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PM100 Series AC Motor Drive User's Manual

Everything you need to know to install, set up, and calibrate the PM100 family of AC drives on asynchronous and PM synchronous motors in your Electric or Hybrid vehicle



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1 Safety First:



ATTENTION

When you see this sign, PAY ATTENTION! This indicates that something important is about to be said, that concerns your safety and the proper operation of the equipment.



DANGER

When you see this sign, you are being alerted to an IMMEDIATE DANGER that could cause severe injury or even death. You MUST review these sections carefully and do everything possible to comply with installation and operation requirements, or you risk injury or death to yourself or anyone else who uses the equipment or the vehicle. Failure to comply with safety requirements will void all warranties and could expose you as the installer to liability in the event of an injury. Use the equipment in the manner in which it was intended.



CAUTION

When you see this sign, you are being advised that the issue under discussion has a serious safety or equipment reliability implication. Use caution and be conservative. Use equipment in the manner described in this User's Manual.

Safety is entirely the responsibility of the installer of this equipment. RMS has done everything it can to ensure that the traction controller itself conforms to international standards for safety, including electrical safety spacings on printed circuit boards and in connectors and wiring harnesses, and for electromagnetic compatibility with other systems on a typical vehicle. This does NOT mean that your installation will be safe, or that it will not interfere with other systems on board your vehicle. It is your responsibility as the installer to review this entire User's Manual, to understand the implications of each and every section, and to know what might be unique about your system application that presents a unique hazard or potential safety issue – and to solve it.



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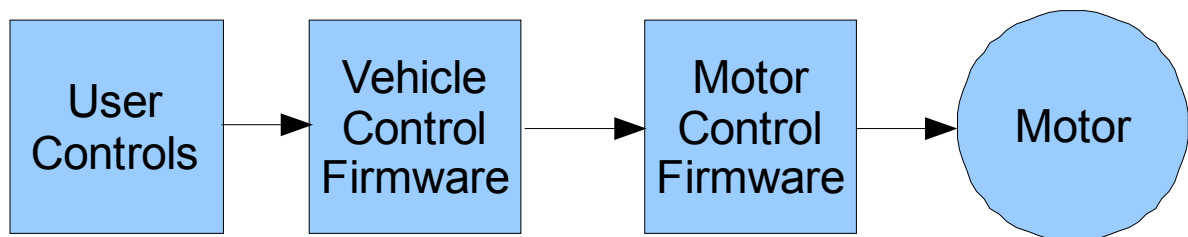
RMS is committed to helping you solve these problems, but cannot take responsibility for the application of this traction controller. We can only promise to meet the specifications for this product and that it meets international safety standards when used in accordance with the instructions in this Manual.



2 Functional Overview:

The PM100 is intended as a traction controller for EV and HEV drive systems, and includes both the motor control function and a rudimentary vehicle controller strategy in the same box. The motor control is a torque commanded, Direct Field Oriented Vector motor control technology that has been used on AC Induction and PM Synchronous motors in many applications. The use of Direct Field Orientation, measuring and regulating the machine flux with the use of an observer, allows the control to track actual torque production in real time, including the effects of transients and disturbances that an Indirect Field Oriented controller cannot handle.

The motor control subsystem firmware is mated to a vehicle controller firmware implemented in the DSP controller. This vehicle controller subsystem handles the driver interface (accel and decel / brake pedal inputs, Fwd/Rev controls, etc) and the vehicle interface (power sequencing, built in test, fault handling and safety issues). It is essentially a state machine in front of the motor controller firmware with a defined interface between the two software processes.

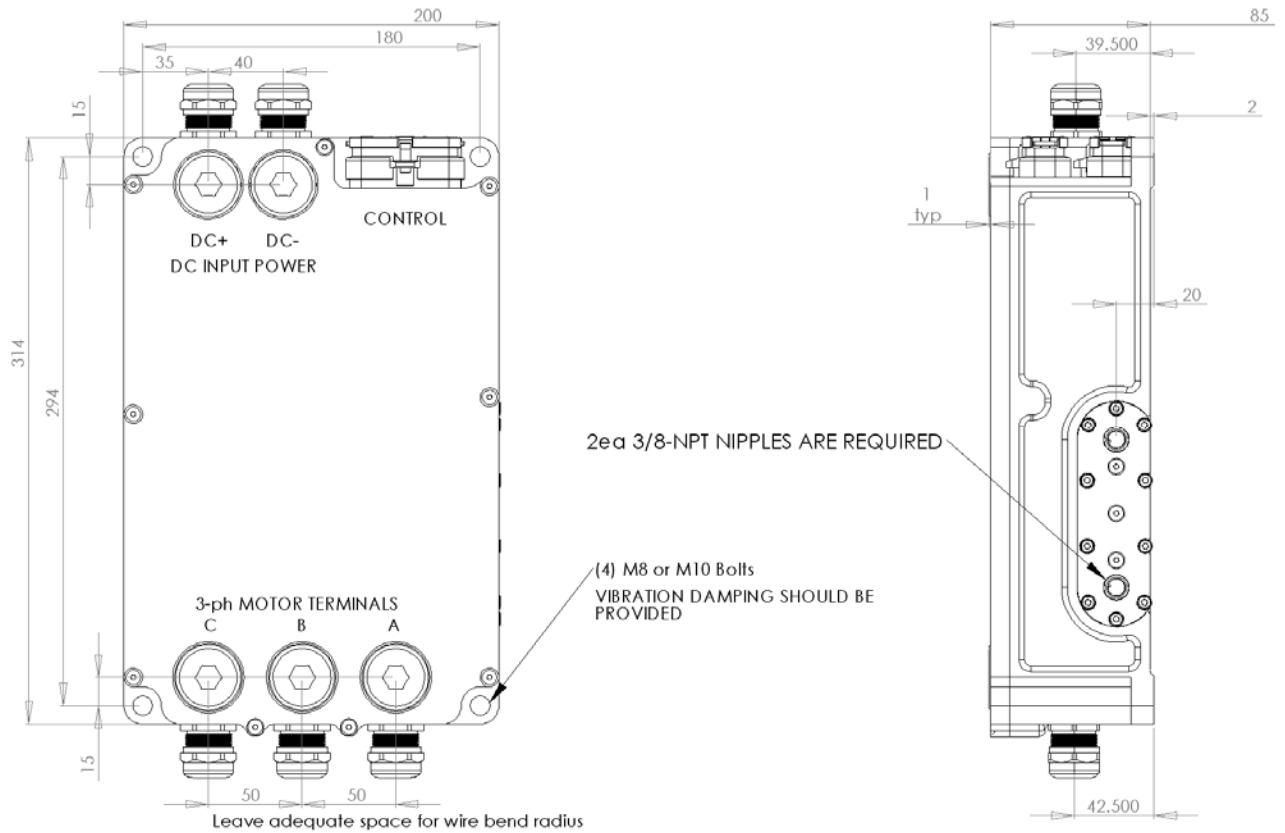


By default, out of the box the standard PM100 is set up in Torque Control Mode, with default motor parameters loaded. The parameters must be changed to match the load motor and operating characteristics before running for the first time. These parameters personalize the drive to the motor and the vehicle.



3 Installing the PM100:

The PM100 controller has 4 mounting locations, one at each corner. Mounting orientation is not critical. The controller should be mounted in a location that is not exposed to direct spray from water. Each mounting hole is sized to handle up to a M10 socket head cap screw.



