DMOC445 and DMOC645 User Manual
For Azure Dynamics DMOC Motor Controller

MAN-080001-001 DECEMBER 2009

AZURE DYNAMICS INC.
An ISO 9001:2000 Certified Company
9 Forbes Road
Woburn, MA
USA 01801

T 781.932.9009
F 781.932.9219

productsupport@azuredynamics.com
www.azuredynamics.com

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Caution

The information provided in this manual is intended for use by persons with appropriate technical skills. Any effort to perform repairs to or service your unit without the proper tools or knowledge required for the work can result in personal injury and product damage and will void your warranty!

Contact Information

Please feel free to call with any suggestions that you may have regarding the content of your manual. If additional service information is needed or to order replacement parts, please call Monday–Friday 8:30AM–5:30PM USA Eastern Time:

T 781.932.9009

F 781.932.9219

E productsupport@azuredynamics.com

How to Report Errors

If, while reading through this manual, you discover an error in the technical information provided, Azure Dynamics asks that you notify its Product Support Department. Please be prepared to provide the following information:

- Your name
- Name and edition of your manual
- Page number(s) where the error(s) appear
- Part number and serial number of your unit

Information contained in this manual is based on the latest product information available at the time of publication. The right is reserved to make changes at any time without notice.

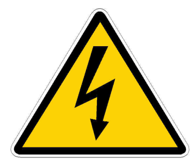
Safety

For your safety and the safety of others, please read and understand this entire manual before installing the components you have received from Azure Dynamics. If you have questions regarding the contents of this manual, please call the Azure Dynamics Product Support Department before proceeding.

Warning Labels

Labels indicate areas in a procedure where you should take appropriate precautions. Labels include:

WARNING AND DANGER



RISK OF ELECTRIC SHOCK

Safety Symbols

Always use caution when working on or around any electrical equipment. Wear eye protection at all times. The following symbols will be located in your manual to indicate sections in a procedure where extra caution and/or safety equipment is required.

HEARING PROTECTION REQUIRED

EYE PROTECTION REQUIRED

Always follow any safety instructions that are given at the beginning of a procedure. If you are uncertain as to the safe and proper handling of your equipment, contact Azure Dynamics Product Support.

Do not open your DMOC. This will void the warranty and is a serious safety issue.

Overview and Specifications

The Azure Dynamics Digital Motor Controllers (DMOCs) are rugged traction inverters for controlling three-phase AC motors and generators. A flexible control-software architecture allows for application-specific customization by loading software application modules, see Figure 1. These application modules communicate with the motor-control core and implement the interface to the higher level controls or respond directly to the driver inputs and outputs for stand-alone systems. The application module can be as simple as a CAN communication layer or as complex as to provide a complete electric vehicle control. The DMOC is based on state-of-the-art control techniques and electronic devices, and offers several layers of protection to prevent safety critical conditions.

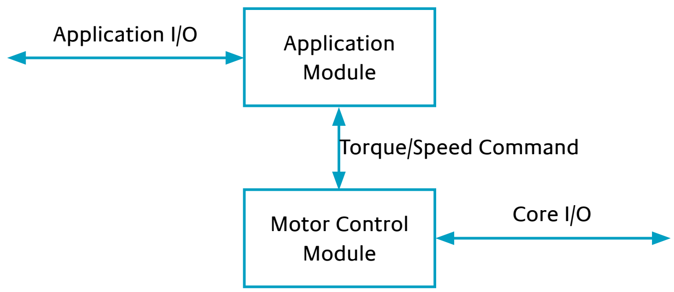


Figure 1: DMOC Application Module and Control Core

Typical applications for the DMOC include traction drive for electric vehicles (EVs), hybrid electric vehicles (HEVs) and fuel cell electric vehicles (FCEVs); and generator controller for HEV auxiliary power units (APUs).

Note that this document only addresses the generic DMOC features. Application-specific details can be found in the manuals listed in Table 1, which are revised and distributed separately.

The DMOC is designed to operate in a system as illustrated in Figure 2.

On the DC side, it is connected to an energy storage system (ESS) such as a battery pack or ultra-capacitor bank. In general, the ESS needs to be able to sink and source power. The DMOC can be used with sources that can only source power, such as fuel cells, but special protections are needed in such cases in order to ensure the safety of the DMOC and ESS.

On the AC side, the DMOC connects to an Azure Dynamics-supported three-phase motor, such as the AC24, AC24LS, AC55 or AC90. Specific instructions on how to safely install the DMOC and make the necessary electrical connections are given in this document. Since the DMOC is part of a high voltage system it is extremely important to follow the directions in this document. Only personnel trained to work with high voltage should install and maintain this product.

A 12V supply is also required to operate the DMOC. (Note, 24V DMOCs are available; please contact Azure Dynamics.)

Note, no contactors should be included in either the DC or AC wires in Figure 2.

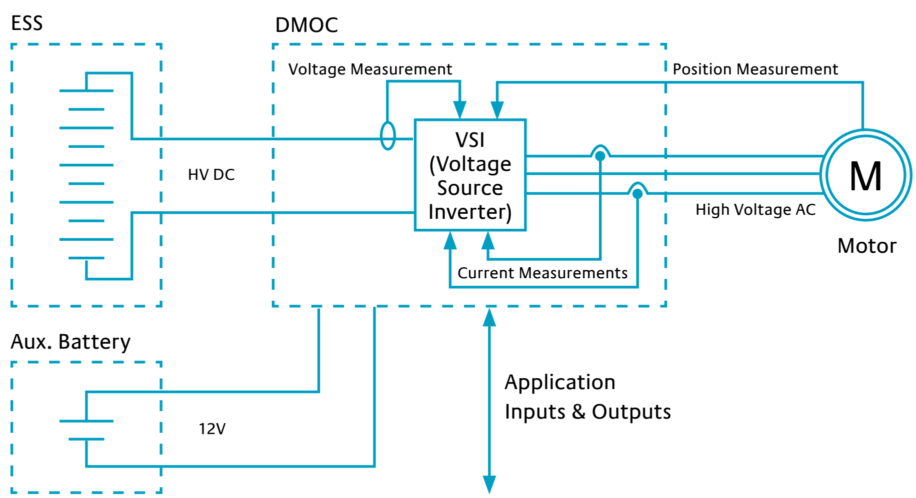


Figure 2: DMOC with Typical Connections

Azure's PC-based diagnostics/calibration tool ccShell allows the user to access and modify DMOC calibration parameters and to visualize and capture variables in real time.

While the meaning of the most important calibration parameters and variables of the DMOC core is described in this document, please refer to the ccShell User Manual for information on how to install and use this tool.

Note, not all calibration parameters may be modified by the customer. Not all variables may be visible to the customer.

Table 1: List of Relevant Manuals

Document Name	Document Number
DMOC445 and DMOC645 User Manual	MAN-080001
Pedal Controller Application User Manual	MAN-080002
CAN Controlled Application User Manual	MAN-080003
ccShell User Manual (Please note, this manual is distributed as part of the ccShell software. It is available under ccShell's "Help" menu.)	MAN-080008

The DMOC specifications are shown in Table 2.

Table 2: DMOC Specifications

	DMOC445	DMOC645
Length	450 mm	585 mm
Width	226 mm	260 mm
Height (air-cooled version)	238 mm	310 mm
Height (liquid-cooled version)	148 mm	162 mm
Weight	14.7 kg	27.5 kg
Minimum Operational Voltage	100 VDC	
Maximum Operational Voltage	400 VDC	
Minimum Battery Voltage for Powerup	120 VDC	
Recommended Minimum Nominal Battery Voltage[1]	144 VDC	
Recommended Maximum Nominal Battery Voltage[2]	336 VDC	
Unit Peak Efficiency	97%	97%
Min/Max Operating Ambient Temperature	-40C to 55C	-40C to 55C
Maximum Motor Current	280A rms	414A rms
Peak Power	78kW @ 312V	118kW @ 336V
Continuous Power	38kW @ 312V	53kW @ 336V
Max. Voltage "On Charge"	450 VDC	
Minimum Auxiliary Supply Input Voltage (12V DMOC)	11 VDC	
Maximum Auxiliary Supply Input Voltage (12V DMOC)	15 VDC	

Please see:

Figure 3: DMOC445 Air-Cooled Model

Figure 4: DMOC445 Air-Cooled Dimensions, Top View

Figure 5: DMOC445 Air-Cooled Dimensions, Side View

Figure 6: DMOC445 Liquid-Cooled Model

Figure 7: DMOC445 Dimensions, Bottom View

Figure 8: DMOC445 Signal Connections

Figure 9: DMOC445 Liquid-Cooled Cooling Connections

Figure 10: DMOC445 Battery Wire Connections

Figure 11: DMOC445 Mounting

Figure 12: DMOC645 Air-Cooled Model

Figure 13: DMOC645 Dimensions

[1] Varies with motor and battery type. With any battery technology, the battery voltage should not drop steeply and sharply under load.

[2] Varies with battery type.

