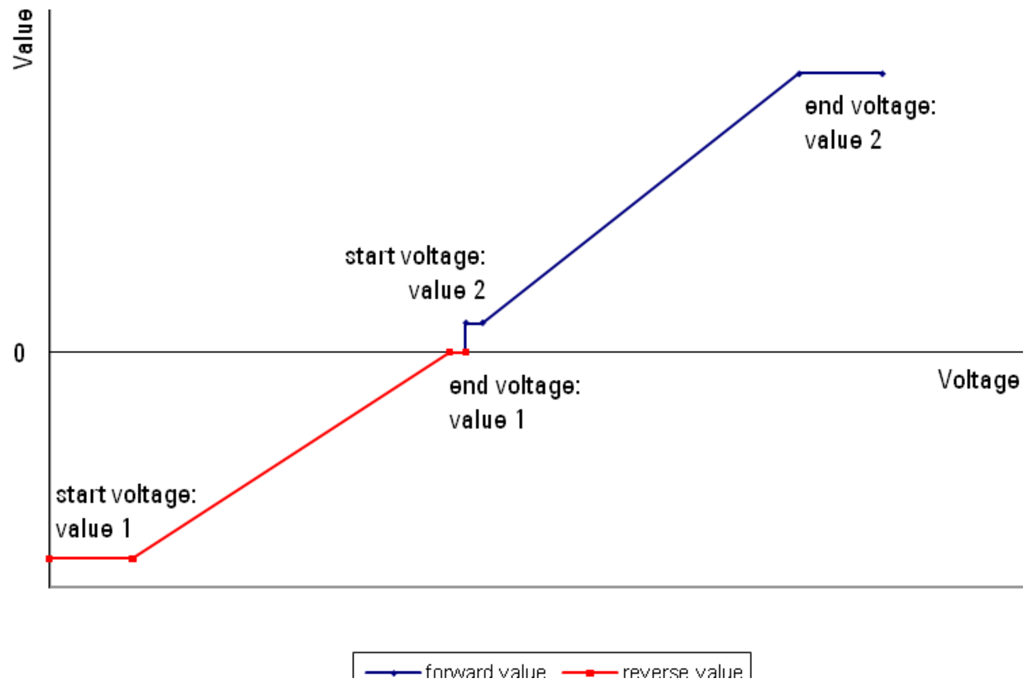


Figure 21 Directional throttle configuration

- Define the input characteristic: this is a profile to the throttle value and can be linear, curved, crawl or user-defined as shown in Figure 22. The curved and crawl characteristics give greater throttle control at low speeds.

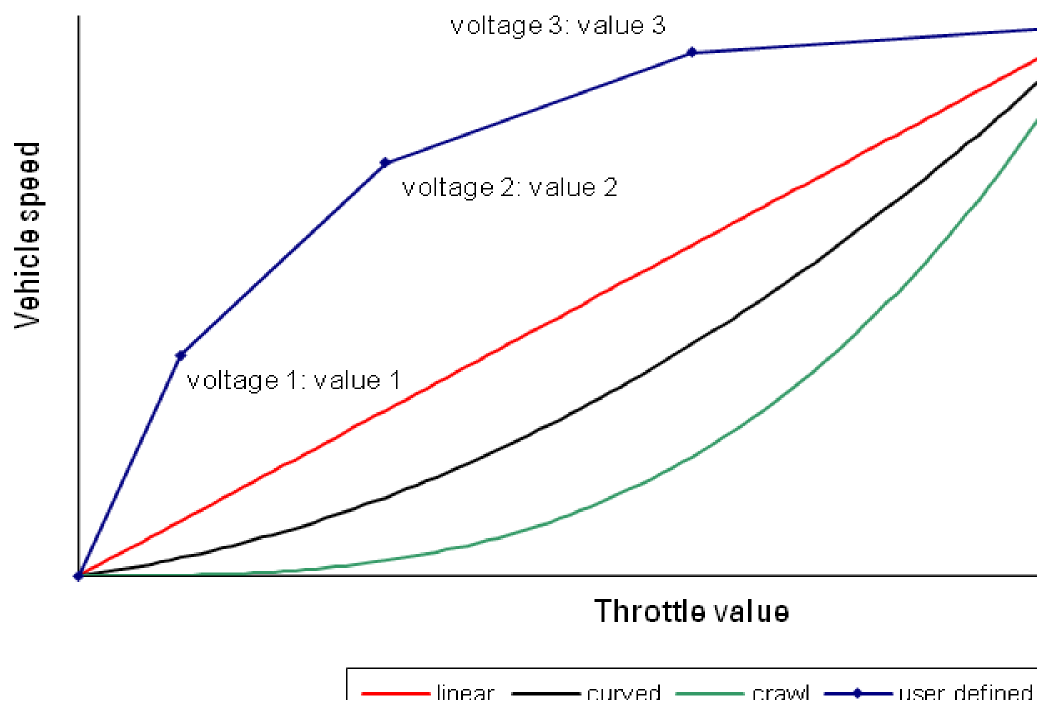


Figure 22 Input characteristics

The throttle value calculated from the voltage can be read at 2620_h.