Liquid Cooling Connections:

The controller must be cooled by passing liquid through it. The controller includes two ports to be used for liquid cooling. Each port is designed to accommodate a 3/8 inch NPT fitting. While it generally isn't critical, it is preferred that the rearmost plenum (the ports furthest from the 3 AC output terminals) be the fluid inlet, as this keeps the coolest fluid near the DC Link capacitor assembly. See table below for coolant specifications:

Coolant Type	50/50 mix ethylene glycol (antifreeze) / water or propylene glycol / water; with Aluminum corrosion inhibitor additive
--------------	--



Coolant Temperature	-30°C to +80°C full power Operation -40.. -30; +80.. +100°C with derated output
Coolant Flow Rate	3 GPM (12 LPM) at rated power
Pressure Drop	< >
Port Size	3/8 inch NPT standard (other options and fittings are available)

3.1 External Signal Connectors:

Two sealed automotive connectors are provided to connect to the internal I/O resources. J1 and J2 are standard AMPSEAL connectors by AMP/Tyco:

3.1.1 J1 – 35p AMPSEAL Plug 776164-1 with crimp contact 770854-1

Pin #	Pin Name	Description	Notes
1	XDCR_PWR	+5V @ 80mA max	Accel Pedal Power
13	AIN1	Analog Input 1 0-5V _{FS}	Accel Pedal wiper
24	AIN2	Analog Input 2 0-5V _{FS}	<default = spare>
2	AGND	Analog Ground	Accel Pedal GND
14	XDCR_PWR	+5V @ 80mA max	Spare 5V transducer power
25	AIN3	Analog Input 3 0-5V _{FS}	<default = spare>
3	AIN4	Analog Input 4 0-5V _{FS}	Motor Temperature Sensor
15	AGND	Analog Ground	
26	XDCR_PWR	+5V @ 80mA max	Spare 5V transducer power
4	RTD1	1000 Ohm RTD Input	
16	RTD2	1000 Ohm RTD Input	
27	RTD3	1000 Ohm RTD Input	



5	RTD4	100 Ohm RTD Input	
17	AGND	Analog Ground	
28	XDCR_PWR	+5V @ 80mA max	Spare 5V transducer power
6	RTD5	100 Ohm RTD Input	
18	<reserved>	DO NOT CONNECT	
29	<reserved>	DO NOT CONNECT	
7	/PROG_ENA	Serial Boot Loader enable	
19	AGND	Analog Ground	
30	DIN1	Digital Input 1 – STG ⁽¹⁾	<default = /FWD_ENA>
8	DIN2	Digital Input 1 - STG	<default = /REV_ENA>
20	DIN3	Digital Input 1 - STG	<default = /BRAKE_SW>
31	DIN4	Digital Input 1 - STG	
9	DIN5	Digital Input 1 – STB ⁽²⁾	
21	DIN6	Digital Input 1 - STB	
32	<reserved>	DO NOT CONNECT	
10	<reserved>	DO NOT CONNECT	
22	GND	Ground	
33	CANA_H	CAN Channel A Hi	
11	CANA_L	CAN Channel A Low	
23	CANB_H	CAN Channel B Hi	
34	CANB_L	CAN Channel B Low	
12	TXD	RS-232 Transmit	
35	RXD	RS-232 Receive	

⁽¹⁾– Switch to GND; ⁽²⁾ – Switch to Battery



3.1.2 J2 – 23p AMPSEAL Plug 7706802-1 with crimp contact 770854-1

Pin#	Pin Name	Description	Notes
1	XDCR_PWR	+5V @ 80mA max	Encoder Power
9	ENCA	Encoder Channel A input	
16	ENCB	Encoder Channel B input	
2	ENCZ	Encoder Channel Z input (Index)	
10	GND	GND	Encoder GND
17	EXC	Resolver excitation output	EXC
3	GND	Resolver excitation return	/EXC
11	SIN	Resolver Sine winding +	SIN
18	/SIN	Resolver Sine winding -	/SIN
4	COS	Resolver Cosine winding +	COS
12	/COS	Resolver Cosine winding -	/COS
19	GND		Resolver Shield GND
5	<reserved>	DO NOT CONNECT	
13	<reserved>	DO NOT CONNECT	
20	<reserved>	DO NOT CONNECT	
6	GND	Main 12V return	Chassis GND
14	GND	Main 12V return	Chassis GND
21	RLY1	Hi-Side Relay Driver	Pre-Charge Contactor Drive
7	RLY2	Hi-Side Relay Driver	Main Relay Drive
15	RLY3	Lo-Side Relay Driver	OK Indicator Drive
22	RLY4	Lo-Side Relay Driver	Fault Indicator Drive

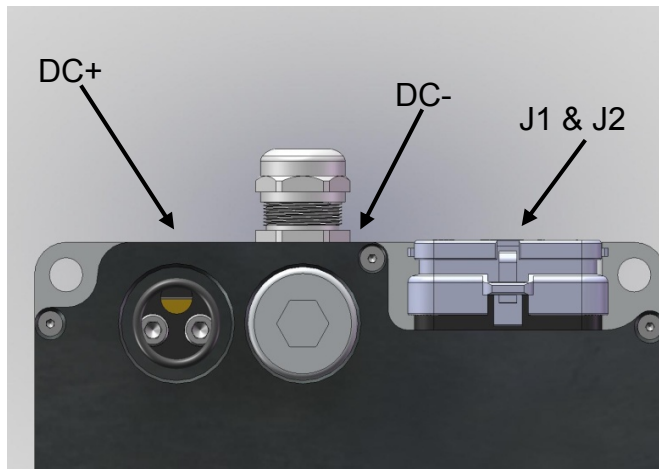


8	BATT+	Main 12V power source	12V Ignition Power Input
23	BATT+	Main 12V power source	12V Ignition Power Input

3.2 External Power Connections:

3.2.1 DC+ / DC-:

DC/Battery power is provided to the controller via two wire ports located at the rear of the



controller. The DC power must be run through an external pre-charge circuit to safely charge the capacitors inside the controller before the main contactor engages (refer to application schematic). The main contactor provides a safety disconnect of the DC power in case of a fault condition. Make sure that the wire to the drive is sized properly to handle the current. The recommended wire size is 2 AWG.

Wiring Procedure:

Remove the plugs in the cover using a 12mm Allen wrench. The plugs have an O-ring seal on them.

Two screw heads will now be visible. Use a 5mm Allen wrench to loosen these screws till the wire opening is at its maximum opening. Do not back both screws out all the way – they must remain threaded in the bottom half of the clam-shell terminal. It may be necessary to push down on the screws to make sure that the lower part of the terminal is moving all the way down.

Install the threaded portion of the cable gland on to the controller. Slide the remaining portion of the cable gland on to the wire.

Strip the wire insulation back 15mm (.625 in).



Slide the wire into the opening through the cable gland. The wire insulation should be visible through the view port hole from the top of the unit. Make sure that the wire is inserted until the insulation completely fills this viewing hole.

Tighten the two screws using the 5mm Allen wrench. It may be necessary to alternate back and forth between the screws to get the pieces to properly tighten.

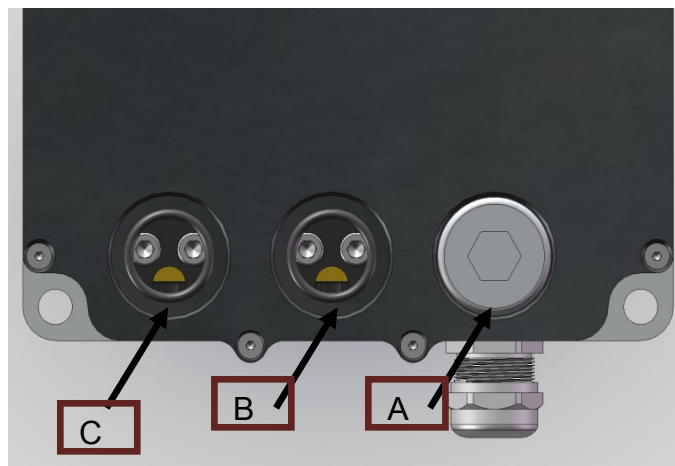
Give it a test pull – make wire that the wire is indeed fully captured, and examine the installation. The cable insulation should be flush with the insulated wiring port, which is visible from the top.