Dimensions

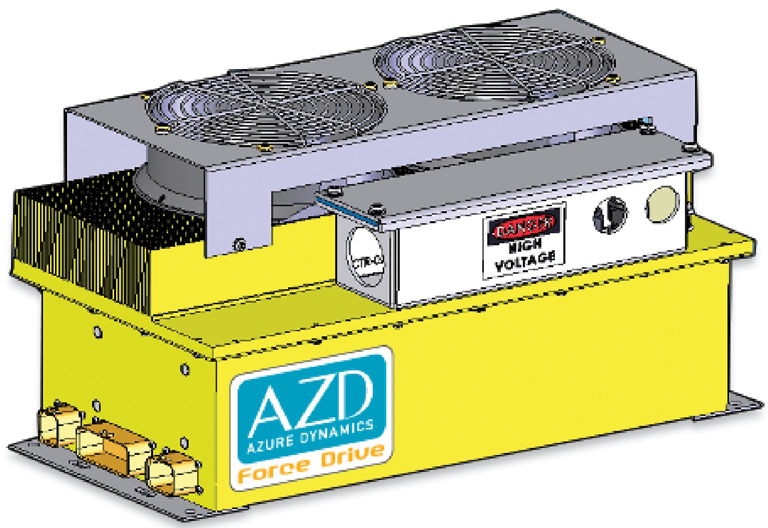


Figure 3: DMOC445 Air-Cooled Model

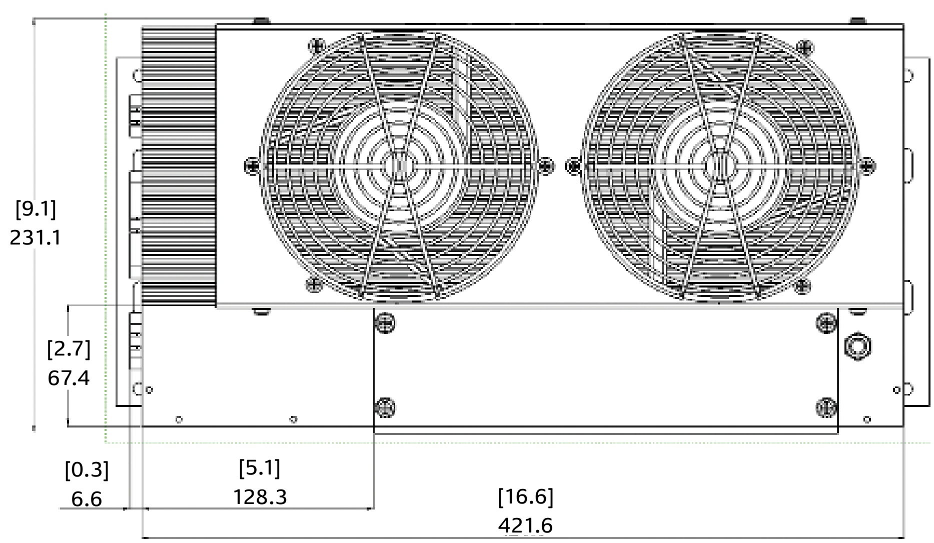


Figure 4: DMOC445 Air-Cooled Dimensions, Top View

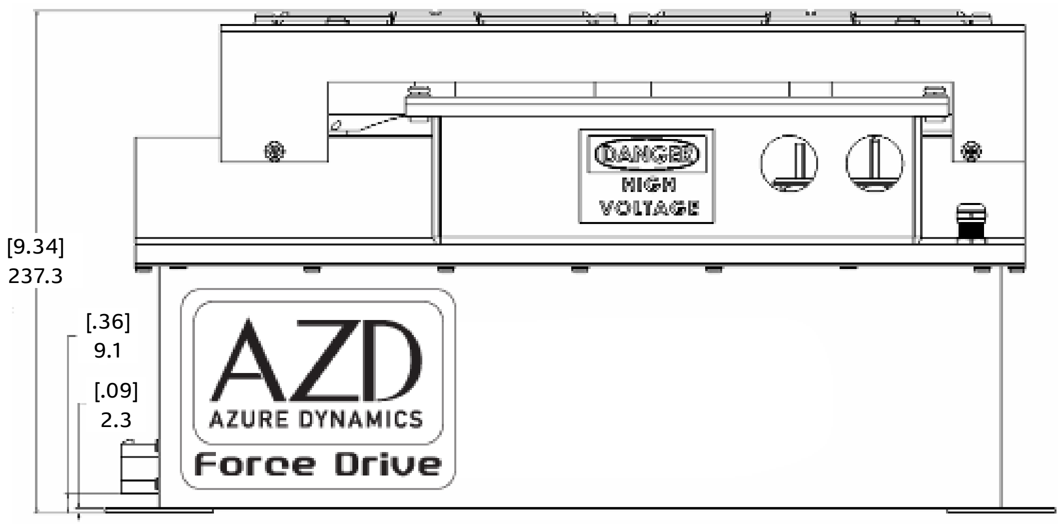


Figure 5: DMOC445 Air-Cooled Dimensions, Side View

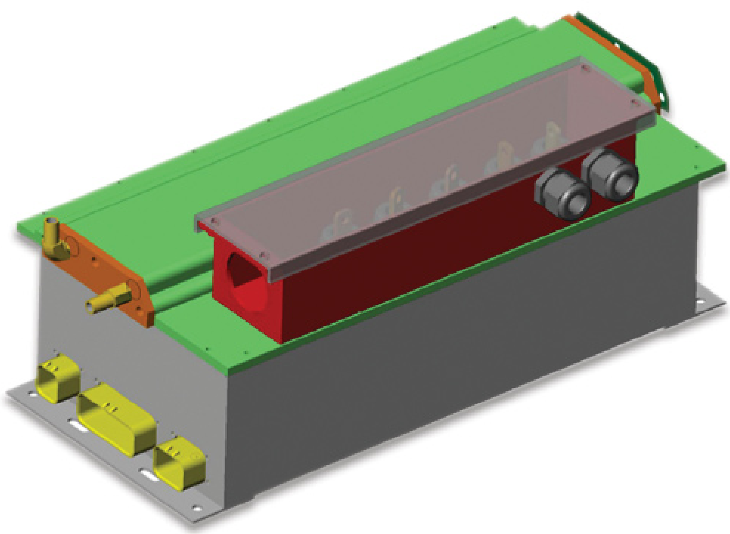


Figure 6: DMOC445 Liquid-Cooled Model

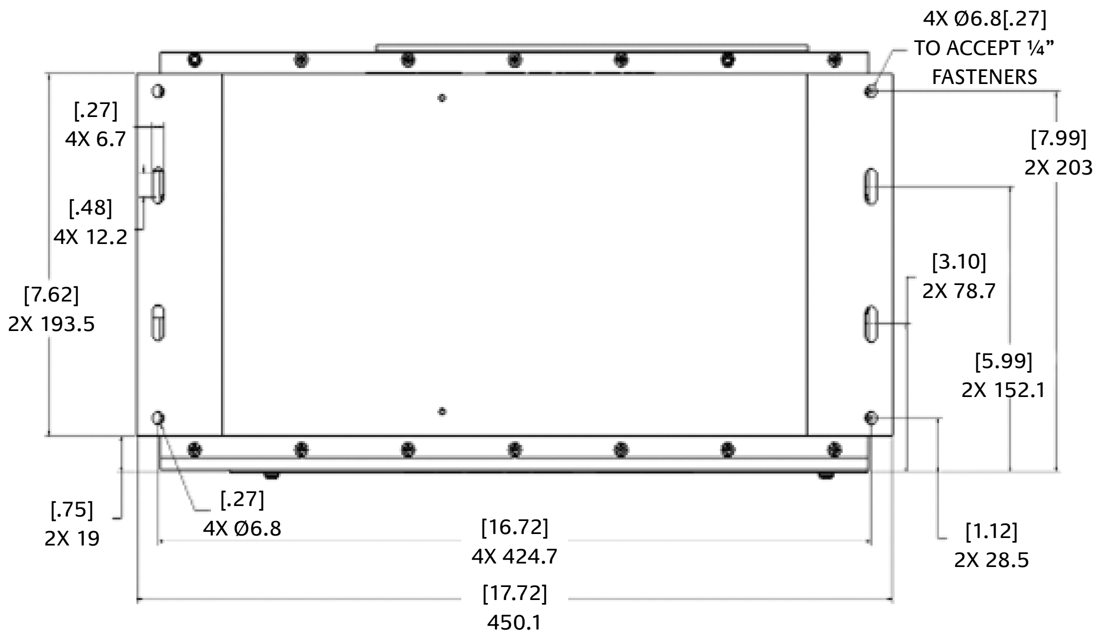


Figure 7: DMOC445 Dimensions, Bottom View

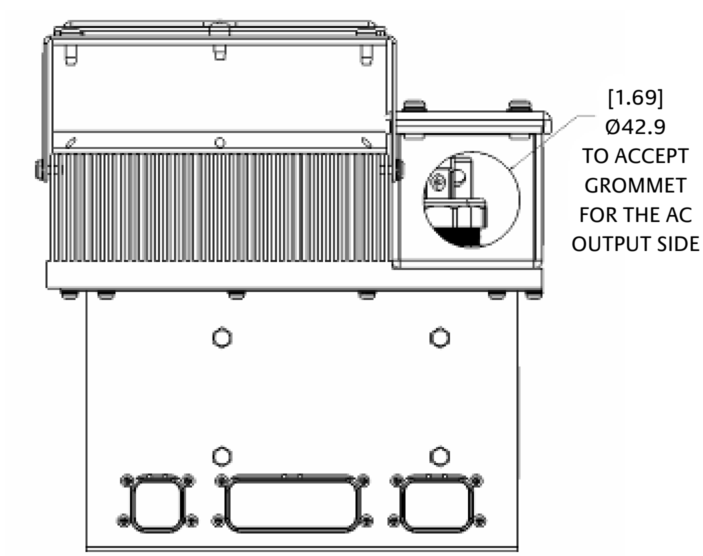


Figure 8: DMOC445 Signal Connections

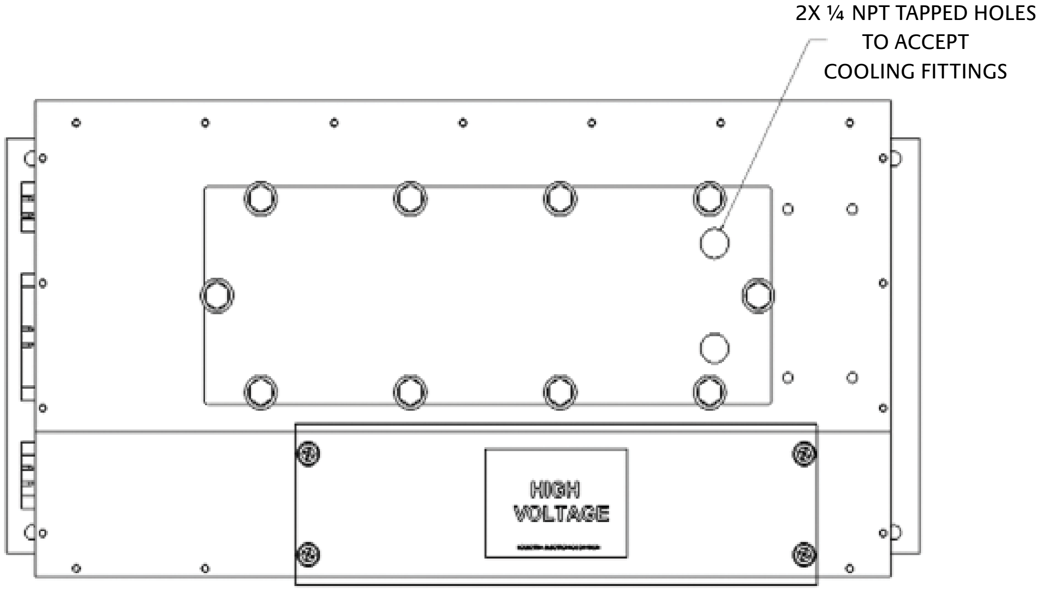


Figure 9: DMOC445 Liquid-Cooled Cooling Connections

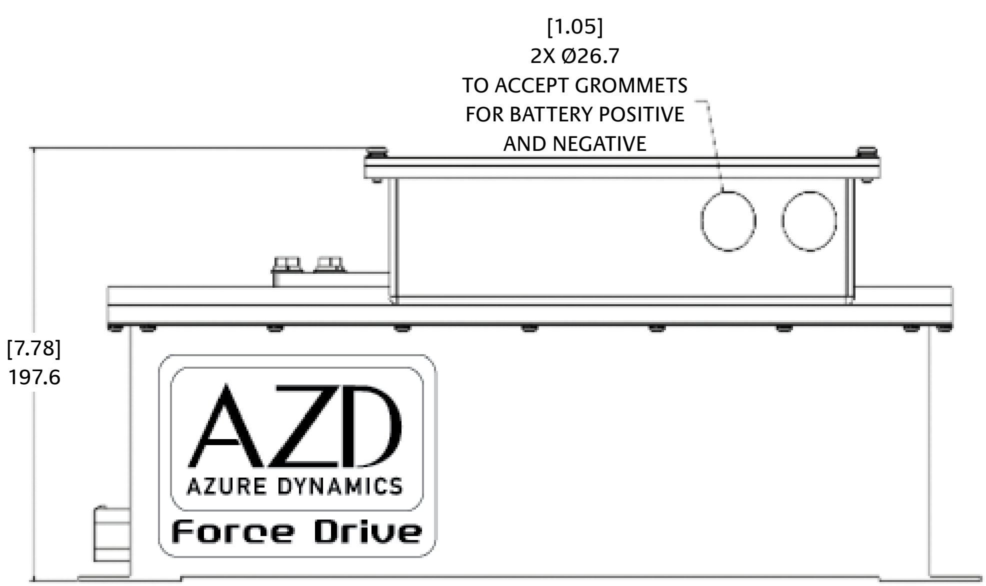


Figure 10: DMOC445 Battery Wire Connections

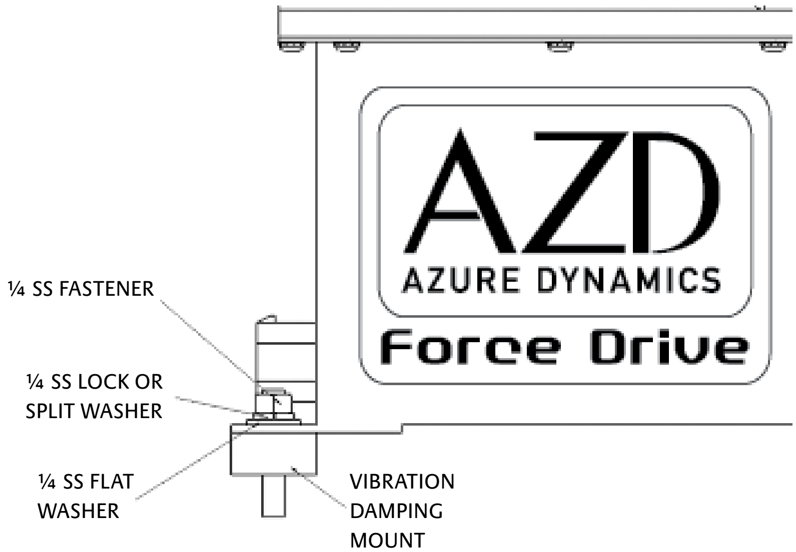


Figure 11: DMOC445 Mounting

Figure 12: DMOC645 Air-Cooled Model

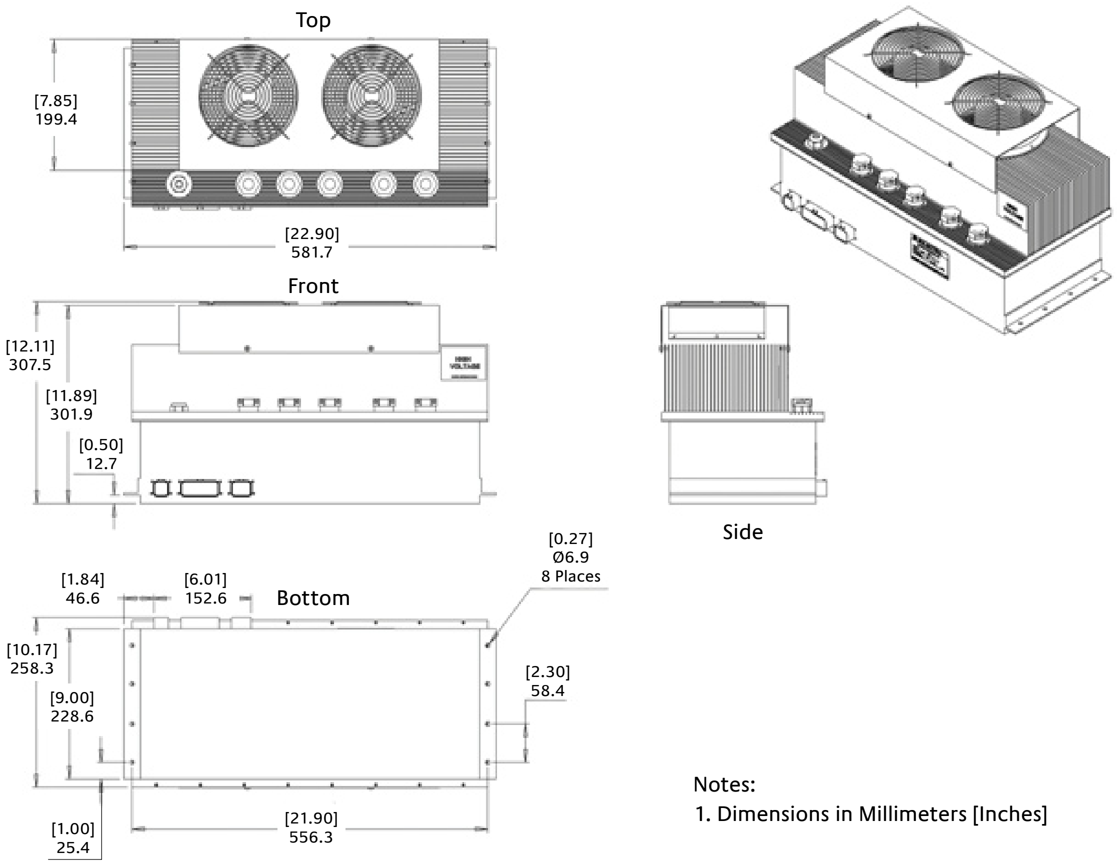


Figure 13: DMOC645 Dimensions

General Information

Mechanical

The DMOC has a light-weight aluminum package which is rated IP54. The component cover and heatsink base are gold-iridited per MIL-C_5541-E-Class 1a for corrosion protection. When installing the DMOC into a system, avoid locations in which the DMOC is frequently exposed to water. Also, the DMOC is not designed to withstand pressure-washing or submersion and needs to be protected accordingly.

In order to isolate the DMOC from vehicle vibrations and shock, it is important that the controller be vibration damping mounted. Please refer to the “Installation” section in this document for further information.

Two DMOC versions exist: air-cooled and liquid cooled. For the air-cooled version, the cooling fans are automatically turned on by the DMOC thermal management system.

The liquid cooled version requires a cooling mixture of water (50%) and ethylene glycol (50%) by volume.

- Maximum fluid pressure is 15 psi.
- Maximum cooling temperature at inlet is +55C.
- Normal cooling flow rate is 8 to 10 LPM @ 15 psi for the DMOC445 and 13 to 16 LPM @ 15 psi for the DMOC645.
- The cooling chamber cover plate on the DMOC445LC has been tapped to accept ¼ NPT fittings (see Figure 9).
- The fittings for the DMOC645LC are an SAE J1926 spec for a straight thread o-ring port, with ¾”-16 threads. This is for a hydraulic fitting with o-ring, and the size is a “-8” (dash 8) for ½” hose.