Acceleration and braking

See 'Drivability profiles' on page 6-25.

Footbrake

The controller can use a switch or analog voltage as the footbrake input. If a footbrake switch is mapped, it applies maximum foot braking when the switch is closed. The footbrake switch object (2130_h) must be mapped to a digital input.

If the footbrake input is an analog voltage, configure the voltage levels in the same way as the throttle. The footbrake voltage (2221_h) must be mapped to an analog input.

Configure the characteristics of the footbrake at 2911_h:

- Drive/foot braking priority. If the throttle and footbrake are pressed at the same time, this setting determines whether the system attempts to drive or brake.
- Minimum speed for braking. Foot braking stops when the vehicle speed drops below this level.
- Footbrake voltage input and Input characteristic. These settings are similar to those for the throttle. Refer to the Throttle section above for more information.

The footbrake value calculated from the voltage can be read at 2621_h.

Steering inputs – twin driving motor systems

Loss of steering information can make a vehicle operate erratically. We recommend the use of steering inputs with wire-off protection.

Twin motor systems, which use the drive motors for turning, require some means of determining the angle of the steering wheel.

To do this use one of these options:

- A steering potentiometer to give an analog voltage which is a linear function of the steering angle. The steer potentiometer voltage (2223_h) must be mapped to an analog input.
- Four digital inputs representing 'inner left', 'inner right', 'outer left' and 'outer right'. The inner switches indicate the steering angle where torque to the inner wheel motor is

removed. The outer switches indicate the steering angle where inner wheel motor changes direction. The outer switches are optional. The steer switches ($212B_h$ to $212E_h$) must be mapped to digital inputs.

To configure steering inputs go to index 2913_h in the Object Dictionary:

- Setup the voltages corresponding to fully left, fully right and straight ahead. Using this information, Gen4 calculates the steering angle based on the voltage from a steering potentiometer.
- Setup the steering map. This map defines the relationship between the inner and outer wheel speeds and the steering angle. Each map has 4 user definable points as shown in Figure 23.

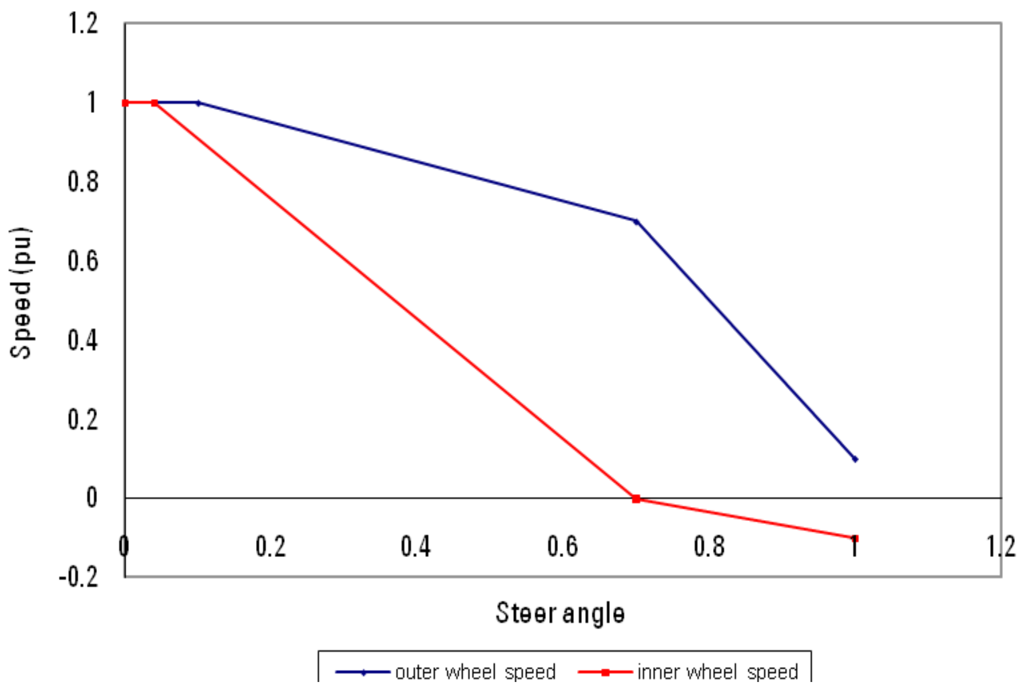


Figure 23 Graph of speed vs. steering angle

The speed and steering angle are normalized. Speed is normalized to maximum vehicle speed and the steering angle to 90°. In object 2913_h, 0 to 1 is represented by values in the range 0 to 32767.

The calculated steering angle can be read at 2623_h. An angle value of -32767 indicates full steering to the left, +32767 full steering to the right and 0 is straight ahead.