Slide the cable gland sealing parts into the threaded portion of the cable gland. Tighten. Reinstall the plug into the cover using the 12mm Allen wrench.

Fastener	Wrench Size	Torque spec
Wiring Plug	12mm	3 Nm
M6 clamp screws	5mm	5 Nm
M25 Cable Gland (optional)	27mm	6 Nm

3.2.2 Phase A / Phase B / Phase C:

Phase A, Phase B, and Phase C are wired to the motor. It is important the 3 wires be wired to the motor such that they give the proper direction of rotation. The motor wires are the most likely to generate EMI and they also carry a higher average current than the DC power wires. When



installed in the vehicle these wires should be kept as short as possible. It is also desirable to shield the three wires. This can be done by adding a copper braid over the wires, or using wire that includes a shield. Special cable glands are available that are metallic that can be used with braided wire. Follow the instructions above for installing the wires into the controller.



3.3.3 Pre-Charge Circuit:



An external pre-charge circuit must be used with the controller. The circuit limits peak inrush current into the controller when the main contactor is engaged. The pre-charge circuit adds a resistor, relay, and fuse in parallel with the main contactor. When the controller is powered on the controller will first engage the pre-charge relay to charge the capacitors internal to the controller. If the capacitors charge properly then the main contactor will engage.

The pre-charge resistor should be sized to rapidly charge the capacitor, but not dissipate too much power in a fault condition. The pre-charge resistor should be sized so that if the controller had a short on its input the pre-charge resistor would not fail.

The pre-charge circuit should be fused with a small fuse appropriate to the wire used. Since the pre-charge current is generally very low, approximately 0.5 amps in the example below, small wire can be used (recommend 18 AWG). A 5 amp fuse would be appropriate for this wire.

Sizing Example:

A typical application could have a maximum DC bus voltage of 320 volts. If a 600 ohm resistor were chosen this would result in a power dissipation of 171 watts. This is within the short term rating of a 50 watt wire-wound resistor. The internal capacitance of the controller is approximately 500uF. It takes approximately 3 time constants before the controller will close the main contactor, thus in this example it will take 0.9 seconds for the pre-charge to complete.

RMS can provide these parts if needed. Reference the following:

- Pre-charge Relay (30A, 12V COIL): RMS p/n 77-0026
- Pre-charge Resistor (600 ohm 50W): RMS p/n 53-0006
- Pre-charge Fuse (5A 500V): RMS p/n 59-0008

3.3.4 Main Contactor:

The main contactor is the switching element between the DC high-voltage power source (typically a battery) and the controller. The main contactor must be sized to handle the operating currents of the controller. In addition the main contactor must be able to open under a fault condition. Generally only one contactor is needed, the application schematic shows the main contactor in series with the positive path from the battery to the



controller. RMS has successfully used the following: Tyco/Kilovac p/n EV200AAANA. This contactor is available from RMS, contact us for more information (RMS p/n 77-0025). The contactor must be rated to handle DC voltage, AC only rated contactors and relays must not be used. DC rated contactors may be polarity sensitive. That is the normal operating current should flow in a particular direction. Refer to the contactor data sheet for more information.

3.3.5 Main Fuse:



The DC Power input to the controller must be fused. The fuse must be rated for the voltage of the battery as well as rated to open under the short circuit current that the battery can produce. Generally, this fuse (or equivalent fusible link) may be a part of the battery pack, but if the pack protection is not present or adequate, this fuse is required to prevent a potential battery pack fire. The fuse should be rated to handle the maximum DC input current of the controller. A semiconductor type fuse is recommended. Bussmann type FWP-400A is a suitable choice in many applications.

3.3.6 12V Power:

The PM100 requires a source of 12V power to operate. Normally this power will be on a switched circuit:

When the vehicle is turned OFF - the 12V power is removed from the controller by a switch.

This switched 12V power is connected to the BATT+ terminals of J2 (pins 8 and 23). The ground return for 12V power is connected to the GND terminals of J2 (pins 6 and 14). For normal applications only one pin is necessary. If necessary the 2nd set of pins can be used for applications that push higher 12V or GND currents through the controller.



Quiescent currents:

12V Operating Power Input Range	8V – 18V
12V Input Current @ 8V, operating	< >
12V Input Current @ 14V, operating	2A _{typ}
12V Input Current @ 18V, operating	1.6A _{typ}
12V Input Current @ 14V, non-operating (PWM off)	< >

These currents do not include any high-side or low-side drivers:

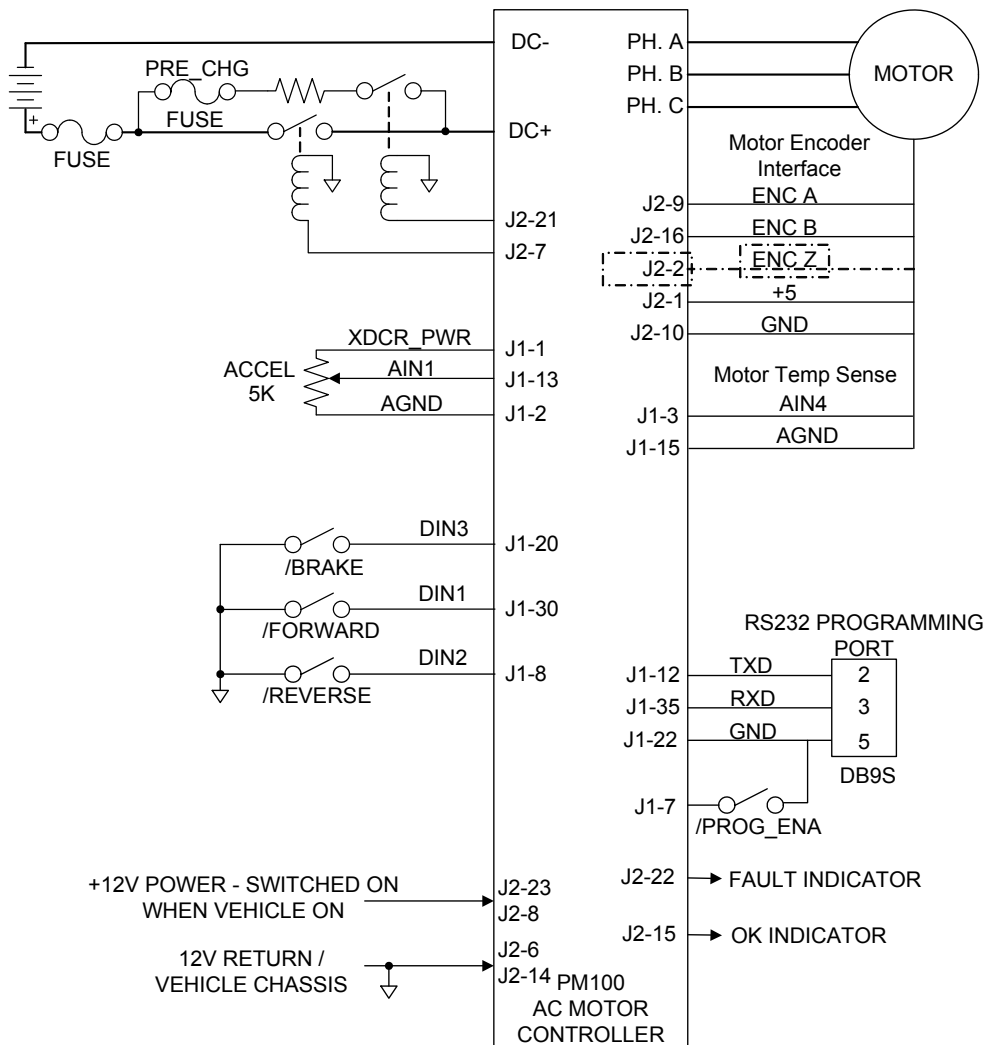
- Any hi-side driver output currents, including the main and pre-charge contactor relay drive currents, will come through the BATT+ pins and will add to the above currents.
- Any low-side driver output currents, including indicator lamp current, will come through the GND pins, and should be considered in sizing this connection.