Electrical

Shock Hazard:
Extreme caution should be used whenever working on or near the high voltage system.

High Voltage Connections

All high-voltage connections are made in the terminal box which is attached to the heatsink of the DMOC. It is imperative that appropriate safety steps are taken when connecting or disconnecting high-voltage cables. This manual provides some recommended safety practices, but it is not meant to be comprehensive. Only personnel with up to date high voltage training should install or uninstall the DMOC. All high voltage connections must be assumed to be "hot" at all times, independent of the state of the DMOC or variables reported by the DMOC.

For correct operation of the traction drive, the AC connections to the motor must be appropriately shielded and the connection to the terminal box must be made according to the instructions in this document. Since the DMOC is only intended to be used with Azure motors, the motor wiring will be "dressed" appropriately for connecting with the DMOC. Do not shorten or lengthen the motor cables without duplicating the original connection and shielding configuration. We suggest that you contact Azure Dynamics if you wish to lengthen or shorten either the power or signal wires.

The DC connection may be non-shielded. Only 2 AWG 600V (for DMOC445) or 2/0 AWG 600V (DMOC645) rated cables are to be used, which need to be properly fused as close as possible to the energy storage system (ESS). Note that the DMOC does not provide any internal fusing on the high voltage connections. It is also very important that the ESS be galvanically isolated (i.e. no direct electrical connection) from the chassis of the vehicle as well as from the low voltage system of the vehicle.

For additional safety as well as for controlling EMI, the DMOC should be grounded to the vehicle frame using a braided ground strap, preferably one that is short and wide in dimension. See the Grounding and Shielding section of this manual, Figure 33 and Figure 34.

We recommend that high voltage to the DMOC not be routinely disconnected. For a shutoff, we suggest disconnecting the 12V by, for example, using a switch. This immediately disables the DMOC power supply and shuts the unit down. An emergency high voltage disconnect should be a normally closed switch, only actuated in emergencies or for maintenance. If a contactor is used as a HV disconnect, it could interfere with the operation of the DMOC's internal contactor, resulting in excessively long precharge times or damage to the controller.

Low Voltage Power Connections

The DMOC requires a 12V auxiliary supply to power its internal circuits, the main contactor, and cooling fans (in case of an air-cooled heatsink). DMOCs with 24V auxiliary supply are available; please contact Azure Dynamics.

The 12V auxiliary supply needs to be able to source 10A of current and must be protected by a 15A fuse. The auxiliary supply also acts as an enable signal for the internal power supply of the DMOC. In other words, a DMOC requires 12V to be present in order to operate.

Signal Connections

Three connectors located on the side of the DMOC cover provide all signal connections. Please select mating connectors from Table 3. Tyco/AMPSEAL connector contacts will accept 20 to 16 AWG wire with insulation diameter of 1.7–2.7 mm. Use CERTI-CRIMP Straight Action Hand Tool, Tyco/AMP p/n 58440-1.

Table 3: Tyco/AMPSeal Automotive Connectors

No. of pins	Connector Manufacturer	Manufacturer's p/n for connector	Manufacturer's p/n for contact (pin)
35	Tyco/AMPSeal	776164-1	770854-3
14	Tyco/AMPSeal	776273-1	770854-3
8	Tyco/AMPSeal	776286-1	770854-3

The 35-pin connector carries general digital and analog I/O pins as well as the inputs for the auxiliary 12V power supply. The 14-pin connector is used for the motor speed and temperature signals. The 8-pin connector provides the signals for CAN communications as well as RS-232. Application-specific connections to the 35-pin are described in the application user manuals, the Pedal Controlled Application User Manual and the CAN Controlled Application User Manual.

Important: The GND_D and GND_A pins should not be connected to vehicle chassis external to the DMOC. GND_D and GND_A are connected through EMI filters inside the DMOC.

Note: Not all signals/functions are necessarily implemented. Please refer to the application specific manuals to find out what is supported by the software of your DMOC.

Table 4, Table 5 and Table 6 show the typical signal connector pinouts.

Table 4: Typical 35-Pin Connector Pinout

J6: Primary Control Interface Connector, 35-pin Amp seal		
Pin #	Signal:	Function:
1	KEYED_12V_SRC	Keyed-12V and relay power
2	reserved	
3	ACCEL_PEDAL	Accelerator pot signal
4	reserved	
5	GND_A	Analog Control Gnd
6	PEDAL_LO	Accelerator pot low
7	REGEN_DISABLE-	Regen brake disable (active low)
8	DRIVE_DISABLE-	Interlock (active low)
9	reserved	
10	reserved	
11	reserved	
12	BACKUP_LT_SINK/LED_EMPTY	Isolated MOSFET collector or LED
13	KEYED_12V_SINK	Keyed-12V and relay power
14	BRAKE_LT_SRC	Isolated MOSFET drain
15	POWER_SAVER	Power saver potentiometer
16	GND_A	Analog Control Gnd
17	reserved	
18	REVERSE-	Reverse direction (active low)
19	GND_D	Digital Control Gnd
20	GND_D	Digital Control Gnd
21	GND_A	Analog Control Gnd
22	reserved	
23	BACKUP_LT_SRC/LED_FULL	Isolated MOSFET collector or LED
24	BRAKE_LT_SINK	Isolated MOSFET collector (source)
25	SPEEDO_BUF	12V open-emitter gauge drive
26	reserved	
27	reserved	
28	PEDAL_HI	Accelerator pot high
29	FORWARD-	Forward direction (active low)
30	DRIVE_ENABLE-	Interlock (active low)
31	reserved	
32	reserved	
33	reserved	
34	reserved	
35	GND_D	Digital Control Gnd

Table 5: Typical 14-Pin Connector Pinout

J4: Motor Signal Connector (14-pin AMPSeal)		
Pin #	Signal	Function
1	ENC_A1	Motor position encoder input
2	ENC_A2	Motor position encoder input
3	ENC_B1	Motor position encoder input
4	ENC_B2	Motor position encoder input
5	GND_D	Digital Control Gnd
6	ENC_I1	Motor position encoder input
7	ENC_I2	Motor position encoder input
8	FUSED_+5V	Fused digital +5V
9	MTR_TEMP	Motor temp input
10	GND_A	Analog Control Gnd
11	Chassis Gnd	Chassis Gnd
12	GND_D	Digital Control Gnd
13	reserved	
14	reserved	

Table 6: Typical 8-Pin Connector Pinout

J5: Communications Connector (8-pin AMPSeal)		
Pin #	Signal	Function
1	RS232_TXD	RS232 Tx
2	RS232_RXD	RS232 Rx
3	GND_B	Communication Gnd (RS232 & CAN)
4	CANH	CAN High
5	GND_B	Communication Gnd
6	CANL	CAN Low
7	GND_B	Communication Gnd
8	Chassis Gnd	Chassis Gnd

The DMOC communications cable (to the DMOC 8-pin connector) uses a standard DB9 pinout for CAN as shown in Table 7. The male connector on the DMOC communications cable is used for CAN.

Table 7: DB9 CAN Pinout

Signal Name	Pin on DB9 Connector
CAN L	2
CAN H	7
Shield (CAN GND) Note, if a CAN network is used on the vehicle, this signal should be connected to 12V GND in one place only, typically at the center of the CAN network.	3

Modes of Operation

Motor Control

At its core, the DMOC is a voltage source inverter (VSI) with high-bandwidth synchronous frame current regulation. See Figure 14 and Figure 15.

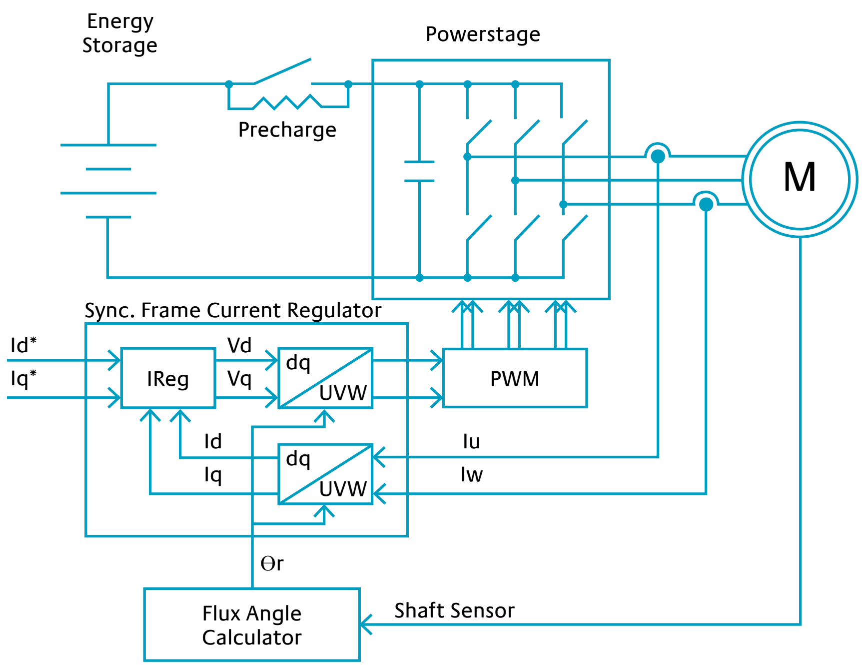


Figure 14: Synchronous Frame Current Regulator

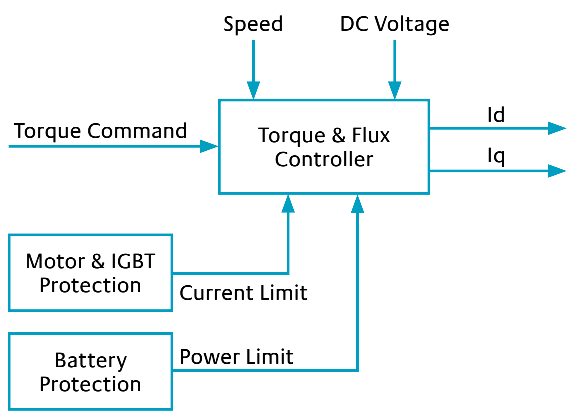


Figure 15: Torque Controller with Protections

Variables and Parameters

DMOC diagnostics and configuration is achieved by means of Azure's diagnostics tool, ccShell, which allows access to a number of variables and parameters (calibrations). Variables are read-only while parameters can be modified (depending on the access rights) in order to configure the DMOC. Parameter changes can be made persistent by saving them to non-volatile memory (EEPROM). There also exists a special category of non-volatile variables which are saved to EEPROM and maintain their values when the unit is powered down, used primarily for fault reporting. Non-volatile parameters and variables can be identified by their prefix. The following naming convention is used:

- EE1, EE2, EEX: parameters
- EE3: non-volatile variables
- ISR, FRC: variables

Error Codes (DMOC Fault Codes)

When a DMOC fault occurs, it is logged into a short error history. Code released after April 2008 ("FRC" or "CND") logs both a bit field error code and a human readable enumerated error. The bit field can log multiple simultaneous faults, but the enumerated error is easier to understand and some faults are only explained by the enumerated code, so start with EE3PSFault0 if your code supports it. Table 8 below shows the faults corresponding to the most recent error logged at the top and the oldest at the bottom. Note, sometimes the DMOC will not enable for reasons that do not trigger a fault. To help diagnose these issues please see the information about Finite State Machines, specifically the ISR2PowerstageStateInfo variable in Table 15, for suggestions.

The DMOC stores error conditions in five non-volatile variables, as show below. Only the four most recent errors are retained.

- EE3LastError: most recent error
- EE3LastError1, EE3LastError2, EE3LastError3: error history; Error3 is the oldest error.
- EE3ErrorCounter: total number of errors

Table 8: DMOC Error Codes Bit Fields Variables and Enumerations

Bit Field Error Code	Enumerated Error Code ("FRC" and "CND" only)
EE3LastError	EE3PSFault0
EE3LastError1	EE3PSFault1
EE3LastError2	EE3PSFault2
EE3LastError3	EE3PSFault3

DMOC error codes are listed in Table 9. For more information and a discussion of the most common errors, see "EE3LastError Codes (DMOC Fault Codes)" in the Troubleshooting section at the end of this manual.

Table 9: DMOC Error Bit Codes and Enumerations

Bit #	Error	Code (Hex)	Code (Decimal)	Enumeration	Triggered by
0	Overcurrent Phase A	0x0001	1	PS_FLT_HARDWARE_OC	hardware
1	Overcurrent Phase B	0x0002	2	PS_FLT_HARDWARE_OC	hardware
2	Overcurrent Phase C	0x0004	4	PS_FLT_HARDWARE_OC	hardware
3	Hardware Overvoltage	0x0008	8	PS_FLT_HARDWARE_OV	hardware
4	Charged Error (Noise)	0x0010	16	PS_FLT_CHARGED_ERROR	hardware
5	reserved				
6	reserved				
7	DESAT	0x0080	128	PS_FLT_DESAT	hardware
8	RELAY_ERROR_FLAG	0x0100	256	PS_FLT_RELAY_ERROR_AT_READY PS_FLT_RELAY_ERROR_AT_ENABLED	software
9	Software Overcurrent	0x0200	512	PS_FLT_SOFTWARE_OC	software
10	Software Overvoltage	0x0400	1024	PS_FLT_SOFTWARE_OV	software
11	OFFSET ERROR (current calibration error)	0x0800	2048	PS_FLT_CURRENT_CALIB_FAULT	software
12	Overspeed error	0x1000	4096	PS_FLT_OVERSPEED	software
13	reserved				
14	reserved				
15	ENUMERATED FAULT (added November 2007, not in “1631” or “1641” code)	0x8000	32768	Additional Enumerated faults including: PS_FLT_DC_BUS_UNDER_VOLTAGE PS_FLT_SPEED_SENSOR_ERROR	software

Most errors can be reset by the application software once there is zero torque request. However, a small subset of errors is considered critical and can not be cleared without completely powering down the controller by disconnecting the 12V supply. Errors falling into the critical category are desat error and current sensor calibration error.

Status Code

The status of the DMOC is displayed by the variable ISR2StatusCode. Similar to the error code, the information is coded in a bit-wise fashion as shown in Table 10:

Table 10: ISR2StatusCode

Bit #	0	1
0	contactor open	contactor closed
1	powerstage not ready	powerstage ready
2	powerstage OK	powerstage faulted
3	more torque available	max torque limit reached
4	more power available	max power reached
5	no thermal limit active	thermal limit active
6	reserved	
7	reserved	

Note that in the ready state, the thermal limit active signal can be ignored, as the IGBTs are “limiting” current before the power stage is enabled.