If steering switches are used instead of a steering potentiometer, only part of the steering map is used as shown in Table 6.

Value	Description
2913_h,5	Outer wheel speed during inner wheel cutback
2913_h,7	Outer wheel speed during inner wheel reversal
2913_h,13	Inner wheel cutback speed
2913_h,15	Inner wheel reverse speed

Table 6 Objects to set when using steering switches

During a turn the inner wheel speed is slowed by power reduction instead of braking to prevent the outer wheel motor working against the inner wheel motor.

Drivability profiles

Drivability profiles allow you to set maximum values for speed, torque, acceleration and deceleration for use in a range of operational situations. Figure 24 shows the change in speed under various driving conditions over a period of time.

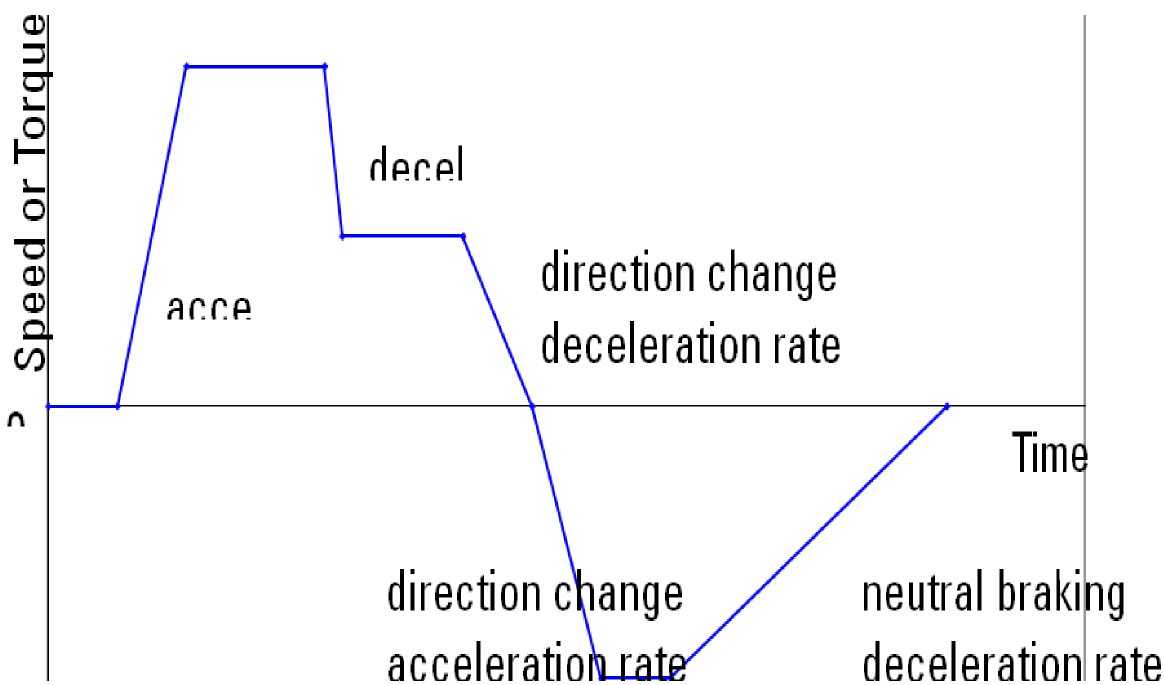


Figure 24 Example acceleration/deceleration parameter settings

In Torque/Speed mode, the acceleration and deceleration rates control the rate of change of torque. In Speed Control mode, the acceleration and deceleration rates control the rate of change of speed.

You can select reverse while driving in the forward direction with your foot still on the throttle. In this situation the controller applies braking in the form of a direction change deceleration rate down to zero speed. It then applies a direction change acceleration rate to increase the vehicle's speed in the reverse direction up to the set maximum speed as shown above.

Configure the following drivability profiles to suit your application (each containing the same set of parameters):

- Traction baseline profile: the default and highest set of values (2920_h).
- Drivability select 1 profile: invoked when drivability select 1 switch is active (2921_h) or an alternative trigger is active (see below).
- Drivability select 2 profile: invoked when drivability select 2 switch is active (2922_h) or an alternative trigger is active (see below).

The traction baseline profile contains the default maximum values. All of the remaining profiles apply lower, modifying values to the baseline profile. BDI and service profiles, when configured, are automatically applied by the software under preset conditions. For example you may want to limit the acceleration and maximum speed of a vehicle when the battery gets low to maximize the operating time before recharge. The remaining profiles are applied by the driver with a switch.

Drivability profiles can also be invoked by alternative internal software signals. Such as BDI low, service required or low speed.   These can be selected to suit specific application requirements in object $2931_{h,}$ each of the triggers operates in parallel with the other and the drivability select switches.

Where more than one profile is active, the lowest value(s) are used by the software.