3.3 Typical Application Wiring Diagram:

PM100 AC MOTOR CONTROLLER BASIC VEHICLE APPLICATION SCHEMATIC

AC Induction Motor Application Example
using Incremental Encoder for motion feedback



J1 IS 35 PIN AMPSEAL CONNECTOR, TYCO P/N 776164-1
J2 IS 23 PIN AMPSEAL CONNECTOR, TYCO P/N 770680-1
CONTACTS ARE TYCO P/N 770854-1

10 Aug 2009



4 CAN Interface:

PMxxx controller has two interfaces CAN A and CAN B. Currently, only CAN A is active. CAN B is reserved for future use. The CAN protocol conforms to CAN 2.0 A using 11-bit identifiers. The default bus speed is 250kbps and every message has a data length code (DLC) of 8 bytes.

The CAN interface has multiple purposes:

- Provides direct control of the motor
- Provides diagnostic and monitoring capabilities
- Provides user-adjustable configuration

The user can change the following configuration parameters through GUI interface:

- Inverter Command Mode: Setting this parameter to 1 allows the CAN mode to become active.
- CAN Bus Speed: Allowed speeds are 125 Kbps, 250 Kbps, 500 Kbps, or 1 Mbps. Enter 125, 250, 500, or 1000 to program the configuration parameter.
- CAN Terminator Resistor: The resistor can be applied or opened.
- CAN Identifier Offset: The default identifier is 0x0A0. However, user can choose any address between 0 and 0x7C0.

5 RS-232 Serial Interface:

There is one RS-232 serial interface with EMI filtering. This port can be used to set up and tune the controller, and to download controller software updates from a PC. RMS offers a simple serial user monitor that runs on the PC to allow changing parameters.

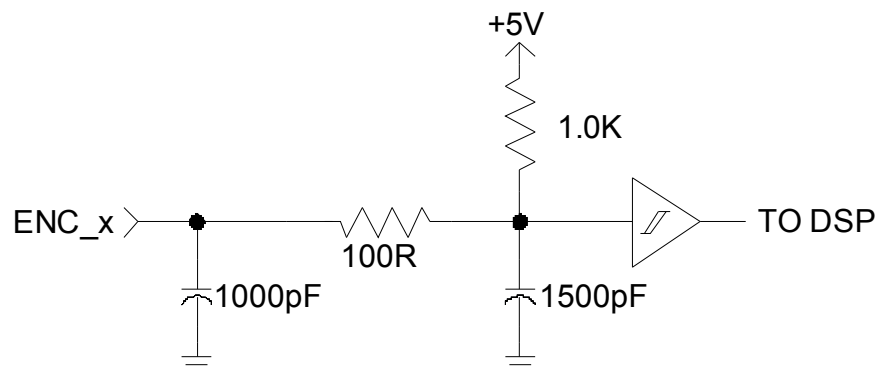
The drive can also be placed in a data-logging mode, and used with a PC, Palm, or other serial device the unit broadcasts datasets at 3Hz of a number of parameters that allow performance and energy consumption data to be gathered in real time.

This capability is described later in the data-logging section.



6 Encoder Interface:

The induction motor control software currently mandates the use of a position encoder on the motor. The encoder provides information about motor speed that is used by the induction motor control software. The controller provides a 5V interface to power the external encoder and to receive, level translate, and filter the signals from A, B and INDEX channels. For induction motor applications the INDEX channel is not used, but it may be wired. The encoder is connected internally to the TI DSP QEP Module (Quadrature Encoder Peripheral), which has special hardware for wide dynamic range speed and angle calculation from the encoder data. The drive has internal pull-up resistors on these inputs, and works with encoders that have either bi-polar or open-collector outputs.



Schematic of Encoder Inputs

7 Resolver Interface:

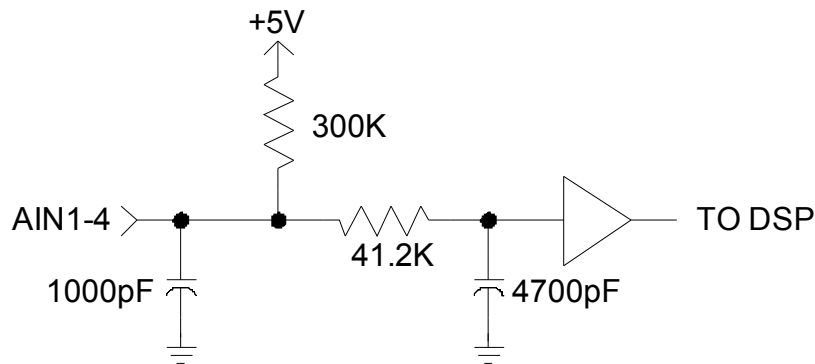
Upon request, a resolver can be used in place of the incremental encoder to determine motor rotor position and velocity. This is usually a good idea with Permanent Magnet (PMSM) machines, or any machine with significant rotor saliencies. The resolver is excited by a precision sinusoid, and the sine and cosine winding outputs are filtered for noise and presented to the DSP to be digitized at 12b resolution. For more information, consult the factory.



8 Vehicle Interface Setup:

8.1 ANALOG INPUTS:

There are 4 analog inputs, intended for general analog signal sensing (0 – 5V). There are 5 dedicated RTD sensor inputs (three 1,000 Ohm and two 100 Ohm calibrated RTD channels).



Schematic of Analog Inputs AIN1 - 4

The vehicle control system assigns the analog inputs as follows:

Input Name	Pin #	Function
AIN1	J1-13	ACCEL. The input should be tied to the vehicle accelerator. The input can be used with either a 0-5V signal or a potentiometer.
AIN2	J1-24	Not assigned.
AIN3	J1-25	Not assigned.
AIN4	J1-3	Motor thermistor. The motor thermistor can be connected between this input and analog ground. An external pull-up resistor will be required.

A 5V power supply (XDCR_PWR) is provided for powering sensors or potentiometers. This supply is available on several pins of J1 and J2 to ease connection. However, the total supply current available from this supply is limited to 80mA.