General CAN Configuration Parameters

The DMOC445 and DMOC645 support CAN 2.0 with standard 11-bit identifiers. The baud rate and the sampling point are configurable by means of the parameters shown in Table 12.

The DMOC can display status messages over CAN. For details on what messages are available, see your specific application manual: the Pedal Controlled Application User Manual or the CAN Controlled Application User Manual.

For a device to display the DMOC status variables over CAN, Azure Dynamics suggests the CANtrak 2600 from Teleflex Morse (now Kongsberg Automotive) in England. It requires programming by the user.

http://www.kongsbergautomotive.com/PageFiles/1800/KA%202600%202610%202009.pdf

Table 11 lists parameter sets that work well on many applications, however, bit segment timing to avoid CAN errors is very application specific, based on CAN network length, etc. Therefore it is the customer's responsibility to find values that work for his application.

One requirement is that (TSeg1 + TSeg2 + 1) should be an even divisor of the DSP Clock ÷ Baud Rate to ensure the desired CAN baud rate can be achieved. For the DMOC445 and DMOC645, with a DSP 2407 clock at 40MHz, (TSeg1 + TSeg2 + 1) totals of 8, 10 or 20 are acceptable). See Table 11.

Table 11: Recommended CAN Baud Rate Settings

CAN Baud Rate EEXCANKBitS	DMOC Clock ÷ Baud Rate	EEXCANTSeg1	EEXCANTSeg2
125	320	7	2
250	160	12	7
500	80	13	6
500, another popular option	80	5	2

General CAN configuration parameters are shown in Table 12.

Table 12: General CAN Configuration Parameters

Variable	Description
EEXCANDMOCDiagReqtID	Reserved for future Azure Diagnostics; you may change this ID if it conflicts with another CAN device on your vehicle.
EEXCANDMOCDiagRespID	Reserved for future Azure Diagnostics; you may change this ID if it conflicts with another CAN device on your vehicle.
EEXCANKBitS	CAN baud rate (in kBits/s)
EEXCANRxTimeout	CAN watchdog 1 timeout for Com State FSM (in increments of 10ms)
EEXCANTSeg1	CAN bit timing TSeg1
EEXCANTSeg2	CAN bit timing TSeg2
EEXCANTxPeriod	Transmission interval for status messages (in increments of 10ms)

Note: Whenever the CAN configuration is changed, parameters need to be saved to EEPROM and the controller must be reset by cycling the DMOC's low voltage connection.

Finite State Machines (FSM)

Most DMOC operation modes are handled by finite state machines (FSMs). Individual FSM states are represented by variables; these are viewed using ccShell. FSMs exist both at core level and application level. Please refer to the application-specific documentation for information regarding the application FSM. Two core-level FSMs are most noteworthy: the Contactor FSM and the Powerstage FSM.

The Contactor FSM handles the pre-charge of the DMOC and closing of the internal contactor. See Table 13 for information on the DMOC variable that enumerates the contactor state.

Table 13: ISR2ContactorState Enumerations

Variable:	ISR2ContactorState	
State	Name	Description
0	OPEN	Contactor open
1	CLOSING	Contactor closing and debouncing
2	CLOSED	Contactor is closed
3	FAULT	Low 12V supply or mechanical problem
4	OPENING	Contactor is Opening
5	INIT	Startup state
6	CRITICAL_FAULT	Critical Contactor fault detected
7	EXTERNAL	DMOC configured for external contactor
8	EXTERNAL_CRITICAL_FAULT	Incorrect contactor calibration

The Powerstage FSM handles the enabling and disabling of the power switches (IGBTs). See Table 14. During regular operation the powerstage state should be either ready or enabled.

Table 14: ISR2PowerStageState Enumerations

Variable:	ISR2PowerStageState	
State	Name	Description
0	POWERUP	Initial state, waiting for current sensor calibration to complete.
1	READY	Power stage is ready, waiting for power request
2	ENABLED	Power stage is enabled and IGBTs are switching
3	FAULT	Power stage faulted and will stay in this state until fault is acknowledged by system controller
4	reserved	
5	CRITICAL_FAULT	Power stage is in critical fault state (which cannot be cleared by software)
6	OFF	Powerstage is off, will advance to READY when all is well.

Table 15 shows the issues that will be highlighted by the ISR2PowerStageStateInfo variable to help debug startup issues.

Table 15: ISR2PowerStageStateInfo Enumerations

Variable:	ISR2PowerStageStateInfo
Power Stage State	Power Stage State Info
POWERUP	WAITING_FOR_CURRENT_SENSOR_CALIBRATION
OFF	INVALID_CONFIGURATION_CHECK_PARAMETERS
	WAITING_FOR_DRIVE_ENABLE_SIGNAL
	WAITING_FOR_CONTACTOR_TO_CLOSE
	WAITING_FOR_MINIMUM_DC_VOLTAGE
	WAITING_FOR_ZERO_POWER_REQUEST
	WAITING_FOR_APPLICATION_CODE_INTERLOCK[4]
READY	WAITING_FOR_POWER_REQUEST
ENABLED	POWER_STAGE_OK
FAULT	WAITING_FOR_FAULT_ACKNOWLEDGE
CRITICAL_FAULT	MUST_POWER_CYCLE_TO_CLEAR_CRITICAL_FAULT

[4] Application code interlocks are handled at the application code level, typically requiring the overcoming of a safety or other interlock to allow "drive enable". Please see the manual for your application: either the Pedal Controlled Application User Manual or the CAN Controlled Application User Manual.

Principal Variables

The most frequently used DMOC diagnostics variables are displayed in Table 16. Note, some variables are not directly relevant to customers, but are used by Azure for diagnostics and troubleshooting. These are marked with an * in Table 16. Also note, not all variables are viewable in ccShell, depending on each customer's .ccs file and software revision level.

Table 16: DMOC Diagnostic Variables

Name	Description
ISR2AbsQPower3Ph*	Reactive power
ISR2AbsStandbyTorqueDesired*	Active in CAN slave software only
ISR2ActiveError	Active error, see error codes in the Troubleshooting section of this manual
ISR2BatVoltage	Battery voltage reading, measured, ≈ISR2BatVoltageWF
ISR2BatVoltage_H*	Hysteresis control; Azure internal use only
ISR2BatVoltage_L*	Hysteresis control; Azure internal use only
ISR2BatVoltageOK	Battery voltage above minimum to keep DMOC on
ISR2BatVoltageUtil*	Usable battery voltage; Azure internal use only
ISR2BatVoltageWF*	Filtered battery voltage, ≈ISR2BatVoltage
ISR2CapsCharged	True if internal precharge is complete, unfiltered signal
ISR2CarDirectionSwitch	1 = forward, -1 = reverse, 0 = neutral
ISR2ContactorState	State of Contactor FSM (formerly ISR2RelayState)
ISR2CurrentCalibrationState	Explains state of current sensor calibration: CURR_CALIB_STATE_INIT — startup CURR_CALIB_STATE_INITIAL_CALIBRATION — calibration in progress CURR_CALB_STATE_OK — ok CURR_CALIB_STATE_FAULT — fault
ISR2DeviceLimit	Limiting due to heatsink temperature and motor speed (0-1). DMOC derates because IGBTs are too hot, usually due to low motor speeds. ISR2DeviceLimit is lower at higher heatsink temperatures. Not usually an issue in normal operation—motor or heatsink limit typically come into play.
ISR2DriveEnabled	Equals TRUE (1) if drive is enabled

ISR2EstBatCurrent	Multiply by voltage to estimate DMOC power
ISR2HeatsinkLimit	Limiting due to heatsink temperature (1 = no limit, 0 = fully derated)
ISR2HeatsinkTemp	Heatsink temperature in deg C
ISR2Hertz	Motor speed in rpm
ISR2HertzWF	Filtered motor speed
ISR2IdF*	Direct current; actual measurements of current in synchronous frame current regulator.
ISR2IdSet*	Set-point for direct torque; for synchronous frame current regulator.
ISR2IqF	Quadrature current; actual measurements of current in synchronous frame current regulator.
ISR2IqSet*	Set-point for quadrature torque; for synchronous frame current regulator.
ISR2IsF*	Peak amplitude filtered motor current. For rms current, divide by $\sqrt{2}$.
ISR2IsLimit*	Current limit.
ISR2IsMaxTherm*	Max current limit due to speed.
ISR2MaxAbsPower	Maximum power allowed for acceleration
ISR2MaxPowerIn	Dynamic power limit (varies with battery voltage), not actual power
ISR2MaxPowerOut	Dynamic power limit (varies with battery voltage), not actual power
ISR2MotorLimit	Limiting due to motor temperature (1 = no limit, 0 = fully derated)
ISR2MotorPTCVoltage	Motor temperature sensor output (non-linear PTC reading)
ISR2MotorTorqueLimitCause	Renamed ISR2MotorTorqueState; see Troubleshooting section of this manual
ISR2MotorTorqueState	Was ISR2MotorTorqueLimitCause; see Troubleshooting section of this manual
ISR2PowerInLimit	Power limiting due to battery overvoltage (0-1)
ISR2PowerOutLimit	Power limiting due to battery undervoltage (0-1)
ISR2PowerStageState	State of power stage FSM; see Table 14
ISR2PowerStageStateInfo	Explains the power stage state; see Table 15
ISR2PSDisableReqCtr*	Disables powerstage when making calibration changes or when configuration is invalid; Azure internal use only
ISR2PSFaultActive	Displays enumerated fault codes when a fault is active; see Table 20
ISR2RealTorque	Estimated torque being produced. Calculated from from current set points IdSet and IqSet, motor magnetizing inductance, and rotor resistance.
ISR2RegenState	Enumerates regen state value
ISR2RelayState	Renamed ISR2ContactorState
ISR2SpeedSensorActiveError	Enumerates speed sensor status; not all-encompassing. Suggests speed sensor/sensor connections good or bad.
ISR2StatusCode	DMOC status, see Table 10.
ISR2ThermCurrentLimitCause	THERMAL_LIMIT_NORMAL_CALIBRATION = 0 (everything normal) THERMAL_LIMIT_IGBT = 1 THERMAL_LIMIT_MOTOR = 2 THERMAL_LIMIT_HEATSINK = 3 THERMAL_LIMIT_DC_VOLTAGE = 4 If both DMOC and motor have reached thermal derate state, ISR2ThermCurrentLimitCause will display the component that is derating the most. Note, THERMAL_LIMIT_IGBT is normal at zero rpm.
ISR2TorqueDesired	Torque desired by speed regulator (after all limits)
ISR2TorqueEst*	Estimated motor torque; Azure internal use only
ISR2TorqueEstFromACPower*	Estimated motor torque from AC power; Azure internal use only
ISR2TorqueEstFromIdIq*	Equal to ISR2RealTorque
ISR2UtilIqMax*	Max usable Iq after all limits; Azure internal use only
ISR2UtilIqMaxP*	Max usable Iq after battery power limits; Azure internal use only
ISR2UtilIqMaxSlip*	Max usable Iq taking flux transients into account; Azure internal use only
ISR2VdF*	System voltage; Azure internal use only

ISR2VqF*	System voltage; Azure internal use only
ISR2VsF*	System voltage; Azure internal use only
ISR2WPower3Ph*	AC power estimation; Azure internal use only
ISR2XhF*	Filtered estimated magnetizing impedance; Azure internal use only
ISR2XhRaw*	Unfiltered estimated magnetizing impedance; Azure internal use only

General Parameters

General DMOC parameters are listed in Table 17. Azure Dynamics strongly recommends that you consult with your Azure contact before making any parameter changes in your DMOC except as described elsewhere in the DMOC manuals. Also note, not all parameters are viewable in ccShell, depending on each customer's .ccs file and software revision level.

Table 17: General DMOC Parameters

Name	Description
EE1DeadTimeComp	Control parameter; Azure internal use only
EE1DeadTimeCompIThresh	Control parameter; Azure internal use only
EE1DeadTimeSignThresh	Control parameter; Azure internal use only
EE1Enable1ZVPWM	Control parameter; Azure internal use only
EE1EncoderDirection	Sequence of phase wires (-1 or 1)
EE1EncoderPulses	Pulses per motor encoder rev; Azure internal use only
EE1EncoderType	Control parameter; Azure internal use only
EE1HardOVLimit	Control parameter; Azure internal use only
EE1IsMaxOffset	Control parameter; Azure internal use only
EE1LoggingRate	Controls the ccShell ScopeLogging Rate; see ccShell User Manual
EE1MaxSwitchingVdc	Control parameter; Azure internal use only
EE1MotorP	Control parameter; Azure internal use only
EE1PosPllKi	Control parameter; Azure internal use only
EE1PosPllKp	Control parameter; Azure internal use only
EE1SpeedoDiv	Speedometer calibration
EE1UsDCFilterK1	Control parameter; Azure internal use only
EE2AccelBatRamp	Undervoltage battery protection ramp; voltage range over which AccelPower is reduced linearly from full power to zero: EEXMaxAccelPower, EEXNormAccelPower, EEXMinAccelPower
EE2BatVHiMem	Small voltage step used for battery voltage measurement filtering
EE2BatVLoMem	Small voltage step used for battery voltage measurement filtering
EE2BatVSFilterK1	Battery voltage filter parameter; Azure internal use only
EE2BatVUtilHyst	Battery voltage filter parameter; Azure internal use only
EE2BatVWFilterK1	Battery voltage filter parameter; Azure internal use only
EE2BoxTempMax	Control parameter; Azure internal use only
EE2BoxTempRamp	Control parameter; Azure internal use only
EE2BrkModulationIndex	Control parameter; Azure internal use only
EE2DisableChargedError	See EE3LastError Codes (DMOC Fault Codes) in the Troubleshooting section of this manual. DMOC code released after September 2009 does not include this parameter and the error is disabled.
EE2EnableContOffsetCalib	Control parameter; Azure internal use only
EE2FanOffTemp	Temperature below which the fans turn off (ºC)
EE2FanOnTemp	Temperature above which the fans turn on (ºC)
EE2HeatsinkTempFilterK1	Control parameter; Azure internal use only