Speed in the Object Dictionary is measured in RPM. However, the vehicle gear ratio (2915_h) can be used to change this unit to any other preferred unit such as KPH or MPH. A gear ratio of 1 is RPM.

Torque is measured in Nm and is converted to a value in 1/1000ths of motor rated torque at object 2916_h. The converted value is used by the application motor objects (2000_h to $20FF_h$) and the DSP402 motor control profile (6000_h to $67FF_h$).

Controlled roll-off

Controlled roll-off limits a vehicle to a slow, safe speed if it starts to move without any operator input. Primarily, it is to prevent uncontrolled movement if a vehicle's brakes fail on an incline. Controlled roll-off operates whether the operator is present or not.

Configure the following at object 2930_h:

- Enable/disable controlled roll-off
- Set a roll-off maximum speed
- Set a roll-off maximum torque

Alternatively, Gen4 can apply an electromagnetic brake if one is mapped and roll-off is detected. Refer to 'Electro-mechanical brake' on page 6-30 for more information.

Hill hold

A vehicle on a hill can be held at a standstill for a configurable time when the operator selects neutral. At the end of this time or if the seat switch indicates the operator is not present, hill hold terminates.

You can set the hill hold delay at object 2901_h. Set the hill hold delay to 0 to disable this feature.

Inching

Inching allows an operator to maneuver a vehicle, at low speeds, towards a load. Inching can be initiated with one switch. A time-out is used to prevent the vehicle from continuing to drive indefinitely if the switch gets stuck or goes short circuit.

To configure inching:

- Ensure forward and reverse inching switches have been mapped to two digital inputs.
- Specify an inching speed (0% to 25% of the full speed of the vehicle) at 2905_h sub-index 1.
- Specify a time-out (0.1 s to 5.0 s) at 2905_h sub-index 2.

Drivability select switches

There are two drivability select switches (2126_h and 2127_h).

To enable either of these they must be mapped to digital inputs. When they are active, the corresponding drivability profiles (2921_h and 2922_h) are applied.

Economy

The economy input is an analog input which can be used to increase vehicle efficiency and extend battery life. It is normally controlled using a potentiometer mounted on the vehicle's dashboard. The economy voltage (2222_h) must be mapped to an analog input.

Efficiency is improved by reducing the acceleration rate or the maximum torque.

Configure the economy input at object 2912_h as follows:

- Economy function: select acceleration or torque.
- Economy voltage input: These settings are similar to those for the throttle (see page 6-20).

The economy value calculated from the voltage can be read at 2622_h.

Pump configuration

The controller can use a mixture of switch and analog voltages as the pump input. In addition, the power steer function can be used as an extra input to the pump if the pump motor is required to supply pump and power steering.

General Setup

Configure the pump features at $2A00_h$:

- Inhibit pump when BDI drops below cutout level. If already operating when the cutout occurs, the pump will continue to operate until all pump inputs are inactive.
- Drive Enable switch and/or Seat switch input disables pump.
- Ignore Line Contactor state. Allows the pump to operate if it is not connected to the battery through the line contactor. Should be set if the pump also supplies power steering and the power steer is required to operate when the line contactor is open.
- Use Power Steer target velocity as pump input, if pump also supplies power steering.

Set the pump maximum speed, acceleration and deceleration at $2A01_h$. The pump speed is calculated as the value from the inputs multiplied by the maximum speed.

Priority/additive inputs

Each pump input can be configured as a priority input or an additive input. When calculating the pump demand, the controller selects the demand from the highest priority active input, and then adds the demand from all the active additive inputs.

Pump throttles

There are 2 pump throttle inputs, which can be configured independently. The pump throttles allow proportional control of the pump speed.

Configure inputs as priority or additive and set the voltage levels in the same way as the traction throttle. The pump throttles must be mapped to analog inputs.

Pump switches

There are 7 pump switch inputs. Configure each input as priority or additive and assign it a value. The pump switches must be mapped to digital inputs.

Power steer configuration

Power steering can be provided:

- Contactor. Map the power steer contactor drive object to an analog output.
- Dedicated motor controller. Map power steer application motor object to motor control slave.
- Pump motor controller. Configure pump to provide power steering. Power steer demand is added to pump demand.

The power steer can be triggered by a number of events:

- Vehicle moving
- FS1 switch activating
- Direction selected.
- Seat switch activating
- Footbrake activating

Set the power steer motor speed, acceleration and deceleration at $2B01_h$. This is not required if the power steer motor is operated by a contactor.

Vehicle features and functions

Ensure you have completed the CANopen network setup, Motor Characterization, I/O Configuration and Vehicle Performance Configuration processes described above.

Contactors

Ensure voltage control has been selected (see 'Analog (contactor) outputs' on page 6-17).

To configure any contactor:

- Set pull-in voltage, pull-in time and hold-in voltage at $2D00_h$
- Enable each output to operate at the pull-in voltage or at the maximum voltage at $2D01_h$
- If required enable each output to reduce to the hold voltage level at $2D02_h$

Line contactor dropout

The line contactor object (2400_h) must be mapped to an analog output.