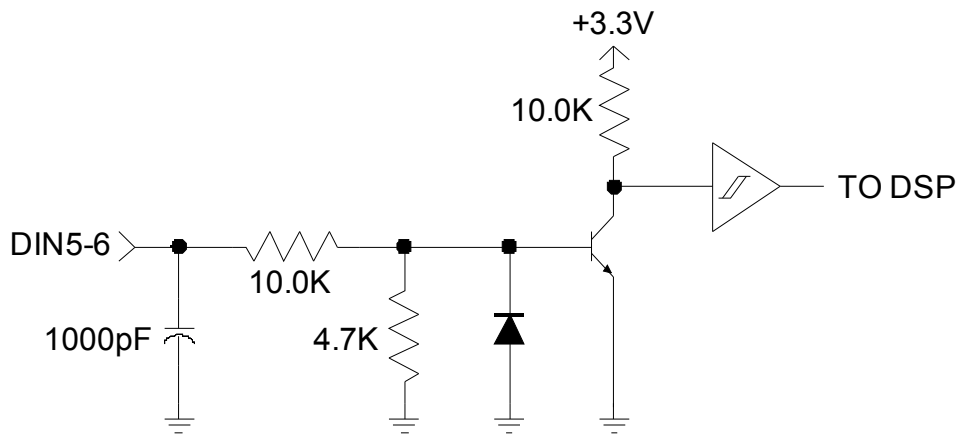
The analog signals should be referenced to one of the analog ground (AGND) pins available on J1. This will reduce noise. Analog ground should NOT be connected to GND or the vehicle chassis.



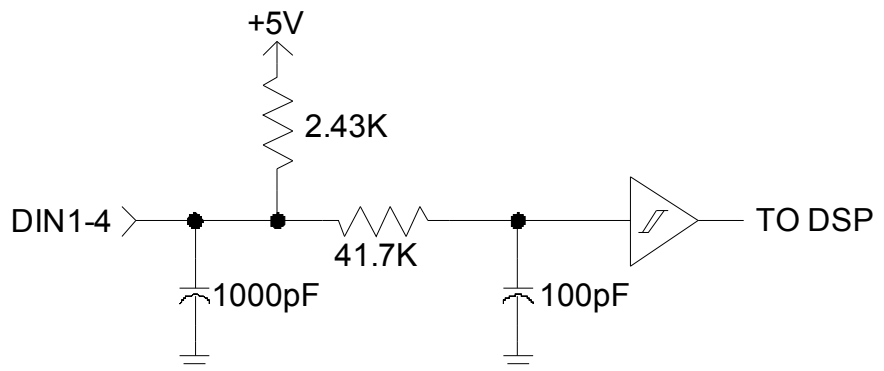
Description	Parameter	Value
AIN 1 – AIN 4		
Input Range	V_{range}	0 .. 5.00V
Offset Voltage	V_{ofs}	+50mV
Gain Accuracy	G	+5%
ADC Resolution		12b
Pull-up Resistance	R_{pu}	300 k Ω
RTD1 – RTD3		
Offset – 25°C ambient		$\pm 3^{\circ}\text{C}$
Temperature error – additional error over temperature		$\pm 3^{\circ}\text{C}$
RTD4 – RTD5		
Offset – 25°C ambient		$\pm 3^{\circ}\text{C}$
Temperature error – additional error over temperature		$\pm 3^{\circ}\text{C}$

8.2 DIGITAL INPUTS:

There are 6 digital inputs for general interface to the vehicle and for feedback from external contactors and switchgear as required in the application. Two inputs are “Switch To Battery” (STB) inputs. These inputs are designed to be used in an application that switches the input to a positive battery potential. There are four inputs that are “Switch To Ground” (STG) inputs. These STG inputs are designed to be used in an application that switches the input to ground.



Switch To Battery (STB) Input Schematic



Switch To Ground (STG) Input Schematic

The vehicle control system software currently assigns these inputs as follows:

Input	Type	Pin #	Function
DIN1	STG	J1-30	FWD_ENA. Forward Enable. This input should be connected to a switch that grounds this input when the user is commanding forward direction.
DIN2	STG	J1-8	REV_ENA. Reverse Enable. This input should be connected to a switch that grounds this input when the user is commanding forward direction.
DIN3	STG	J1-20	BRAKE. This input should be connected to a switch that grounds the input when the brake is pressed.
DIN4	STG	J1-31	Not assigned.

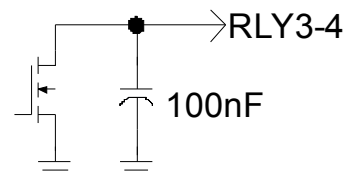
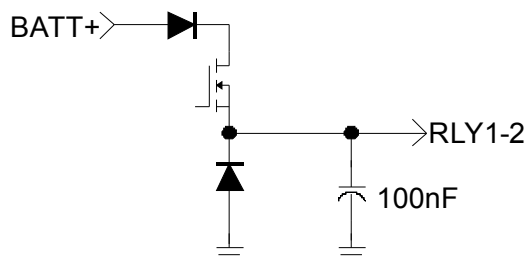


DIN5	STB	J1-9	Not assigned.
DIN6	STB	J1-21	Not assigned.

Description	Parameter	Value
Switch to Ground Inputs (DIN1 - DIN4)		
Voltage level for "ON"	V_{STG-ON}	<0.9 V
Voltage level for "OFF"	$V_{STG-OFF}$	>4.2 V
Pull-up resistor to 5V	V_{STG-PU}	2.4 k Ω
Maximum Voltage on Input	$V_{STG-MAX}$	18 V
Switch to Battery Inputs (DIN5 - DIN6)		
Voltage level for "ON"	V_{STB-ON}	>2.5 V
Voltage level for "OFF"	$V_{STB-OFF}$	<1.3 V
Pull-down resistor	R_{STB-PD}	10 k Ω
Maximum Voltage on Input	$V_{STB-MAX}$	18 V

8.3 DIGITAL OUTPUTS:

There are 4 digital outputs for general interface to the vehicle. Two of the outputs provide a high-side driver (output switches to battery potential). Two of the outputs are low-side drive (output switches to ground).



Schematic of High-Side Driver (RLY1-2)

Schematic of Low-Side Driver (RLY3-4)

The vehicle control system assigns the outputs as follows:



Output Name	Pin #	Function
RLY1 / HSD	J2-21	PRECHARGE DRIVE. This output provides power to the pre-charge relay.
RLY2 / HSD	J2-7	MAIN DRIVE. This output provides power to the main contactor.
RLY3 / LSD	J2-15	OK INDICATOR. This output provides a grounded signal to the OK indicator. The indicator turns on when power is applied to the drive and the drive has completed the pre-charge sequence.
RLY4 / LSD	J2-22	FAULT INDICATOR. This output provides a grounded signal to a fault indicator. The indicator will blink a fault code if the drive has detected a fault.

Description	Parameter	Value
Hi-Side Drivers (RLY1-2)		
Output Current - Continuous	lo_cont	1.5A
Output Current – Surge	lo_pk	7A
Low-Side Drivers (RLY3-4)		
Output Current - Continuous	lo_cont	1.5A
Output Current - Surge	lo_pk	3A

Each of the digital outputs is rated for 1.5 Amp. However, the two high-side drivers (RLY1 and RLY2) share a common reverse polarity diode thus the total current consumption of these two outputs cannot exceed 1 amp continuous.



9 Parameter Setup:

There are a number of internal parameters (consider them “calibrations”) that must be set in the controller before it is ready to operate a vehicle.

Parameter setup is accomplished using custom software provided by RMS. Refer to “Programming EEPROM Parameters using GUI” for more information on how to change, and how to program these parameters in non-volatile memory.