EE2HertzFilterK1	Control parameter; Azure internal use only
EE2HertzOscFilterK1	Control parameter; Azure internal use only
EE2IdL50	Control parameter; Azure internal use only
EE2IdMax	Control parameter; Azure internal use only
EE2IqMaxSlew	Control parameter; Azure internal use only
EE2IRegDecoupling	Control parameter; Azure internal use only
EE2IRegSatEnable	Control parameter; Azure internal use only
EE2IsKi	Control parameter; Azure internal use only
EE2IsKp	Control parameter; Azure internal use only
EE2IsMax	Control parameter; Azure internal use only
EE2IsMaxSlew	Control parameter; Azure internal use only
EE2IsMaxTherm	Control parameter; Azure internal use only
EE2IsMaxThermSpeed	Control parameter; Azure internal use only
EE2IsMaxThermSpeedRamp	Control parameter; Azure internal use only
EE2IsQKi	Control parameter; Azure internal use only
EE2IsQKp	Control parameter; Azure internal use only
EE2IsRegMargin	Control parameter; Azure internal use only
EE2KVPsiMaxT	Control parameter; Azure internal use only
EE2LSigma	Control parameter; Azure internal use only
EE2LSyncCap	Control parameter; Azure internal use only
EE2LSyncMax	Control parameter; Azure internal use only
EE2MaxCurrentAngleCos	Control parameter; Azure internal use only
EE2MaxCurrentAngleSin	Control parameter; Azure internal use only
EE2MaxIqIdRatio	Control parameter; Azure internal use only
EE2MaxRegenPower	Regen power limit
EE2MinPowerLimitSpeed	Ignore power limits below motor absolute speed lower than this; Azure internal use only
EE2ModulationIndex	Control parameter; Azure internal use only
EE2MotorPTCCold	Control parameter; Azure internal use only
EE2MotorPTCHot	Control parameter; Azure internal use only
EE2MotorPTCisNTC	Control parameter; Azure internal use only
EE2MotorPTCMin	Control parameter; Azure internal use only
EE2MotorTempFilterK1	Control parameter; Azure internal use only
EE2NegOverspeed	Maximum negative motor speed
EE2NoAccelBat	Minimum battery voltage (zero power provided below this setting)
EE2NoRegenBat	Maximum battery voltage (zero power provided above this setting)
EE2OscDeltaHz	Control parameter; Azure internal use only
EE2OscDeltaT	Control parameter; Azure internal use only
EE2PosOverspeed	Maximum positive motor speed
EE2PSOffBat	Below this battery voltage powerstage automatically disables
EE2PsiOptMax	Control parameter; Azure internal use only
EE2PsiRIm63	Control parameter; Azure internal use only
EE2PsiRIs63	Control parameter; Azure internal use only
EE2PsiRMax	Control parameter; Azure internal use only
EE2PsiRSat	Control parameter; Azure internal use only
EE2PsiRSlew	Control parameter; Azure internal use only
EE2PSOnBat	Minimum battery voltage required for powerstage enable
EE2RegenBatRamp	Overvoltage battery protection ramp
EE2RotorResistance	Control parameter; Azure internal use only

EE2ShaftDirection	Direction of positive speed (CW = -1, CCW = 1)
EE2SlipConstant	Control parameter; Azure internal use only
EE2SpeedDeltaFaultThr	Control parameter; Azure internal use only
EE2StallDutyFactor	Control parameter; Azure internal use only
EE2StatorResistance	Control parameter; Azure internal use only
EE2TorqueEstEnableVoltage	Control parameter; Azure internal use only
EE2TorqueEstRampVoltage	Control parameter; Azure internal use only
EE2TorqueInductance	Control parameter; Azure internal use only
EE2TPerPsi	Control parameter; Azure internal use only
EEX2ZVTurnOffSpeed	Control parameter; Azure internal use only
EEX2ZVTurnOnSpeed	Control parameter; Azure internal use only
EEXAutoFaultClearTime	CAN software only; Azure internal use only
EEXEnable1ZV2ZVToggling	Control parameter; Azure internal use only
EEXMaxTimesOfAutoFaultClear	Control parameter; Azure internal use only
EEXMinAccelPower	Acceleration power limit
EEXNormAccelPower	Acceleration power limit
EEXMaxAccelPower	Acceleration power limit

Battery Protection

The DC source (typically a battery) is protected from overcharge/overdischarge by means of ramps, as shown in Figure 16.

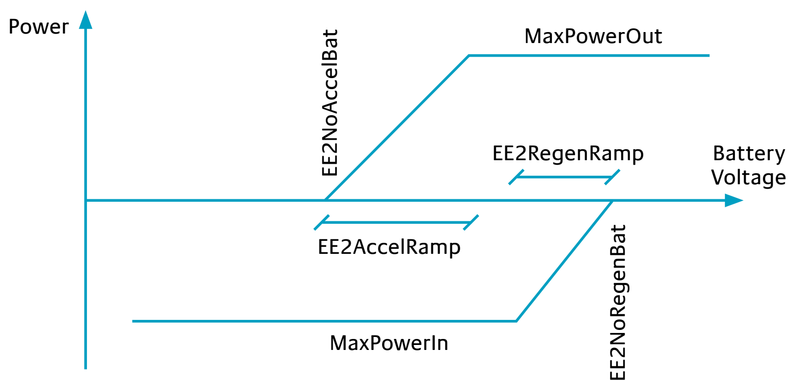


Figure 16: Battery Protection

Azure Dynamics programs the DMOC to the limits provided by the customer. **Warning: While the DMOC battery ramps are effective in protecting lead-acid batteries, this protection is not adequate for batteries which do not tolerate undervoltage or overvoltage events, such as advanced lithium chemistry-based batteries.** Azure Dynamics requires the user to sign a release stating that Azure will not cover damage related to advanced batteries. Most advanced batteries require a battery management system (BMS) for battery protection.

While the battery power limit for regenerative braking (power flows into the battery) is fixed, in the Pedal Controlled Application, the acceleration power level is selectable using a three-position selector switch (part of the optional DMOC Interface Kit). Please see the Pedal Controlled Application User Manual for more information.

Battery voltage parameters are listed in Table 18.

Table 18: Battery Voltage Parameters

Parameter	Description
EE2NoAccelBat	Battery voltage below which acceleration is zero
EE2AccelBatRamp	Voltage range over which AccelPower is reduced linearly from full power to zero (EEXMaxAccelPower or EEXNormAccelPower or EEXMinAccelPower)
EE2NoRegenBat	Battery voltage above which no regen is allowed
EE2RegenBatRamp	Voltage range over which EE2NoRegenBat is reduced linearly from full regen power to zero (EEXMaxRegenPower)

Damping of Mechanical Drivetrain Oscillations

In DMOC code released in October 2009 and later, Azure has added an optional active damping feature to reduce or eliminate oscillation due to drivetrain resonance response to rapid torque changes. This is vibration during rapid acceleration/deceleration of the motor/vehicle.

The severity of the oscillation is highly dependent on the specific application, influenced by vehicle and driveline inertia, driveline elasticity, gear backlash, etc. The motor speed oscillation frequency also varies with the application, but is typically in the 5-10Hz range. For these reasons, we must evaluate each installation individually, and cannot simply enable this feature for all DMOCs.

An example of this type of oscillation can be seen in Figure 17. The x-axis is time in seconds. You can see the speed oscillate at approximately 10Hz after each rapid torque change request.

DMOCs are shipped with the damping feature disabled; however damping may be enabled by the customer via ccShell. If you think your vehicle may benefit from the activation of this feature, you will need to perform several tests, log DMOC variables using ccShell, and work with your distributor or Azure contact to be sure.

How to Determine if Damping May Improve Your Vehicle’s Driveability

It is critical that the drive system is behaving as intended before embarking on this process. This means that the DMOC cannot be faulting, there should be no noise in the pedal or gear selector inputs, the battery pack must not be too “soft” (i.e. the pack voltage must not drop steeply/ quickly under load), etc.

If the system has no problems other than oscillation due to drivetrain resonance response to rapid torque changes, then you must first determine the drivetrain resonance without damping enabled.

a. Perform a windup/unwind test.
    i. Set the emergency brake to prevent movement.
    ii. Set ccShell’s Scope tool to log the following variables: ISR2Hertz, ISR2TorqueDesired, ISR2RealTorque, ISR2HertzNoOsc.
    iii. Set EE1LoggingRate to -1.
    iv. Step on the accelerator for full torque and switch to neutral, then quickly trigger the scope in ccShell to capture the event.
    v. Email the .txt file and the .gif file to your Azure contact.

b. Perform a torque step test.

   i. This test can be done at different vehicle speeds and different torque slew rates. We prefer to see a a combination of speed and torque slew that introduces drivetrain oscillation.

   ii. Set ccShell's scope tool to log the following variables: ISR2Hertz, ISR2TorqueDesired, ISR2RealTorque, ISR2HertzNoOsc.

   iii. Set EE1LoggingRate to -1.

   iv. Press and release the accelerator and trigger ccShell's scope to capture the event.

   v. Your ccShell scope capture may be similar to Figure 17.

   vi. Email the resulting .txt file and .gif file to your Azure contact.

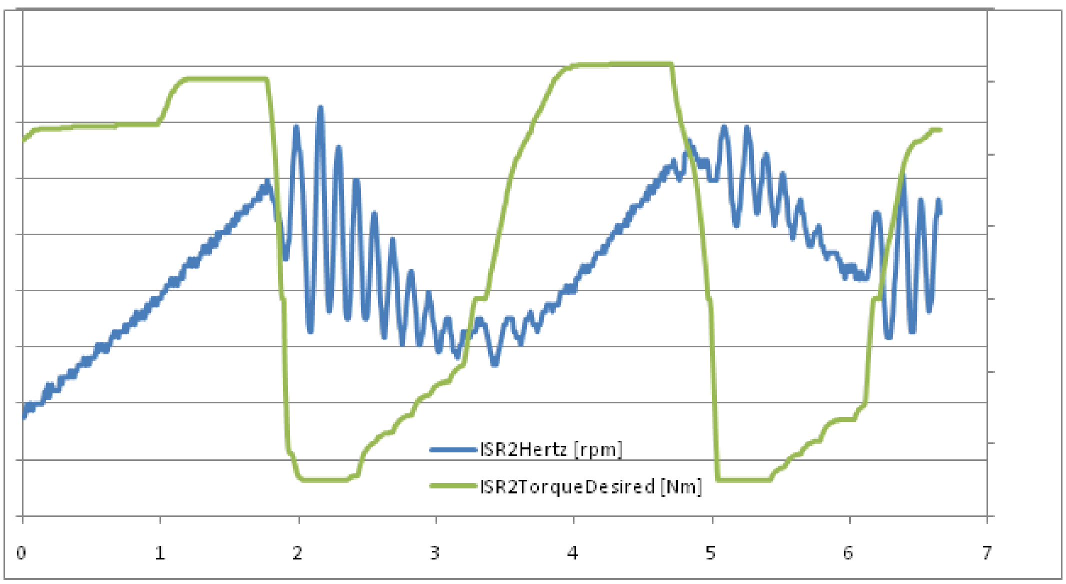


Figure 17: Example Torque Step Test Results Without Damping Enabled

Oscillation damping is enabled by setting the parameter EE2OscDampKComp to a positive gain rather than 0 (zero). Please wait for Azure to review your data before you attempt to change this parameter. Different drive systems require different settings; and other parameters may require tuning as well. In some cases, a new .ccs file is required to allow you to access additional parameters in ccShell.

Once you have changed EE2OscDampKComp and other parameters as suggested by Azure Dynamics, please repeat the tests described above.

Your test results with damping enabled may be similar to Figure 18.

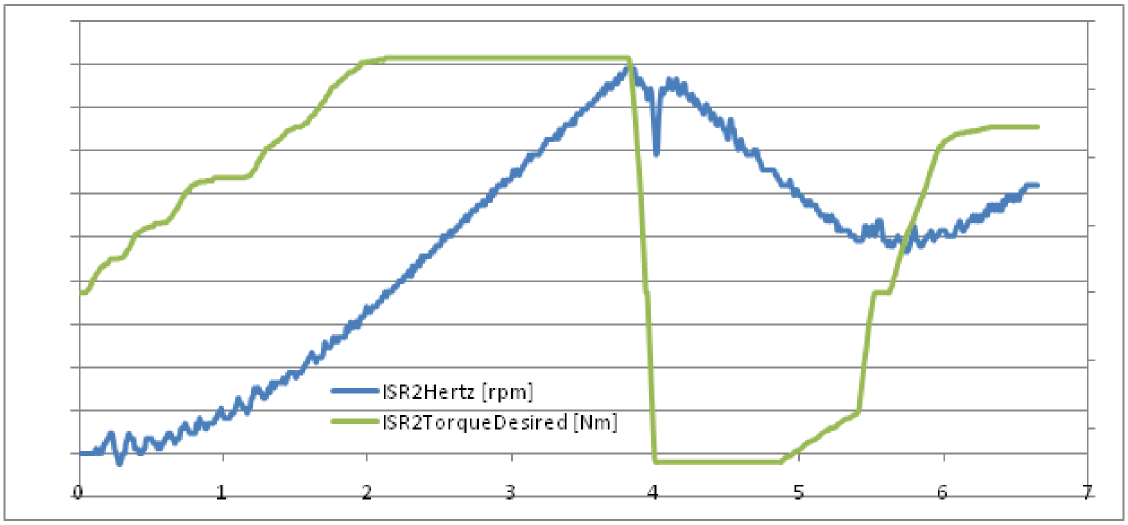


Figure 18: Example Torque Step Test Results With Damping Enabled

Installation Requirements

Mounting

We recommend that the DMOC be mounted with the cooling fans face-up, with sufficient clearance for airflow, ideally at least a distance equal to 1.5 to 2 times the fan diameter. Rubber mounts (as provided in the optional Azure Dynamics DMOC Interface Kit) should be used, and the DMOC should be mounted on a flat rigid surface.

The DMOC should be kept dry at all times, however, it is understood that some water splash to the underside of a vehicle is unavoidable. The DMOC is factory sealed to withstand small amounts of moisture.