The line contactor is used to isolate controllers and motors from the battery during power down or in case of a serious fault. It is normally closed all the time the vehicle is powered, but it can be configured to open when the vehicle has been stationary for a period of time.

Configure line contactor dropout at object 2820_h. See also 'Contactors' above.

The controller has a capacitor pre-charge feature used to protect line contactor tips from damage due to in-rush currents when the contactor closes. Writing to 5180_h starts a pre-charge cycle. The pre-charge circuit can only supply enough current to charge the capacitors of one controller. Where more than one controller is present, the pre-charge circuit on each must be used. If an Gen4 is configured as the vehicle master, it controls the pre-charge of all slave nodes automatically.

Pre-charge the capacitors once only before closing the line contactor. Repeated pre-charging can damage the circuit.

Electro-mechanical brake

The electro-mechanical brake object (2420_h) must be mapped to an analog output.

Set the conditions under which it is applied at 2903_h.

The brake can be applied when the vehicle stops or when roll-off is detected. If the brake is configured to apply when the vehicle stops, it is not applied until the vehicle has been stationary for more than the brake delay time.

To prevent vehicle roll away on inclines, the electro-mechanical brake normally does not release until the traction motor(s) are producing torque. This feature can be disabled using 2903_h,3.

External LED

This mirrors the operation of the controller's on board diagnostic LED. The external LED object 2401_h can be mapped to an analog output to drive a lamp on a vehicle dashboard.

Alarm buzzer

The alarm buzzer object (2402_h) must be mapped to an analog output.

Configure the alarm buzzer output, if required, to be activated by one or more of these conditions at 2840_h:

- forward motion or forward direction selected
- reverse motion or reverse direction selected
- faults other than information faults
- controlled roll-off

A different cadence for each of the above conditions can be configured.

Brake Lights

A brake light output object is available (2404_h) and can be mapped to an analog output. The brake lights will illuminate whenever the footbrake is pressed (providing either an analog or digital footbrake input is available) or the system is in direction change braking.

Horn

Ensure a digital input switch is mapped to the horn switch object (2101_h) and an analog output is mapped to the horn object (2403_h).

Service indication

The controller can reduce vehicle performance and indicate to the operator when a vehicle service is required. The interval between services is user-configurable.

Configure the following at object 2850_h:

- Service indication: via an analog (contactor) output (e.g. to drive a dashboard lamp) and/or Gen4's LED.
- Source hours counter: selects the hours counter and is used to determine when a service is required.
- Service interval: hours between vehicle services. Can be used by the reset function (see below) or for information only.
- Next service due: Servicing is required when the source-hours counter reaches this time. This can be set manually, or automatically using the reset function; see below.
- Reset function: write to the reset sub-index at 2850_h to automatically reset the service timer for the next service. The next service due time is calculated as the source hours counter time plus the service interval.

Service profile

This is a drivability profile where you can set maximum torques, speeds and acceleration rates to be applied when a vehicle needs servicing (2925_h). See 'Drivability profiles' on page 6-25.

Traction motor cooling fan

This object can be used to drive a motor cooling fan when the operator is present on the vehicle (as indicated by the seat switch). The cooling fan object (2421_h) must be mapped to an analog output.

Motor over-temperature protection

The controller protects motors from over-temperature. It maintains a motor temperature estimate and can also accept a direct temperature measurement via an analog input (for a thermistor) or a digital input (for an over-temperature switch).

The temperature estimate is calculated by monitoring current to the motor over time. The estimate is configured at 4621_h.

The estimate is always applied, since it can detect increases in motor temperature more quickly then the direct measurement. Direct measurement is normally done on the motor casing, which lags behind the internal temperature.

Battery protection

The nominal battery voltage must be set at $2C00_h$.

Over voltage

Battery over voltage usually occurs during regenerative braking.

To provide protection set values for these parameters at $2C01_h$:

- Over voltage start cutback: the value at which the braking effort is linearly reduced to limit voltage increase.
- Over voltage limit: the value at which the controller cutouts out. A fault is set if the voltage exceeds the cutout voltage.

Under voltage

To prevent excessive battery discharge, set values for these parameters at $2C02_h$:

- Under voltage start cutback: the value at which the current drawn from the battery is reduced to limit voltage decrease.
- Under voltage limit: the value at which the controller cutouts out. A fault is set if the voltage drops below the cutout voltage for longer than the protection delay
- Protection delay: the time it takes for the controller to cutout after the under voltage limit has been reached ($2C03_h$).

Battery Discharge Indicator (BDI)

Monitor battery voltage using Gen4's Battery Discharge Indicator (BDI). The BDI presents the driver with a percentage remaining charge figure and has become an industry standard in recent years.

The BDI is not a measure of the absolute battery charge remaining and therefore we recommend you regularly check the absolute value in accordance with the battery manufacturer's instructions.