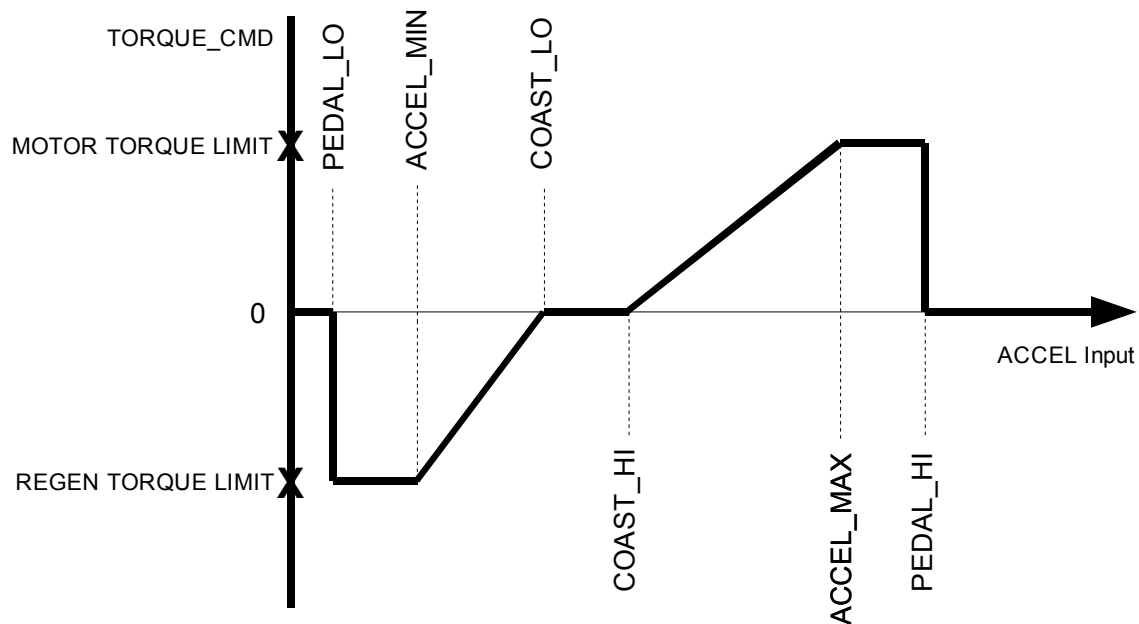
General Parameters:

DSP_Gui Parameter	GUI ADDRESS	Value Range	Description
Precharge_Bypassed_ EEPROM	0x0115	0 or 1	Set to 1: Setting this to a 1 will bypass the pre-charge sequence. When the drive is powered it will go directly to state “Wait State”. Set to 0: Setting this to a 0 will enable the pre-charge sequence as described below. Default is 0.
Run_Mode_EEPROM	0x0116	0 or 1	Set to 1: Setting this to a 1 will force the drive into speed control mode. This mode is only recommended for demonstration purposes when the motor is not connected to a high inertia load such as a vehicle. The Accelerator input will command a speed. Contact the factory for more information. Set to 0: Setting this to a 0 will place the drive into torque mode. This is the normal operating mode for the drive. Default is 0.
DC_UnderVolt_Thres_ EEPROM	0x0117	0 to 400 V	This is the under-voltage fault threshold voltage. If it is desired that the drive no detect under-voltage faults the value can be set to 0. Default value is 80V.



9.1 Accelerator Parameters:

The accelerator pedal input provides a torque command to the motor. The graph below details the relationship between the accelerator input voltage and the torque command:



Below is a list of the parameters that effect how the accelerator input works. The accelerator input has a range of 0 to 500. This corresponds to a physical range of 0 to 5.00 volts on the input. The parameters are designed for a pedal that provides a low input voltage when the pedal is released and a higher voltage as the pedal is pressed. If the vehicle has a pedal that operates in the opposite direction use the ACCEL PEDAL FLIPPED parameter as described below.

For initial setup and calibration, the accel pedal voltage can either be monitored by a volt meter, or it can be monitored by the GUI software over the serial port.



DSP_Gui Parameter	GUI ADDRESS	Value Range	Description
Accel_Pedal_ Flipped_ EEPROM	0x0114	0 or 1	If the pedal increases in voltage as it is pressed use a value of 0 (not flipped). If the pedal decreases in voltage as it is pressed use a value of 1 (flipped). When this parameter is 1, the pedal voltage will first be processed by the equation $\text{new_pedal_voltage} = 5.00 - \text{old_pedal_voltage}$. Thus will make the pedal act the same as a pedal that normally increases in voltage.
Pedal_Lo_ EEPROM*100	0x0107	1 – 500	For accelerator inputs less than this value the torque command is zero. This value should be set to a value that is lower than the lowest possible accelerator position, but higher than zero. If the accelerator input were to be shorted to ground the desired torque command is zero.
Accel_Min_ EEPROM*100	0x0108	1 – 500	For accelerator inputs between PEDAL_LO and ACCEL_MIN the torque command is set to a constant value of REGEN TORQUE LIMIT. Depending on the desired characteristics of the vehicle this range could be very small.
Coast_Lo_ EEPROM*100	0x0109	1 – 500	For accelerator inputs between ACCEL_MIN and COAST_LO the torque command is linearly from REGEN TORQUE LIMIT to zero. If desired this range allows the operator to control the amount of regen torque.
Coast_Hi_ EEPROM*100	0x010a	1 – 500	For the range between COAST_LO and COAST_HI the torque command is zero. Normally this range would be fairly small.
Accel_Max_ EEPROM*100	0x010b	1 – 500	For the range between COAST_HI and ACCEL_MAX the torque is linearly increased from zero to the MOTOR TORQUE LIMIT. This would be the normal driving range.
Pedal_Hi_ EEPROM*100	0x010c	1 – 500	For the range between ACCEL_MAX and PEDAL_HI the torque command is held constant at MOTOR TORQUE LIMIT. PEDAL_HI should be set above the normal range of pedal motion, but below 500.



Motor_ Torque_ Limit_ EEPROM	0x0110	1 – 300 Nm	This value sets the upper limit of the torque that can be commanded by the controller in motoring mode. However, if the current limit of the drive is reached before the torque command has been achieved the controller will limit on the current first. If this happens the operator will feel an additional amount of unused pedal range at the top end.
Regen_ Torque_ Limit_ EEPROM	0x0111	1 – 300 Nm	This value sets the upper limit of torque that is commanded when the accel pedal is released. Normally this value would be set to a small percentage of the available motor braking torque, to simulate engine braking. This value only sets the torque limit when the pedal is released with no brake applied. The torque applied when the brake is active is set by a separate parameter (Regen_Torque_Const_ EEPROM).
Regen_ Torque_ Const_ EEPROM	0x0112	1 – 300 Nm	

The Motor_Torque_Limit_EEPROM and Regen_Torque_Limit_EEPROM parameters set the maximum value of commanded torque. They will be modified internally based on motor speed as the motor cannot put out full torque over the entire speed range.

The accelerator should be designed so that in its normal range of operation it is greater than 0 volts and less than 5 volts. The parameters Pedal_Lo_EEPROM and Pedal_Hi_EEPROM should be set so that if the input goes to 0 or 5 the torque command goes to zero.

The parameters allow the controller to be setup to command a pedal off amount of regen torque. This regen torque would mimic the engine compression feel that vehicles often have.

Example Setup:

As an example let's assume that assume that the accelerator input comes from a potentiometer. That is, the one end of the pot is connected to AGND. The other end is connected to XDCR_PWR (+5V), and the wiper is connected to AIN1. This setup is shown in the example application schematic.



First we need to determine the range of travel of this potentiometer. With the controller 12V turned on measure the voltage on the wiper of the pot (AIN1). Note how the voltage changes as the pedal is pushed and released. If the voltage increases as the pedal is pressed then the ACCEL_PEDAL_FLIPPED_EEPROM parameter needs to be set to 0. If the voltage decreases then the ACCEL_PEDAL_FLIPPED_EEPROM parameter needs to be set to 1. Whenever the parameter is set to 1 all of the other parameter settings must be calculated as follows (parameter = 500 – actual voltage*100). For example if you desire a parameter to be set to 1.20 volts then the actual parameter setting will be $500 - 1.20 * 100 = 380$.