- Avoid locations where the DMOC will be routinely exposed to water.
- Do not wash the DMOC with a pressure sprayer. Large amounts of water will cause a malfunction.
- If you have reason to believe water has entered the DMOC, do not open the case. Disconnect the DMOC and contact Azure Dynamics for service as soon as possible.
- When not in use, keep the protective plastic cap over the unit's serial data port (8-pin Tyco/AMPSeal) or connector.
- The Tyco/AMPSeal connectors are watertight. Do not populate unused pins and do not puncture the waterproof membrane for unpopulated pins.
- Vibration damping mounts should have ¼ inch nominal diameter threaded studs on each end of the mount. A minimum of four (4) mounts are required to secure the DMOC on a stationary surface.
- Position the vibration damping mounts, DMOC, washers and fasteners as depicted in Figure 11.
- Torque all ¼ inch fasteners on the vibration damping mounts to 10-11 ft-lb.
- If non-factory supplied vibration damping mounts are used, please consult with the new vibration damping mount manufacturer for the proper fastener torque.
- All power wires, cables and cooling hoses should be strain relieved through the use of cable or hose clamps that are attached to solid surfaces.
- 42.9mm [1.69 inch] diameter through holes are provided to accept grommets or similar cable retention devices for the DMOC445 AC wires (see Figure 8). Grommets should meet IP67.
- 26.7mm [1.05 inch] diameter through holes are provided to accept grommets or similar cable retention devices for the DMOC445 battery positive and negative wires (see Figure 10). Grommet should meet IP67.
- The DMOC645 uses Cam-Lok connectors from Cooper Crouse-Hinds. These are color-coded, waterproof molded connectors that allow easy connection of the motor phase wires and the battery positive and negative cables to the DMOC645. See Figure 30 and Table 19.

DMOCs with extensive water damage may not be repairable. DMOCs returned to Azure Dynamics with the factory seal broken will be ineligible for warranty service.

All electronic systems must be isolated from vehicle vibration. This is done through the use of vibration mounts.

Azure Dynamics DMOC Interface Kits contain rubber vibration mounts. If you have provided your own DMOC interface kit, please obtain and use appropriate mounts. Attaching the DMOC directly onto a solid surface or rigid vehicle frame without vibration damping mounts is not recommended. Rigid-mounting the DMOC will greatly reduce the life expectancy of the unit and void the unit warranty.

Vibration mounts must be operated in compression, with the weight of the DMOC on them. For improved vibration protection, or when the DMOC is not mounted face-up, heavy-duty mounts must be used. Please contact Azure Dynamics if you have questions.

Electrical Connections

Shock Hazard:
Extreme caution should be used whenever working on or near the high voltage system.

- To prevent the possibility of electric shock, switch off the DMOC completely before connecting or disconnecting any cables.
- Never pull on the wires or cables in the DMOC harness. The connectors can only be removed by lifting the retention clip with a small screwdriver and then pulling the connector plug out of the receptacle.

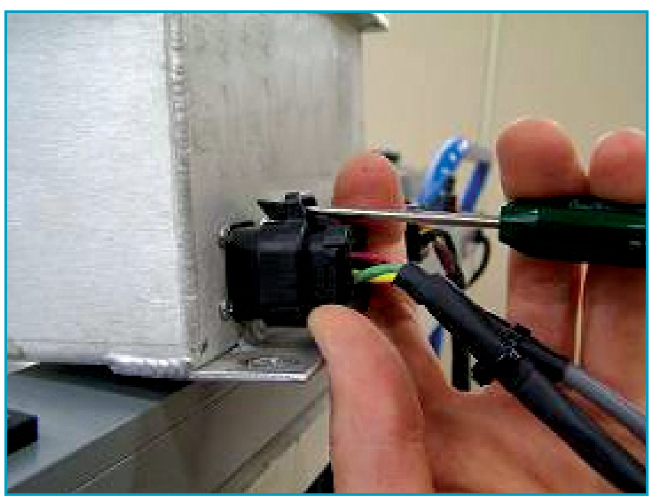


Figure 19: Removing 8-Pin Communications Connector

Connecting the Motor Sensor

The 14-pin Tyco/AMPSeal motor sensor connection allows the DMOC to monitor the speed, direction and temperature of your motor. Your Azure Dynamics motor comes with a signal cable and connector that uses this port. See Figure 20.

Push the 14-pin Tyco/AMPSeal motor sensor connector into the 14-pin connector port, located to the right of the 35-pin connector port.

Connecting the Vehicle Interface Cable

To connect the 35-pin Tyco/AMPSeal vehicle interface cable to the DMOC, push the connector head into the 35-pin connector port, located between the 8-pin and 14-pin connector ports. The Azure Dynamics DMOC Foundation Harness, included with the Azure Dynamics DMOC Interface Kit, uses this port. See Figure 20. The two application manuals, the Pedal Controlled Application User Manual and the CAN Controlled Application User Manual, contain a wiring diagram for the DMOC Foundation Harness.

Connecting the Communications Connector

To connect the 8-pin Tyco/AMPSeal communication (RS232/CAN) connector to the DMOC, first remove the protective dummy plug. Then push the connector head into the 8-pin connector port, located to the left of the 35-pin connector port. The Azure Dynamics DMOC Communications Cable uses this port. See Figure 19 and Figure 20.

Note, the Azure Dynamics DMOC Communications Cable has two DB9 connectors, one male and one female. The male connector is used for CAN communication and the female connector is used for RS232 communication.

Figure 20: All three DMOC connectors in position

Shock Hazard:
Extreme caution should be used whenever working on or near the high voltage system.

Connecting the Motor Cable (DMOC445 only)

Do not connect or disconnect while high-voltage is present. See Figure 21.

Figure 21: Motor Cable Lugged Ends for DMOC445

It is important that all cables be properly crimped. Use the appropriate crimper for all lugs and cables. Improper crimping can lead to failures and fires.

Figure 22: DMOC445 Motor Power Wire Connections

Use two opposing wrenches so that you will not apply torque to the controller terminal. See Figure 22.

It is important to use the correct tightening hardware and install the hardware correctly.

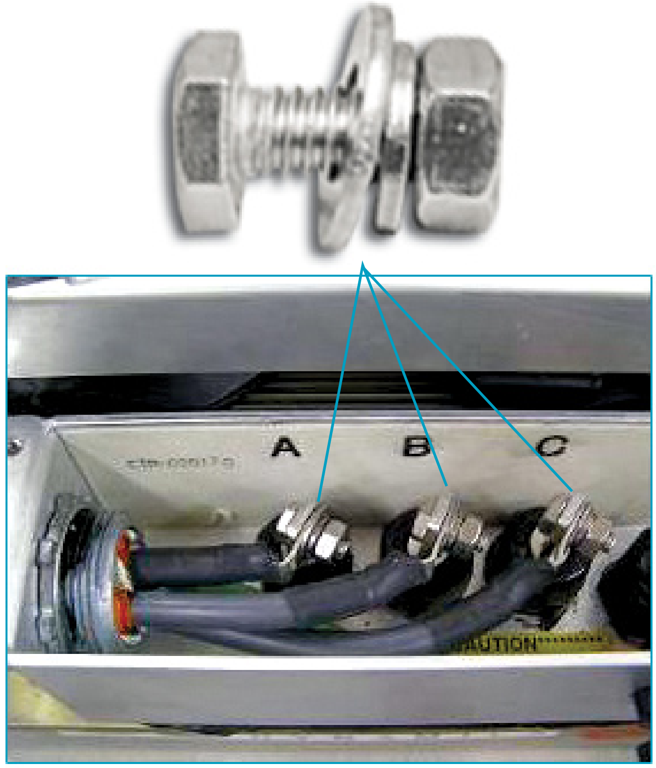


Figure 23: DMOC445 Motor Connection Hardware and Terminals

Figure 23 shows a typical flat washer/lock washer/nut installation. It is important to ensure the locking washer is fully compressed and is adjacent to the nut. After the terminal is completely assembled, there should be a **minimum of two or three threads showing on the screw when the nut is properly tightened.** The screws should not be so long that they are closer than ½" to the adjacent terminal or the enclosure wall.

The cable connecting the DMOC AC terminals to the electric motor should be shielded. This cable shield should be properly terminated using a 360 degree connection to the DMOC terminal box cable entrance fitting, see Figure 26. The rubber seal, which is a removable part of the entrance fitting, should be slid underneath the cable shield as shown in Figure 24 and Figure 25.

Next slide the shield with rubber seal (underneath) into the entrance fitting. Ensure that the cable shield makes contact with the fitting around the entire inside wall of the fitting (i.e. a complete 360 degree connection). Trim off excess cable shielding such that no shielding extends into terminal box as shown in Figure 27. NOTE: EXCESS SHIELDING INSIDE THE TERMINAL BOX CAN CREATE AN ELECTRIC SHOCK HAZARD.

Finally, install the entrance fitting cap (Figure 28) and tighten using a suitable wrench to ensure that adequate compression of the rubber seal is achieved. Make sure to put the black plastic flange washer underneath the fitting cap. The flange washer (Figure 29) makes contact with the shield and rubber seal.

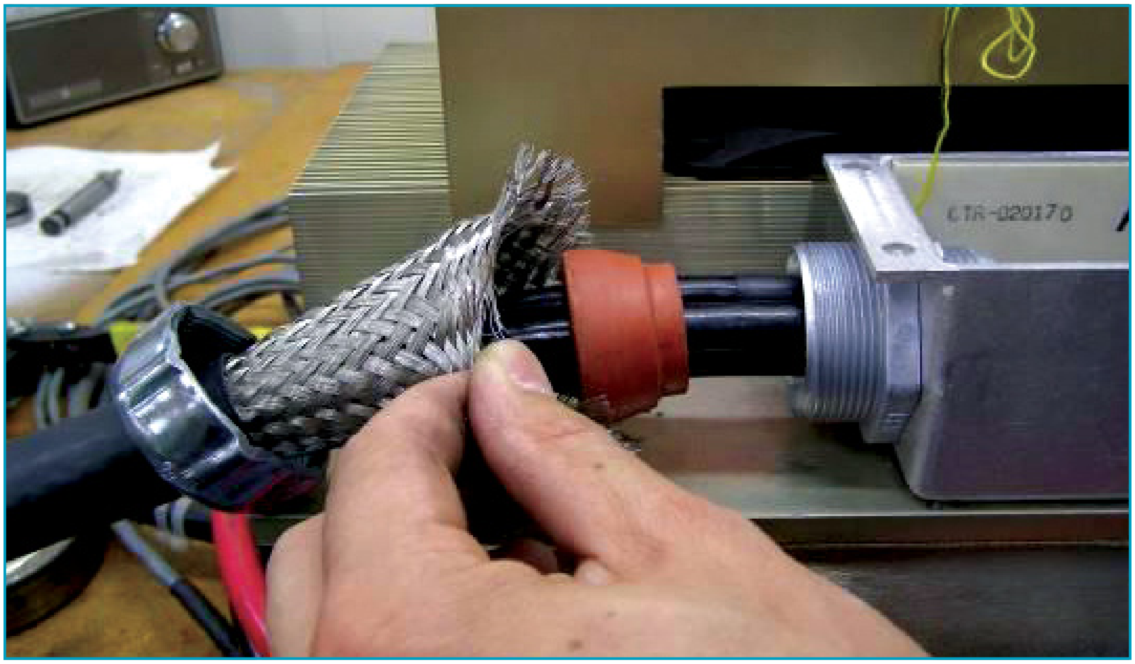


Figure 24: DMOC445 Motor Power Cable Entrance Fitting

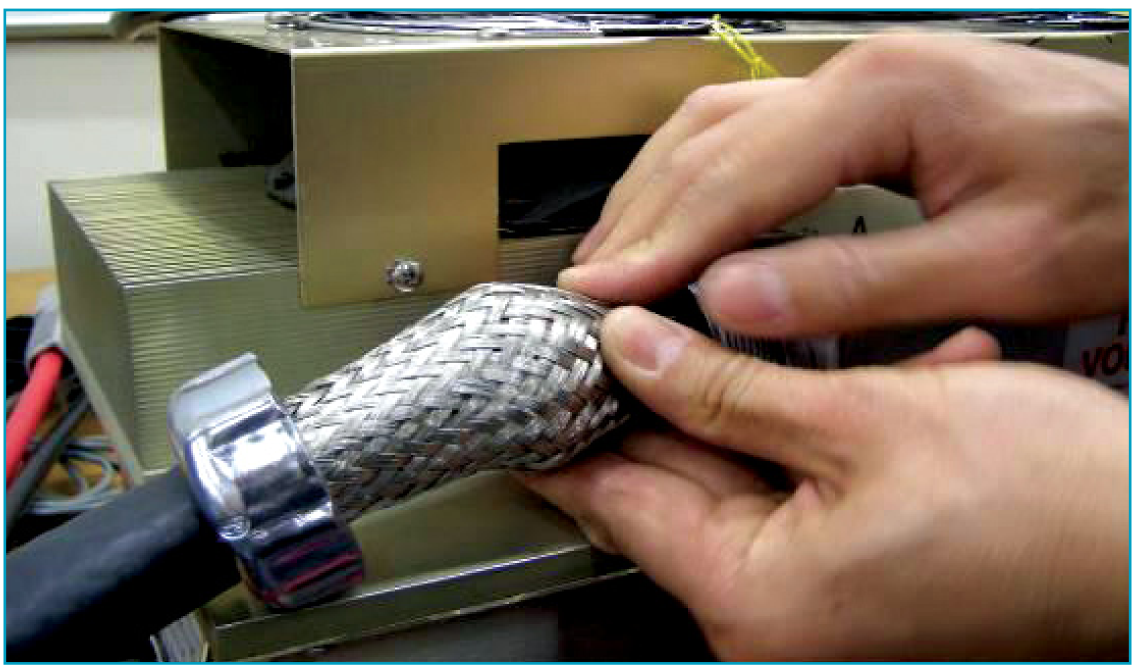


Figure 25: DMOC445 Motor Power Cable Shielding

Figure 26: DMOC445 Motor Power Cable Entrance, 360º Shielding

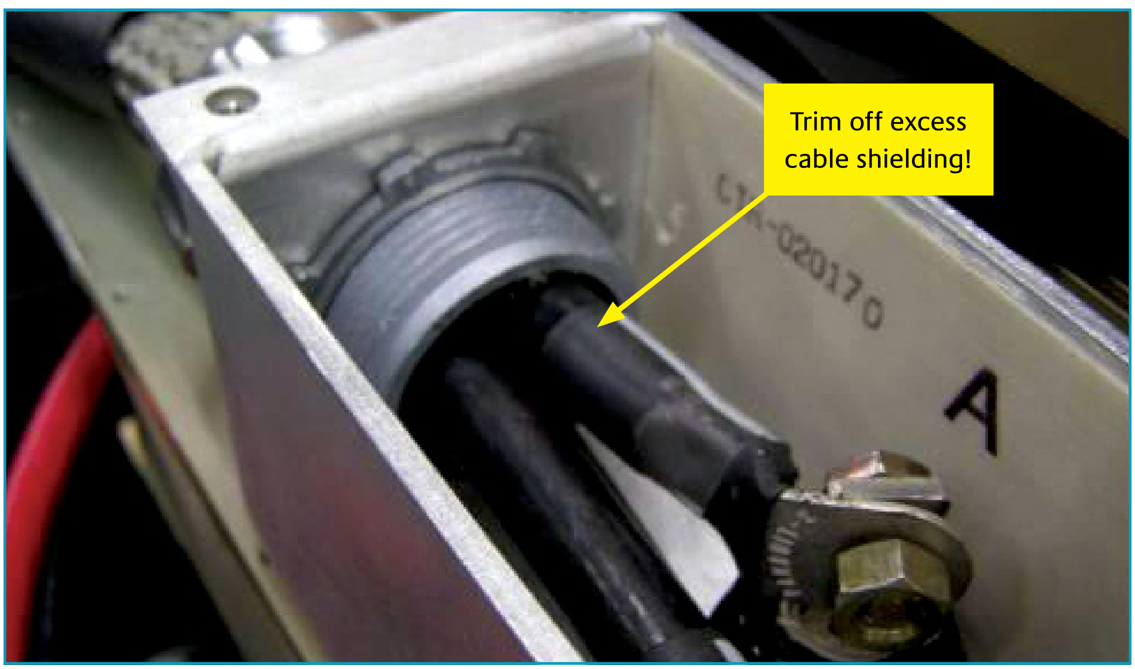


Figure 27: DMOC445 Motor Power Cable, Trim Shielding

Trim excess cable shielding inside the terminal box. If excess cable shielding makes contact with the DMOC AC terminals, a shock hazard will be created. Make sure no shielding enters into the terminal box. Exposed cable shielding should be a minimum of ½” from the terminal.