To use the BDI, configure the following parameters at $2C30_h$ in the Object Dictionary:

- Cell count: this is the number of battery cells and is normally half the battery voltage, as cells are usually 2 volts each.
- Reset voltage (V): set this to the cell voltage when the batteries have just been charged. This resets the BDI back to 100%.
- Discharge voltage (V): set this to the cell voltage when the battery is discharged.
- Cutout level (%): this is the level at which the vehicle adopts the low battery drivability profile.

Setting the warning and cut-out levels to 0% disables the warning and cut-out functionality.

Read the percentage remaining charge value from 2790_h sub-index 1 in the Object Dictionary.

Vehicle hours counters

All vehicle hours counters have user configurable offsets. This allows vehicle hours counters to be maintained if the master controller is replaced.

Apply offsets at 2780_h

Vehicle hours counters can be read at 2781_h to 2785_h.

Chapter 7: Monitoring Gen4

Reading status variables

All status variables are in Gen4's object dictionary. They can be accessed using SDOs. Some can be mapped to PDOs for continuous transmission to remote nodes such as displays and logging devices.

Motor measurements

The following status objects can be read:

- Motor slip frequency, power and temperature at object 4600_h.
- Motor torque, speed, etc. at objects 6000_h to $67FF_h$.

Heatsink temperature

Read the heatsink temperature at object 5100_h, sub-index 3.

Identification and version

Read identification and version information at:

- 1008_h – Controller name.
- 1009_h – Hardware version.
- $100A_h$ – Software version.
- 1018_h – Identity object. Contains CANopen vendor ID, product code, CANopen protocol revision, and controller serial number.
- 5500_h – NVM (EEPROM) format.
- 5501_h – Internal ROM checksum.
- 5502_h – External ROM checksum.

Battery monitoring

The controller measures actual battery voltage at two points:

- Battery voltage; measured at keyswitch input and read at 5100_h sub-index 1.
- Capacitor voltage; measured at the B+ terminal and read at 5100_h sub-index 2.

The controller also has a battery discharge indicator (BDI), which can be read at 2790_h.

Hours counters

The controller supports many different hours counters for various functions. Some counters run on all units and some only run on the Gen4 configured as the vehicle master. Hours counters which run on all units are:

- Controller key hours: increments while the keyswitch is in the ON position (5200_h).
- Controller pulsing hours: increments when the controller is powering its connected motor (4601_h).

Hours counters which run only on the Gen4 configured as the vehicle master are:

- Vehicle key hours: increments as controller key hours (2781_h).
- Vehicle traction hours: increments when the vehicle is driving or braking (2782_h).
- Vehicle pump hours: increments when the pump motor is running (2783_h).
- Vehicle power steer hours: increments when the power steer motor is running (2784_h).
- Vehicle work hours: increments when the traction, pump or power steer motors are running (2785_h).

Hours counters are preserved with a minimum resolution of 15 seconds when the system is powered down.

Logging

The controller can log events in the system (along with additional event-related information) and minimum and maximum levels of important parameters. You need different levels of access to clear the contents of the logs.

Logs are normally reset individually. However, to reset all logs at once write to 4000_h.

FIFO event logs

Events are recorded by these two separate FIFOs (first in, first out logs), which operate identically:

- System: this FIFO is 20 elements deep and is used for events such as software upgrades, user logins and some hardware upgrades (4100_h to 4102_h).
- Faults: this FIFO is 40 elements deep and is used for detected faults (4110_h to 4112_h).

At object $41X0_h$:

- Reset the FIFO

- Read its length
- Apply a configurable filter. The filter allows you to exclude some events from the FIFO event log.

You can access the FIFO using objects $41X1_h$ and $41X2_h$. The FIFO index is entered at $41X1_h$ and the data is read from $41X2_h$.

Event counters

The controller provides 10 event counters at 4200_h to $420A_h$. Each event counter can record information about occurrences of one event. The allocation of event counters to events is user-configurable however Gen4 will automatically count important events in unused counters. The information recorded in each event counter is:

- The time of the first occurrence
- The time of the most recent occurrence
- The number of occurrences

Operational monitoring

At objects 4300_h and 4301_h, Gen4 monitors and records the minimum and maximum values of these quantities:

- Battery voltage
- Capacitor voltage
- Motor current
- Motor speed
- Controller temperature

Two instances of the operational monitoring log are maintained. You can access and clear the first log; the second is accessible and clearable only by Sevcon engineers. The Customer copy is normally recorded and reset each time the vehicle is serviced. The Sevcon copy records data over the controller's entire working life.