For this example we will assume that the voltage increases as the pedal is pressed. So Accel_Pedal_Flipped_EEPROM will be set to 0.

First measure the wiper voltage (AIN1) when the pedal is in the fully off position. For this example let's assume the measured value is 0.83 volts.

The Pedal_Lo_EEPROM parameter should be set to a value that is lower than this measured value. In this example let's set it to 0.40 volts (this corresponds to Pedal_Lo_EEPROM = 40). We want to set the parameter Accel_Min_EEPROM to be equal to this measured value (Accel_Min_EEPROM = 83). This will cause the torque to start increasing as soon as the pedal begins to be pressed.

Now measure the value of the wiper voltage (AIN1) when the pedal is fully pressed. For this example let's assume that measured value is 4.75 volts.

When the pedal is fully pressed we want to be commanding full torque so set the Accel_Max_EEPROM parameter to this measured value (Accel_Max_EEPROM = 475).

The Pedal_Hi_EEPROM parameter should be set to a value that is above this measured value but less than 5.00 volts. In this example let's set the value to 4.90 volts (Pedal_Hi_EEPROM = 490).

The Coast_Lo_EEPROM and Coast_Hi_EEPROM parameters define a range of pedal position where the torque command will be zero. For this example we'll define this range to be fairly narrow and with the pedal only slightly depressed. So we will set Coast_Lo_EEPROM to 1.10 volts (110) and Coast_Hi_EEPROM to 1.20 volts (120).



10 Vehicle State Machine:

The drive has an internal state machine that steps through a series of actions at startup, at shutdown, and generally whenever operation “transitions” from one mode or state to another. Following is a list of the states the drive sequences through upon application of power:

The particular state that the drive is in can be tracked via the DSPGui software. The state is monitored via the VSM_State symbol. This symbol will take on the following values:

VSM_State	Name
0	Start State
1	Pre-charge sequence initial state – Turn on the pre-charge relay
2	Pre-charge sequence active state – Waiting for capacitor to finish charging.
3	Pre-charge sequence finish state – Completes the final checks before proceeding to Wait State.
4	Wait State – waiting for activation of forward or reverse.
5	Ready State – Activates the inverter state machine to begin energizing the motor.
6	Motor Running State – Normal motor running
7	Fault State – The controller has faulted
0xFFFF	Recycle Power State – This indicates that the power to the controller needs to be recycled after EEPROM Programming is complete.

10.1 Start State (VSM_state = 0):

10.1.1 12V Power-up:

When the vehicle is powered up, this is the default state. Boot over the serial port is initiated if the relevant input is low.

10.1.2 Default Initialization:

This is the processor setup and initialization process, including setting all I/O pins to the correct state (in/out, pull-up or –down, weak or strong, etc). At this point, the initialization process sets up a default list of parameters with pre-assigned default values.



10.1.3 Load from EEPROM:

This state will load the application parameters to set the drive and vehicle controllers up for the actual application. This also loads CALIBRATIONS from memory, as these are just a class of EEPROM parameters.

10.1.4 Power on Self Test (POST):

A number of tests are to be performed in this state. Each test will have an associated fault flag. Following is a list of parameters checked:

- Current Sensor offsets: match to factory default
- ACCEL: check accelerator input data is in valid range
- T_PCB: check PCB temperatures in range
- T_GDB: check GDB temperatures in range
- T_MODA, T_MODB, and T_MODC: check substrate temperatures in range
- SENSE_XDCR: 5V and external transducer power
- SENSE_12V: 12V voltage sense
- VREF_2.5
- VREF_1.5
- HW Faults (Saturation and over current): Attempt to clear Faults

If a Power-On Self Test fault occurs it will blink the fault indicator. The number of blinks gives a general indication of the particular fault. The table below shows the number of blinks and the corresponding fault information.

The particular fault that occurred can be determined from monitoring the post_fault_hi and post_fault_lo variables with the DSPGui. If more than one fault has occurred the number indicated will be an AND of the two faults. For example, if ACCEL_SHORT (hi = 0x0000, lo = 0x0004) and HW_OC (hi = 0x0000, lo = 0x0002) both are present then the variables will show post_fault_hi = 0x0000 and post_fault_lo = 0x0006.

Post_fault_hi	Post_fault_lo	Fault Indicator Number of Blinks	Fault Description
0x0000	0x0001	5	GATE_FAULT
0x0000	0x0002	5	OVER_CURRENT
0x0000	0x0004	4	ACCEL_SHORTED. The voltage on AIN1



			is less than voltage represented by Pedal_Lo_EEPROM.
0x0000	0x0008	4	ACCEL_OPEN. The voltage on AIN1 is more than the voltage represented by Pedal_Hi_EEPROM.
0x0000	0x0010	3	Current Sensor low
0x0000	0x0020	3	Current Sensor High
0x0000	0x0040	1	Module Temperature Low
0x0000	0x0080	1	Module Temperature High
0x0000	0x0100	1	Control PCB Temperature Low
0x0000	0x0200	1	Control PCB Temperature High
0x0000	0x0400	1	Gate Drive PCB Temperature Low
0x0000	0x0800	1	Gate Drive PCB Temperature High
0x0000	0x1000	2	5V Sense Voltage Low
0x0000	0x2000	2	5V Sense Voltage High
0x0000	0x4000	2	12V Sense Voltage Low
0x0000	0x8000	2	12V Sense Voltage High
0x0001	0x0000	2	2.5V Sense Voltage Low
0x0002	0x0000	2	2.5V Sense Voltage High
0x0004	0x0000	2	1.5V Sense Voltage Low
0x0008	0x0000	2	1.5V Sense Voltage High
0x0010	0x0000	6	DC Bus Voltage High
0x0020	0x0000	6	DC Bus Voltage Low
0x0040	0x0000	6	Pre-charge Timeout
0x0080	0x0000	6	Pre-charge Voltage Failure
0x0100	0x0000	7	EEPROM Checksum Invalid
0x0200	0x0000	7	EEPROM Data Out of Range
0x0400	0x0000	7	EEPROM Update Required

Table of Power-On Self Test Fault Codes



10.2 Pre-charge Sequence (VSM_State = 1, 2, 3):

The following is brief description of the pre-charge sequence.

Turn-on the PRE_CHG output if Vdc has not exceeded VIN_MAX. Otherwise, set VDC_OOR_HI fault and go to the FAULT state.

1. If all of the following conditions are true:
 - Vdc stops rising by less than PRECHARGE_RATE V/s
 - Vdc is greater than VIN_MIN, Vdc is less than VIN_MAX
 - Time has not exceeded 1 second

Then do the following:

- Engage the MAIN_OUT output
 - Turn-off the PRE_CHG output
 - Go to the 30ms delay.
2. If total pre-charge time exceeds 1 second then:
 - If the DC BUS is greater than VIN_MAX:
 - Turn the PRE_CHG output off
 - Declare VDC_OOR_HI fault.
 - If the DC BUS is less than VIN_MIN:
 - Turn the PRE_CHG output off
 - Declare VDC_OOR_LOW fault
 - If Vdc is still rising by more than or equal to PRECHARGE_RATE V/s
 - Turn off the PRECHARGE_OUT output
 - Declare PRECHARGE_TIMEOUT fault
 3. Delay 30ms.
 4. Measure Vdc.
 - If Vdc is above VIN_MAX, declare VDC_OOR_HI fault.
 - If VDC is below VIN_MIN, declare VDC_OOR_LO fault.