Figure 28: DMOC445 Motor Power Cables Grommet

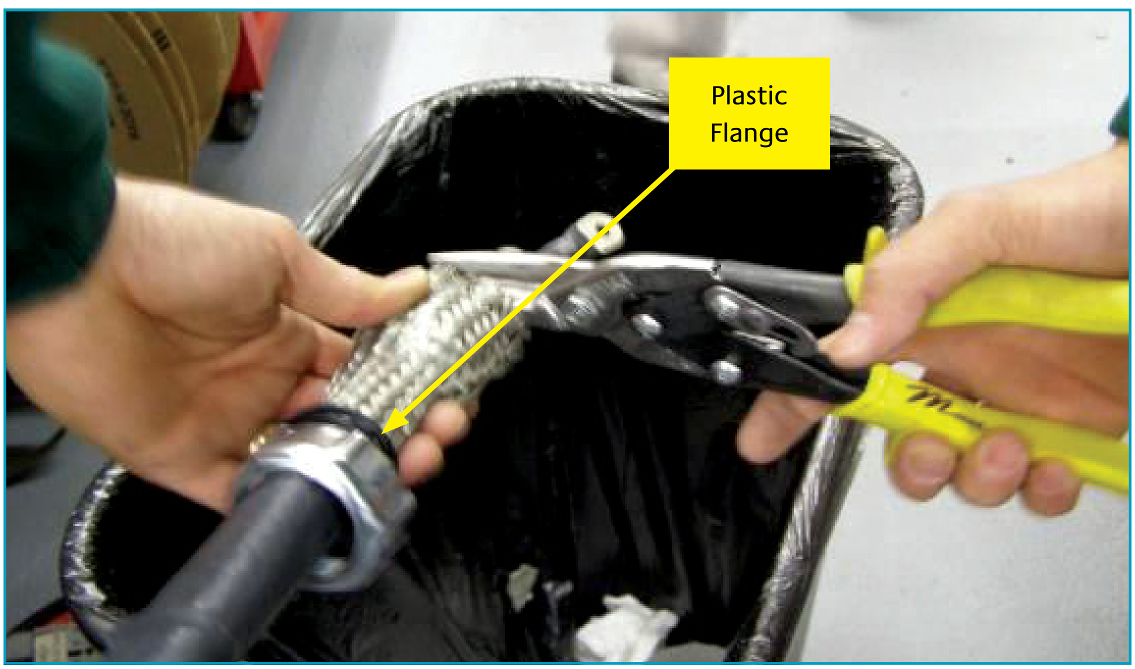


Figure 29: DMOC445 Motor Power Cable Black Plastic Flange Washer

Connecting High Voltage (DMOC445 only)

Shock Hazard:
Extreme caution should be used whenever working on or near the high voltage system.

Follow the same general guidelines and precautions when connecting the DMOC445 battery terminals. See Figure 30.

Figure 30: DMOC445 High Voltage Battery Terminals

Special Note Regarding Welding

Azure Dynamics does not recommend that the DMOC be exposed to the effects of weld currents when welding is performed on a vehicle with a DMOC installed. If you need to weld anything on your vehicle, remove the high voltage connections and signal connections to the DMOC before welding.

Water Ingress Prevention on DMOC445

After completing all high voltage connections on the DMOC445, the junction box cover must be reinstalled using the proper gasket. Battery and motor cable fittings should be tightened to ensure a liquid-tight seal between the cable jackets and fitting grommets. Figure 31 demonstrates proper cable fitting installation.

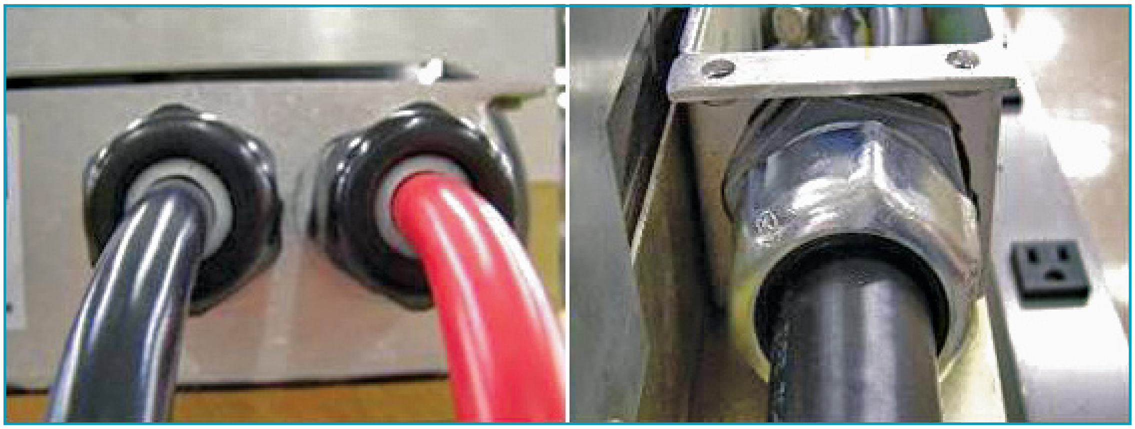


Figure 31: DMOC445 Battery Cable and Motor Cable Fittings

Connecting Motor Cables and High Voltage (DMOC645 only)

The DMOC645 uses Cam-Lok connectors from Cooper Crouse-Hinds for its high voltage cables. See Table 19 and Figure 32.

Table 19: DMOC645 Cam-Lok High Voltage Connectors (300A, with double-set screw, #2-2/0 cable size)

Connector Color	Function	Cam-Lok part # on DMOC645	Mating Cam-Lok part number
blue	motor phase A	E-Z1016-8381 female	E-Z1016-8356 male, on Azure AC90 motor
white	motor phase B	E-Z1016-8380 female	E-Z1016-8355 male, on Azure AC90 motor
green	motor phase C	E-Z1016-8379 female	E-Z1016-8354 male, on Azure AC90 motor
red	battery +	E-Z1016-8352 male	E-Z1016-8377 female, optional Azure 645 interface kit
black	battery -	E-Z1016-8350 male	E-Z1016-8375 female, optional Azure 645 interface kit

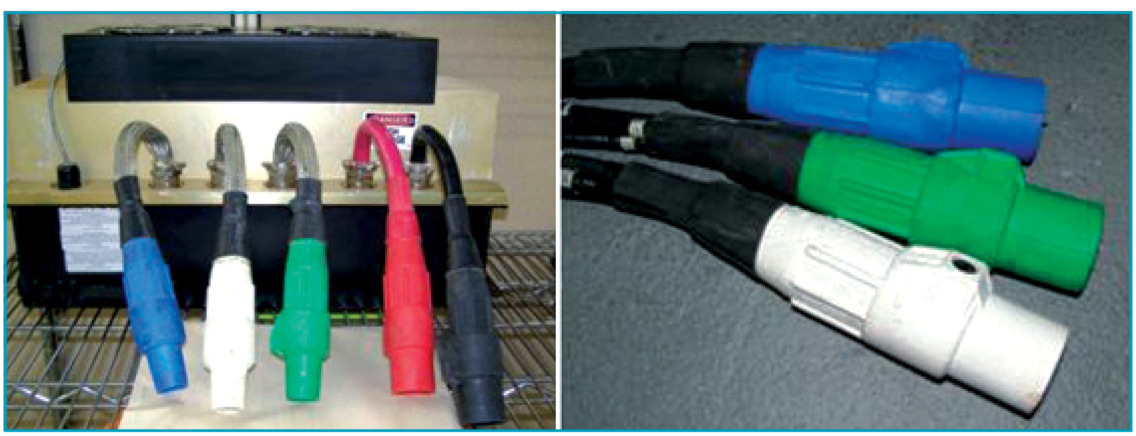


Figure 32: DMOC645 High Voltage Cables with Cam-Lok Connectors and AC90 Motor Power Cables

Grounding and Shielding

Proper shielding and grounding are important in the design and maintenance of EV traction drive systems. Inadequate shielding or grounding can lead to unreliable operation of the DMOC and other systems, such as EMI and electrostatic discharge damage to sensitive electronics, as well as shock hazard. Perform all grounding and shielding connections as shown in Figure 33.

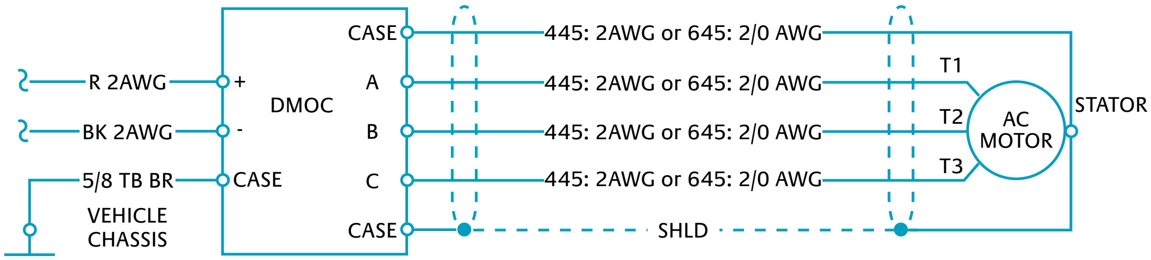


Figure 33: DMOC Grounding

Figure 34: Example DMOC Grounding Strap Connection

The 12V ground and the vehicle ground are typically the same. The DMOC case should be grounded to the vehicle chassis, which is assumed to be connected to the 12V battery negative. (Note, the ground strap should make good electrical contact with the chassis; do not bolt it to a painted or coated surface.) See Figure 34.

Pins 19, 35 and 20 on the 35-pin connector are all grounded inside the DMOC. These pins should not be connected to any other ground external to the DMOC, to avoid ground loops.

In the 8-pin connector, pins 3, 5 and 7 are all tied together internally. This should be considered when designing your CAN shield grounding, to avoid ground loops. (Note, the CAN shield should be grounded to the chassis at only one point in the vehicle network.)

Troubleshooting

Minimum DMOC Connections

If your DMOC will not spin the motor, here are some things to try before contacting your distributor or Azure. First of all, the DMOC's internal contactor must be closed before the DMOC will spin the motor. Did you hear the contactor close? You can check with ccShell (look at ISR2ContactorState or ISR2RelayState.) If the contactor is open, and you have both 12V and high voltage, check the DMOC parameter EEXNoIgnSwitch.

The DMOC has a "drive enable" and a "drive disable" signal (digital inputs) which are both active low (i.e. need to be pulled to GND to be active). For the DMOC to enable, drive enable has to be active and drive disable needs to be passive. If the "drive enable" feature is not desired, it can be switched off by setting the parameter EEXNoIgnSwitch to 1 from 0. Grounding "drive disable" will always result in disabling the DMOC.

Once the DMOC contactor is closed, check the following: the DMOC requires (in order)

1. high voltage connected inside the junction box
2. 12 volts on pin 1 on 35-pin connector
3. ground pin 13 on 35-pin connector to the 12V return
4. connect pins 19 and 29 on 35-pin connector to each other

The DMOC should power up and spin the motor once the pedal is pressed.

However, pins 19 and 29 cannot be left connected (Step 4 provides a "forward" request—in the Pedal Controlled software application.) This is because the DMOC contactor needs to close and then the DMOC needs to see a neutral signal and then a forward signal each time the DMOC is power-cycled.

ISR2MotorTorqueLimitCause (or ISR2MotorTorqueState)

ISR2MotorTorqueLimitCause (or ISR2MotorTorqueState)

This variable is available in software releases after May 2008, mainly to help debugging in situations where there is not enough torque.

Sequence of torque limit causes:

Listed below from highest priority to lowest priority—in other words, if the DMOC is limiting under both SLIP_LIMIT and BAT_POWER_OUT_LIMIT, the variable ISR2MotorTorqueState will display SLIP_LIMIT. If the DMOC is limiting under both BAT_POWER_OUT_LIMIT and VOLTAGE_LIMIT, ISR2MotorTorqueState will display BAT_POWER_OUT_LIMIT.