CANopen abort code

The controller will sometimes respond with a CANopen General Abort Error (08000000_h) when the object dictionary is accessed. This can occur for many reasons. Object 5310_h gives the exact abort reason. These are:

0	None	7	Cannot go to operational	14	Unable to reset service time
1	General	8	Access level too low	15	Cannot reset log
2	Nothing to transmit	9	Login failed	16	Cannot read log
3	Invalid service	10	Range underflow	17	Invalid store command
4	Not in pre-operational	11	Range overflow	18	Bootloader failure
5	Not in operational	12	Invalid value	19	DSP update failed
6	Cannot go to pre-operational	13	EEPROM write failed	20	GIO module error failed

Faults and warnings

Introduction

In the event of a fault Gen4 takes the following action:

1. Protects the operator and vehicle where possible (e.g. inhibits drive).
2. Sends out an EMCY message on the CANbus.
3. Flashes the LED in a pattern determined by the fault type and severity.
4. Logs the fault for later retrieval.

Fault identification

You can identify a fault as follows:

- Check the number of LED flashes and use Table 7 below to determine what action can be taken. A complete and comprehensive fault identification table will be available from Sevcon in due course.
- Pick up the EMCY on the CANbus and read the fault condition using configuration software
- Interrogate the fault on the node directly using DriveWizard or other configuration software.

LED flashes

Use Table 7 below to determine the type of fault from the number of LED flashes. The LED flashes a preset number of times in repetitive sequence (e.g. 3 flashes – off – 3 flashes – off – and so on). Only the faulty node in a multi-node system flashes its LED. Possible operator action is listed in the right hand column of the table.

LED flashes	Fault	Level	Set conditions	Operator action
0 (off)	Internal hardware failure	RTB	Hardware circuitry not operating.	
0 (off)	Hardware failsafe checks	RTB	Hardware failsafe circuitry not operating.	
1	Configuration item out of range	VS	At least one configuration items is outside its allowable range.	
1	Corrupt configuration data	VS	Configuration data has been corrupted.	

LED flashes	Fault	Level	Set conditions	Operator action
2	Sequence fault	DI	Any drive switch active at power up.	Reset drive switches
2	SRO fault	DI	FS1 active for user configurable delay without a direction selected.	Deselect FS1 and select drive
2	FS1 recycle	DI	FS1 active after a direction change	Reset FS1
2	Seat fault	DI	Valid direction selected with operator not seated or operator is not seated for a user configurable time in drive.	Must be seated with switches inactive
2	Belly fault	DI	Set after belly function has activated.	
2	Inch sequence fault	DI	Inch switch active along with any drive switch active (excluding inch switches), seat switch indicating operator present or handbrake switch active.	
2	Invalid inch switches	DI	Inch forward and inch reverse switches active simultaneously.	Both inch switches inactive.
2	Two direction fault	DI	Both the forward and reverse switches have been active simultaneously for greater than 200 ms.	Reset switches
3	Fault in electronic power switching circuit	VS	Fault in electronic power switching circuit (e.g. MOSFET s/c).	
3	Short circuits on power outputs	VS	Short circuit detected on power outputs	
4	Line contactor welded	S	Line contactor closed at power up or after coil is de-energized.	
4	Line contactor did not close	S	Line contactor did not close when coil is energized.	
6	Steering pot wire-off	VS	Steering pot wire-off is detected.	Check pot. wiring
6	Steering switch wire-off	VS	Steering switch wire-off is detected.	Check switch wiring
6	Speed measurement wire-off	VS	Speed measurement input wire-off is detected.	Check encoder wiring
6	Belly switch wire-off	VS	Belly switch wire-off is detected.	Check switch wiring
6	Throttle wire-off	DI	Throttle wire-off is detected.	Check throttle wiring
6	Throttle pressed at power up	DI	Throttle demand is greater than 20% at power up.	Reduce demand

LED flashes	Fault	Level	Set conditions	Operator action
7	Controller high voltage protection with line contactor open.	S	Battery voltage or capacitor voltage is above the maximum level allowed for the controller with line contactor open.	Isolate controller and investigate high battery voltage
7	Battery low voltage protection	DI	Battery voltage or capacitor voltage is below a user definable minimum battery level for a user definable time.	Increase battery voltage above user defined level
7	Controller low voltage protection	DI	Battery voltage or capacitor voltage is below the minimum level allowed for the controller.	Increase battery voltage above minimum level
7	Controller high voltage protection with line contactor closed.	DI	Battery voltage or capacitor voltage is above the maximum level allowed for the controller with line contactor closed.	Investigate and reduce battery voltage below maximum level.
7	Battery high voltage protection	DI	Battery voltage or capacitor voltage is above a user definable maximum battery level for a user definable time.	Investigate and reduce battery voltage below user defined maximum level.
8	Controller too hot	I	Controller has reduced power to motor(s) below maximum specified by user settings due to controller over temperature.	Remove loading to allow controller to cool down.
8	Controller too cold	I	Controller has reduced power to motor(s) below maximum specified by user settings due to controller under temperature.	Allow controller to warm up to normal operating temperature.
8	Motor over temperature	I	Controller has reduced power to motor(s) below maximum specified by user settings due to motor over temperature.	Reduce load to motor to allow it to cool down.
12	Communication error	S	Unrecoverable network communication error has been detected.	
13	Internal software fault	RTB	Software run time error captured	

Table 7 Fault identification

Fault list

Use DriveWizard to access the Fault list. If you don't have DriveWizard you can use any configuration tool as follows:

1. Object 5300_h gives information about all active faults. Read sub-index 1 to get the number of active faults. Write to sub-index 2 to select one of the active faults (0 = highest priority) and read back sub-index 3 to read the fault ID at that index.
5. Object 5610_h can be used to read a text description of the fault. Write the fault ID to sub-index 1 and read back the fault description from sub-index 2.