5. Delay 15ms.
6. Take another measurement of Vdc.
 - If Vdc is above VIN_MAX, declare VDC_OOR_HI fault.
 - If VDC is below VIN_MIN, declare VDC_OOR_LO fault.
7. Verify that voltage is within VDC_MATCH_RANGE_THRESHOLD of the first measurement.
If not, declare VDC_DATA_MISMATCH fault.

Application Parameters:

Parameter	Value	Unit	Description
VDC_MATCH_RANGE_THRESHOLD	10	V	Variation in VDC after pre-charge is complete
PRECHARGE_RATE	54	V/s	VDC rate of charge must fall below this value for pre-charge to be complete.
VIN_MIN			VIN_MIN is set by the EEPROM parameter DC_UnderVolt_Thres_EEPROM
VIN_MAX	380	V	VIN_MAX is set by the EEPROM parameter DC_Voltage_Limit_EEPROM. If VDC is above this value a fault will be issued.



10.3 Wait State (VSM_state = 4):

This state checks to see that both /FORWARD and /REVERSE switches are inactive. Once both switches are in the acceptable state, it then waits for one of the switches to become active. If both switches, /FORWARD and /REVERSE, are active, the state shall declare a FWD_RVS_INVALID_STATE_FAULT.

After startup, this state also waits for an EEPROM Programming command only once, before its first transition to the READY state.

10.4 Ready State (VSM_State = 5):

The READY state shall send out the Enable Inverter Command and wait for Inverter Ready Flag to be set. If there is no response within a specific amount of time, the state shall declare an INVERTER_RESPONSE_TIMEOUT_FAULT.

This state automatically transitions to the next state if there are not faults.

10.5 Motor Running State (VSM_State = 6):

This is the normal running operation of the torque commanded field oriented controller that rides on top of the power electronics hardware. While running the drive can be switched from torque command to speed command mode, and may be exercised within the full operating envelope of the machine / drive combination.

10.6 Fault State (VSM_State = 7):

If a fault occurs either during Power-On Self Test, or while the drive is running the drive will go to the fault state.

If the drive has a fault during the running state a fault code will be set and the fault indicator will begin blinking.

The particular fault code can be found by monitoring the run_fault_hi and run_fault_lo parameters. If multiple faults have occurred the parameters will indicate the logical AND of the two faults. Below is the table of faults:



run_fault_hi	run_fault_lo	Fault Indicator Number of Blinks	Fault Description
0x0000	0x0001	6	Motor Over-speed Fault
0x0000	0x0002	3	Over-current Fault
0x0000	0x0004	2	Over-voltage Fault
0x0000	0x0008	1	Inverter Over-temperature Fault
0x0000	0x0010	4	Accelerator Input Shorted Fault
0x0000	0x0020	4	Accelerator Input Open Fault
0x0000	0x0040	7	Direction Command Fault (Both directions active at the same time)
0x0000	0x0080	8	Inverter Response Time-out Fault
0x0000	0x0100	5	Hardware Desaturation Fault
0x0000	0x0200	5	Hardware Over-current Fault
0x0000	0x0400	2	Under-voltage Fault
0x0000	0x0800	8	CAN Command Message Lost Fault

Table of Run Faults



10.7 Recycle Power State (VSM_State = 0xFFFF):

This state indicates that the EEPROM Programming has been successfully completed. For new EEPROM values to take effect, the controller must be re-powered.

11 Drive Startup Sequence:

To begin driving, the drive insists that an orderly sequence of events occurs during the transition from READY state to RUNNING state. The following conditions must be met and held:

- BRAKE must be ON. This means the brakes must be pressed hard enough to actuate the pressure hydraulic switch for the brake lights.
- FORWARD switch must be OFF.
- REVERSE switch must be OFF.

Once these conditions have been met the operator can switch either the FORWARD switch ON or the REVERSE switch ON. The BRAKE switch must still be ON. This switch (input) transition will move the drive from READY to RUNNING state, fluxing the machine for one rotor time constant, and then engage the current regulators and then the torque regulator to energize the motor. The operator can now release the Brake pedal (BRAKE goes away) and begin driving the vehicle.

When it comes time to reverse directions the BRAKE must be applied, both switches must go off, and then the new switch can be toggled to engage the new direction. The pedals should operate naturally in either direction.

Commanding Torque:

Torque Capability Curve is a function of Motor Speed, a feedback parameter from the Motor Control. Figure 2-3 shows the relationship between Torque Capability and Motor Speed:

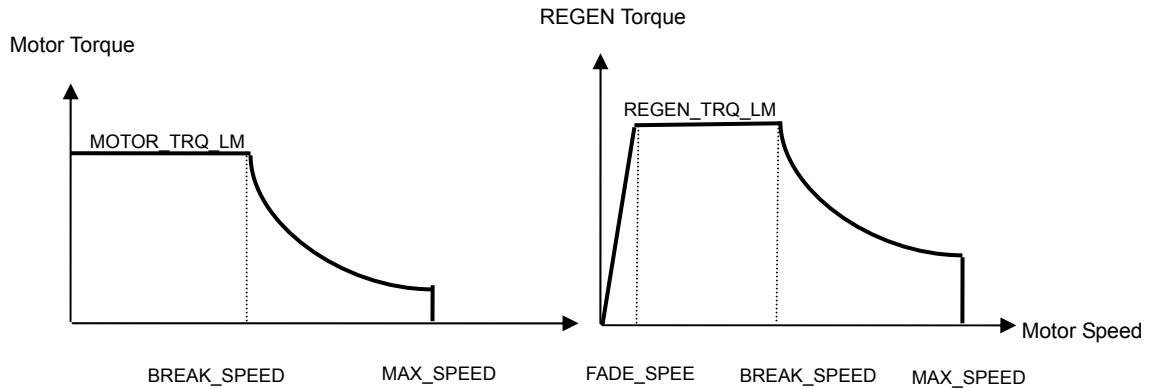


Figure 2-3 – Torque Capability vs. Motor

There are two types of Torque Capability curves, Motor Torque Capability and REGEN Torque Capability. The two quantities MOTOR_TRQ_LMT and REGEN_TRQ_LMT differentiate the two curves from each other. Moreover, the BREAK_SPEED, currently a constant, will also be different for each curve.

Following table lists the calibration parameters that pertain to the above graphs. The values of these parameters come from the EEPROM and are set via the DSPGui software.

DSP_Gui Parameter	GUI ADDRESS	Value Range	Description
Motor_Torque_Limit_EEPROM	0x0110	1 to 300 Nm	This parameter sets the maximum torque that can be commanded via the accelerator pedal. (Default value: 160 Nm)
Regen_Torque_Limit_EEPROM	0x0111	1 to 300 Nm	This parameter sets the maximum amount of regenerative torque that will be applied when the pedal is released. (Default value: 5 Nm)
Regen_Torque_Const_EEPROM	0x0112	1 to 300 Nm	This parameter sets the amount of torque that will be commanded when the brake pedal is pressed. (Default value: 15 Nm)



Break_Speed_ EEPROM	0x010e	1 to 10000 RPM	The parameter sets the speed at which the maximum torque command is reduced to compensate for a reduction of available torque due to field weakening. (Default value: 3000 RPM)
Max_Speed_ EEPROM	0x010f	1 to 10000 RPM	The parameter sets the maximum allowable speed. If the speed is above this value the torque command will be reduced to zero. (Default value: 10,000 RPM)
Regen_Fade_ Speed_EEPROM	0x010d	1 to 10000 RPM	The parameters sets at which the amount of regen torque available is reduced. (Default value: 200 RPM)

All of these values must be adjusted to suit the vehicle and motor you are using. These adjustments are part of personalizing the drivability and vehicle dynamics to suit the final application of the vehicle.