Highest Priority
TORQUE_REQUEST_LIMIT (or MOTOR_STATE_TORQUE_AS_REQUESTED)
SLIP_LIMIT (or MOTOR_STATE_FLUX_TRANSIENT)
BAT_POWER_OUT_LIMIT or BAT_POWER_IN_LIMIT (or MOTOR_STATE_MAX_BAT_POWER_OUT_REACHED or MOTOR_STATE_MAX_BAT_POWER_IN_REACHED)
VOLTAGE_LIMIT (or MOTOR_STATE_MAX_AC_VOLTAGE_REACHED)
CURRENT_LIMIT (or MOTOR_STATE_MAX_AC_CURRENT_REACHED)
Lowest Priority

These states are enumerated as follows:

TORQUE_REQUEST_LIMIT (MOTOR_STATE_TORQUE_AS_REQUESTED)	= 0
CURRENT_LIMIT (MOTOR_STATE_MAX_AC_CURRENT_REACHED)	= 1
VOLTAGE_LIMIT (MOTOR_STATE_MAX_AC_VOLTAGE_REACHED)	= 2
BAT_POWER_OUT_LIMIT (MOTOR_STATE_MAX_BAT_POWER_OUT_REACHED)	= 3
BAT_POWER_IN_LIMIT (MOTOR_STATE_MAX_BAT_POWER_IN_REACHED)	= 4
MOTOR_STATE_CURRENT_TRANSIENT	= 5
SLIP_LIMIT (MOTOR_STATE_FLUX_TRANSIENT)	= 6

TORQUE_REQUEST_LIMIT or MOTOR_STATE_TORQUE_AS_REQUESTED

- Torque is limited by the request, in other words, the motor is doing what was asked.
- Related variables: ISR2TorqueDesired
- Related EE parameters: Pedal Map parameters
- Related Hardware: Pedal and Pedal Potentiometer
- Debugging: For Pedal (FRC) application, ISR2TorqueDesired should be equal to EE2AccelMaxTorque when the pedal is pressed all the way;
- If ISR2TorqueDesired is already equal to EE2AccelMaxTorque, and DMOC reports TORQUE_REQUEST_LIMIT (or MOTOR_STATE_TORQUE_AS_REQUESTED), EE2AccelMaxTorque can be increased if more torque is needed.

BAT_POWER_OUT_LIMIT or MOTOR_STATE_MAX_BAT_POWER_OUT_REACHED

- There is always a limit on how much power the DMOC can pull from the batteries. This is why BAT_POWER_OUT_LIMIT (or MOTOR_STATE_MAX_BAT_POWER_OUT_REACHED) can occur even if the battery voltage has not decreased to EE2NoAccelBat + EE2AccelBatRamp.
- If the battery voltage does drop to EE2NoAccelBat + EE2AccelBatRamp, the limit is reduced (in other words, there is a limit on top of the "normal" limit.)
- In all cases, torque is limited by the battery output power limit ISR2MaxPowerOut.
- Related variables: ISR2MaxPowerOut, also CAN max power commands in CAN applications.
- Related EE parameters: Acceleration battery ramp parameters EE2NoAccelBat, EE2AccelBatRamp.
- Max, Norm, Min power setting for FRC code (i.e. may be able to increase EEXMaxAccelPower)
- Related Hardware: Max Power, Norm, Econ power selector.
- Debugging: Is battery voltage close to EE2NoAccelBat, power starts to ramp down? Is power selector selecting the right level?

BAT_POWER_IN_LIMIT or MOTOR_STATE_MAX_BAT_POWER_IN_REACHED

- Occurs in regen. Torque is limited by ISR2MaxPowerIn (how much can battery be charged?) This is the mirror image to BAT_POWER_OUT_LIMIT (or MOTOR_STATE_MAX_BAT_POWER_OUT_REACHED), discussed above.
- Related variables: ISR2MaxPowerIn, also CAN max power commands in CAN applications.
- Related EE parameters: Regen battery ramp parameters; EE2NoRegenBat, EE2RegenBatRamp, EEXMaxRegenPower
- Debugging: Is battery voltage too high and close to EE2NoRegenBat?
- Usually this limit only affects how much you can regen. However, there is a special case at zero motor speed, the motor winds up a little bit and the DMOC can't decide whether it wants to brake or accelerate just by looking at the speed and torque signs. If meanwhile the battery is overcharged and the regen power limit is zero, the regen power limit will apply to this "accelerating" case. This "false" limiting prevents the vehicle from moving when the battery voltage is too high. Solution: increase EE2MinPowerLimitSpeed if you aren't concerned about overcharging/draining the battery at speeds below EE2MinPowerLimitSpeed.

CURRENT_LIMIT or MOTOR_STATE_MAX_AC_CURRENT_REACHED

- Torque is limited by the max current DMOC/motor can do. This is normal at low motor speeds.
- Related variables: ISR2IsLimit, ISR2ThermCurrentLimitCause, ISR2MotorLimit etc.
- Related EE parameters: EE2IsMax.
- Debugging: is the motor/DMOC thermal limited? Compare ISR2IsLimit to EE2IsMax; if ISR2IsLimit is smaller, check ISR2MotorLimit. If ISR2MotorLimit is smaller than 1, the motor is overheated; if ISR2HeatsinkLimit is smaller than 1, the DMOC is overheated. ISR2ThermCurrentLimitCause (available in newer code revisions) is a enumerated variable which tells why motor current is limited.

VOLTAGE_LIMIT or MOTOR_STATE_MAX_AC_VOLTAGE_REACHED

- Torque is limited by the DMOC DC voltage. This is considered normal at high speed (beyond base speed). It will limit more when the DC voltage gets lower. Note, this is NOT where the current is limiting because the battery voltage is approaching the lower voltage limit EE2NoAccelBat + EE2AccelBatRamp.

SLIP_LIMIT or MOTOR_STATE_FLUX_TRANSIENT

- Normal at transient. If it persists for a few seconds or longer, contact Azure Dynamics.

EE3LastError Codes (DMOC Fault Codes)

See DMOC error codes are listed in Table 9. For more information and a discussion of the most common errors, see below.

Table 9. Below is a discussion of the most-commonly seen codes.

EE3LastError 1, 2 or 4 or PS_FLT_HARDWARE_OC

- DMOC software is incorrect for motor.
- Bad or noisy motor speed sensor.
- Soft battery; a dramatic change in DC voltage can trip this fault.
- May be caused by changing DMOC parameters on the fly.

EE3LastError 8 or PS_FLT_HARDWARE_OV

This is usually related to the battery bus voltage being much higher than the DMOC expects. Causes include:

- DMOC parameters are not correct for battery system.
- Energy storage system is too “soft” and voltage changes quickly with load.
- Something on the high voltage bus is causing a voltage spike.
- Contactor opening or fuse blowing during regen.
- Battery is overcharged.

EE3LastError 16 or PS_FLT_CHARGED_ERROR

Vehicles with improper or substandard grounding and shielding sometimes exhibit nuisance errors flagged as EE3LastError = 16, or enumeration = PS_FLT_CHARGED_ERROR. Once every measure for improving the grounding and shielding has been taken, it is OK to disable this error if the problem persists. This can be achieved by setting EE2DisableChargedError = 1. Note, in software code released after September 2009, this error is disabled and the parameter EE2DisableChargedError is not available.

EE3LastError 128 or PS_FLT_DESAT

DMOCs have three levels of overcurrent protection, with different response times and trip levels:

- Software overcurrent: slowest response time, trip level adjustable by software parameters.
- Hardware overcurrent: medium response time, trip level fixed in hardware, high trip level.
- Desaturation detection: fastest response time, trip level fixed in hardware, highest trip level.

This fault indicates an IGBT experienced excessive current. This is the last level of hardware protection, triggering a critical fault which requires power cycling the DMOC to re-enable.

Possible causes include:

- Motor or motor power cable has phase-to-phase short; disconnect motor cables and measure resistance between each phase and ground. Resistance should be over 1 megaΩ. Perform hi-pot test on vehicle and measure motor inductance phase to phase.
- IGBT or other internal circuitry of the DMOC has catastrophically failed.
- DMOC current sensor failed or disconnected.

EE3LastError 256 or PS_FLT_RELAY_ERROR_AT_READY or PS_FLT_RELAY_ERROR_AT_ENABLED
This is typically a result of problems with the 12V supply causing the DMOC's internal contactor to open when it should not. Check your 12V supply.

EE3LastError 512 or PS_FLT_SOFTWARE_OC
Rarely seen.

EE3LastError 1024 or PS_FLT_SOFTWARE_OV
Flagged when software detects an overvoltage condition. The threshold for this error detection is set by parameter calibration. May trigger at the same time as EE3LastError 8 or PS_FLT_HARDWARE_OV.

EE3LastError 2048 or PS_FLT_CURRENT_CALIB_FAULT
Rare; may be associated with 12V supply problems.

EE3LastError 4096 or PS_FLT_OVERSPEED
DMOC detects motor RPM exceeded parameter limit EE2PosOverspeed in the positive (forward) direction, or EE2NegOverspeed in the negative (reverse) direction. Possibilities include:

- Legitimate overspeed
- Noisy speed sensor signal, failed speed sensor, bad speed sensor connection or speed sensor filter box; verify all speed sensor wire routing and shielding connections
- Speed ramp calibration error
- Inappropriate speed set points or limits set
- If fault is repeatable, use scope tool in ccShell to log ISR2Hertz variable and capture this trace when the fault occurs to examine speed sensor signal

EE3LastError 32768 or PS_FLT_DC_BUS_UNDER_VOLTAGE
DC bus voltage drops below EE2PSOffBat (minimum powerstage operating threshold, typically 100V) while power stage is enabled. Note battery voltage must be above EE2PSOnBat (typically 120V) before powerstage will enable. Since in many applications the DMOC does not receive an OFF signal, the HV "bleeding away" is a normal shutdown event, therefore this fault is only flagged if the DMOC was switching (torque being commanded) when the DC bus voltage drops out. This fault is meant to highlight abnormal shutdown sequences; it is really more a warning than a fault. Possible causes:

- Battery failure or battery cable connection failure
- Other abnormal shutdown sequence
- Error in parameter calibration

EE3LastError 32768 or PS_FLT_SPEED_SENSOR_ERROR
Speed sensor noisy or disconnected. Check speed sensor, harness and connectors for integrity and proper shielding and grounding.

RS-232 Communication Errors

Check the obvious like the cable, connectors, pins, etc. on both ends. Azure Dynamics also suggests an RS-232 isolator. We recommend the B&B Electronics Model 9POP4, 4-channel isolator for RS-232.

http://www.bb-elec.com/bb-elec/literature/9pop4-3903ds.pdf

ISR2PSFaultActive or EE3PSFault Error Codes

Powerstage active faults are listed in Table 20.

Table 20: ISR2PSFaultActive or EE3PSFault0, EE3PSFault1, EE3PSFault2, EE3PSFault3

	ISR2PSFaultActive	State
	NO_FAULTS	0
Non-Critical Faults		
	ERROR_ON_ENABLE	2
	RELAY_ERROR_AT_READY	3
	RELAY_ERROR_AT_ENABLED	4
	CHARGED_ERROR	5
	HARDWARE_OV	6
	HARDWARE_OC	7
	SOFTWARE_OC	8
	SOFTWARE_OV	9
	DC_BUS_UNDER_VOLTAGE	10
	OVERSPEED	11
	SVPWM_ERROR	12
	SPEED_SENSOR_ERROR	13
Critical Faults		
	DESAT	128
	CURRENT_CALIB_FAULT	129
	EXTERNAL_PS_DISABLE_AT_ENABLED	130
	KERNEL_DISPATCHER_ERROR	131
	UNDEFINED_CASE_ERROR	132

RS-232 to USB Adaptor for DMOC Communication

Many new computers don't have RS-232 connectors, so an RS-232 to USB adapter is required. Many are available from various manufacturers. Azure has had problems using these adapters with ccShell on computers with dual cores (dual processors). Check for two processors by right-clicking on "My Computer" and choosing "Properties". Click the "Hardware" tab, then the "Device Manager" button. Scroll to "Processors" and click the "+" button. If two processors are shown, it's a dual core machine.

One processor can be disabled to use ccShell by pressing Ctrl-Alt-Delete once and clicking the "Task Manager" button. Click the "Processes" tab, and select ccShell. When ccShell is selected (highlighted), right click on it and choose "Set Affinity". Uncheck the "CPU 1" box. This change is not permanent; it must be repeated each time the DMOC is connected to the computer.

One problem all USB serial adapters share is ccShell will hang if the device is disconnected from the laptop while a .ccs file is open. To avoid this, close the file before disconnecting the USB device. We do not recommend letting the computer "sleep" with a USB serial device connected; if the device is disconnected while the laptop cover is closed or asleep, the computer may crash.

Azure Dynamics' current hardware recommendation is the Aten UC-232A.

http://www.aten-usa.com/?product&cat=595&Item=UC232A

Speedometer/Tachometer

The DMOC has a frequency-modulated 12V push-pull output (open-emitter gauge drive) that can drive some speedos/tachs. Azure Dynamics has had success with the Continental (was Siemens) VDO, "Cockpit Series", 85mm diameter, wired to work with "electronic transmissions". This output is Pin 25 from the DMOC 35-pin connector, marked on the Azure Dynamics Foundation Harness in the Azure Dynamics DMOC Interface Kit.

Speedometer Installation and Operation Instructions Download PDF

http://www.usa.vdo.com/generator/www/us/en/vdo/main/products_solutions/cars/performance_instruments/vdo_performance_instruments/instrument_series/cockpit/speedometers/download/flc_0515012051programmablespeedometer_en.pdf

The DMOC parameter called EE1SpeedoDiv can be adjusted for specific speedos/tachs. However, every speedo/tach is different and the software isn't designed to work with all of them.

- To calibrate EE1SpeedoDiv:
- Connect speedo output to speedometer
- Calculate km/h corresponding to 2500 rpm at the motor
- Don't spin the motor during the calibration process
- Set EE1SpeedoDiv = -100, speedometer should move
- If reading is higher then km/h calculate above, make the number more negative (e.g. -110)
- If reading is lower then km/h calculate above, make the number less negative (e.g. -90)
- Once the speedometer displays the correct speed, flip the sign of EE1SpeedoDiv (make it a positive number)
- Now drive the vehicle and double-check speedometer calibration

The equation for the speedo is:

2 X rpm ÷ EE1SpeedoDiv ≈ speedo output frequency

AZURE DYNAMICS
part of the solution™

DETROIT
14925 W 11 Mile Road
Oak Park, MI
USA 48237
T 248.298.2403
F 249.298.2410

VANCOUVER
3900 North Fraser Way
Burnaby, BC
Canada V5J 5H6
T 604.224.2421
F 604.419.6392

BOSTON
9 Forbes Road
Woburn, MA
USA 01801
T 781.932.9009
F 781.932.9219

TORONTO
4020A Sladeview Crescent, Unit 6
Mississauga, ON
Canada L5L 6B1
T 905.607.3486
F 905.607.6391

www.azuredynamics.com