Clearing faults

5301_h and 5302_h allow faults to be cleared.

Upgrading the controller software

It is possible to field update the firmware of the Gen4 controller , typically using Sevcon's DriveWizard configuration tool.

Please contact Sevcon for assistance with this process.

Appendices

Automatic Configuration Tables

This section lists the pre-defined digital and analogue input and output configurations that can be used with the CANopen automatic object mapping (see page 6-14).

The entries in the tables refer to the pin a particular function is connected to. MX refers to a pin on the master node, SR refers to a pin on the slave node driving the right traction motor, and SP refers to a pin on the slave node driving the pump motor. For example, analogue input configuration number 3 has throttle and footbrake inputs going to pins 22 and 34 on the master node, and an economy input going to pin 22 on the right traction slave node.

Digital Inputs

IO Selection→		0	1	2	3	4	5	6	7	8
Key switch	2100h									
Horn switch	2101h									
Drive enable switch	2120h						MX20			
Forward Switch	2121h	MX18	MX18	MX18	MX18	MX18	MX18		MX18	MX18
Reverse Switch	2122h	MX30	MX30	MX30	MX30	MX30	MX30		MX30	MX30
FS1 switch	2123h	MX19	MX19	MX19	MX19		MX19		MX19	MX19
Seat switch	2124h		MX31	MX31	MX31		MX31		MX31	MX31
Handbrake/Tiller switch	2125h		MX32	MX21	MX20	MX19	MX9		MX20	MX20
Driveability Select 1 switch	2126h			MX20	MX9	MX31	MX20		MX9	MX9
Driveability Select 2 switch	2127h				MX32				MX32	MX32
Inch forward switch	2129h	MX32				MX20			SR18	SR18
Inch reverse switch	212Ah	MX21				MX9			SR30	SR30
Inner left Steer switch	212Bh								SR19	

IO Selection →		0	1	2	3	4	5	6	7	8
Outer left Steer switch	212Ch								SR31	
Inner right Steer switch	212Dh								SR20	
Outer right Steer switch	212Eh								SR9	
High speed switch	212Fh									
Footbrake switch	2130h			MX32			MX32			
Traction Inhibit	2137h									
Belly	2139h					MX32				
Pump 1 switch	2140h		SP18	SP18			SP18	MX18		
Pump 2 switch	2141h		SP30	SP30			SP30	MX30		
Pump 3 switch	2142h		SP31	SP19			SP19	MX19		
Pump 4 switch	2143h						SP31	MX31		
Pump 5 switch	2144h						SP20	MX20		
Pump 6 switch	2145h						SP9	MX9		
Pump Inhibit switch	2150h							MX32		
Pump Drivability 1 switch	2152h							MX21		
Pump Drivability 2 switch	2153h									
Power Steer trigger switch	2160h				MX21	MX21		MX35	SR32	SR9

Analogue Inputs

IO Selection →		0	1	2	3	4	5
Throttle Input Voltage	2220h	MX22		MX22	MX22	MX22	MX22
Footbrake Pot Input Voltage	2221h				MX34	MX34	SR34
Economy Input Voltage	2222h				SR22	SR22	SR23
Steer Pot Input Voltage	2223h			SL22		SR34	MX34
Motor temp thermister	2224h						
Pump Throttle 1 Input Voltage	2240h		MX22	SP22			

IO Selection→		0	1	2	3	4	5
Pump Throttle 2 Input Voltage	2241h		MX34				

Analogue Outputs

IO Selection→		0	1	2	3	4	5	6	7	8	9	10
Line contactor	2400h	MX3	MX11	MX3	MX3	MX3	MX3	MX3	MX3	SL3	MX3	MX3
Line contactor	2400h			SP3		SP3						
External LED	2401h									SL7	MX7	MX7
Alarm buzzer	2402h											SP3
Horn	2403h									SR3		SR3
Lights	2404h								MX7		SR3	SP7
Service Due	2405h						MX7			SR7		SR7
Electro-mechanical brake	2420h	MX7		MX7	MX7			MX7		MX11	MX11	MX11
Traction Motor Cooling Fan	2421h											SP7
Motor Isolation Contactor	2422h											
High / Low Speed Indication	2423h											SP11
Pump contactor	2440h							MX11			SR7	
Power Steer contactor	2460h	MX11	MX3		MX11		MX11		MX11	SR11	SR11	