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AEM EV
Tesla LDU Inverter Control Board
Product Description

Feature descriptions and instructions for setup and calibration of a VCU managed Tesla LDU system

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DANGER!

USE THIS PRODUCT WITH EXTREME CAUTION. MISUSE AND/OR IMPROPER INSTALLATION CAN CAUSE SIGNIFICANT DAMAGE TO YOUR VEHICLE AND PROPERTY BELONGING TO YOU OR OTHERS, AS WELL AS PERSONAL INJURY OR DEATH. IF YOU ARE NOT TRAINED IN ELECTRICAL ENGINEERING OR COMPLETELY FAMILIAR WITH THE SAFETY REQUIREMENTS OF HIGH VOLTAGE ELECTRIC VEHICLES, AND/OR ARE NOT WELL-VERSED IN CONFIGURING THE NECESSARY CONTROL CALIBRATIONS IN THE AEM VEHICLE CONTROL UNIT (VCU), DO NOT UNDER ANY CIRCUMSTANCES ATTEMPT TO INSTALL OR USE THIS PRODUCT. REFER THE INSTALLATION AND CALIBRATION TO A REPUTABLE INSTALLATION FACILITY, OR CONTACT AEM EV FOR A REFERRAL IN YOUR AREA. IT IS THE RESPONSIBILITY OF THE INSTALLER TO ULTIMATELY CONFIRM THAT THE INSTALLATION AND CALIBRATIONS ARE SAFE FOR ITS INTENDED USE.

THE AEM LDU INVERTER CONTROL BOARD (“ICB”) WAS DEVELOPED TO ENABLE QUALIFIED INSTALLERS AND USERS TO INSTALL A USED TESLA LARGE DRIVE UNIT (“LDU”) INTO ANY VEHICLE. TESLA LDU’S USED IN EV CONVERSIONS AND PURPOSE-BUILT RACE VEHICLES ARE USED PRODUCTS AND THEIR CONDITION CANNOT BE EASILY VERIFIED. AEM’S ICB MAKES MORE TORQUE, ALLOWS HIGHER MOTOR SPEED AND MAY ALLOW FOR HIGHER DC CURRENT DRAWS THAN THOSE OF A STOCK TESLA LDU INVERTER. AEM HOLDS NO RESPONSIBILITY FOR ANY DAMAGE OR MECHANICAL DEGRADATION TO A TESLA LDU AND RELATED DRIVETRAIN COMPONENTS, OR VEHICLE HIGH VOLTAGE SYSTEMS AS A RESULT OF THE INSTALLATION OR USE OF THIS PRODUCT.

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Information

Revision History

Revision	Date	Change Description
A	3/21/2022	Initial Release

Document Conventions

Information Type	**Font Convention**
VCU calibration *maps, tables, options*, and *channels*	*Italics*
VCU calibration option **value**	**Bold**

Symbol	**Information**
	When you see this symbol, ***PAY ATTENTION!*** This indicates that something important is about to be said that concerns your safety and the proper operation of the product. Use caution and be conservative. Use the product in the manner described.
	When you see this symbol, you are being alerted to an ***IMMEDIATE DANGER***. You MUST review these sections carefully and do everything possible to comply with installation and operation requirements or you risk injury or even death. 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.

Reference Files and Documents

File Name	**Location**
AEM EV Tesla LDU Control Board Installation	LINK
AEM EV VCU200-04 CAN Protocol	VCU200-04 Build 7XX CAN Tx Protocol
AEMCal Software Help File	Available from the Help menu within the AEMCal
Molex Connector Application Specification	AS-98420-002-001.pdf
Molex Crimper Application Specification	ATS-638119100-001.pdf
Molex Extractor Application Specification	ATS-638132400-001.pdf

Cautions and Warnings

Working on tractive systems (which includes but is not limited to motor(s), inverter(s), high voltage battery packs and high voltage cables) requires special experience and training. AEM EV has implemented fault detection and failsafe logic into its vehicle control units ("VCU"), however this does not mean that your VCU installation will be safe or effective, or that your VCU installation will not interfere with other systems on your vehicle and create a hazardous situation. It is the responsibility of the installer to understand the implications of each stage of tractive system installation and testing and to recognize what might be unique about your application that presents potential hazards or safety issues – and it is the responsibility of the installer to solve or address any such hazards or issues.

The following list includes basic recommended practices. ***This is not a comprehensive list; as noted below, if you are not well-versed in the appropriate installation and testing procedures, you should refer the installation and calibration to a reputable installation facility or contact AEM EV for a referral in your area.***

- When access is required near the battery pack, the cell segments must be separated by using an appropriate maintenance disconnect plug.
- When working on the battery pack or tractive system, safety goggles with side shields and appropriate insulated tools must be used.
- Always wear Class 0 gloves rated at 1000V with leather protectors.
- Only use CAT III rated digital multimeters (DMM) and test leads.
- When working on the battery pack or tractive system, work with one hand while keeping the other behind your back.
- During initial system power up and testing, the vehicle must be raised off the ground and supported appropriately. Wheels and tires should be removed.
- During the VCU firmware upgrade process, battery cell segments must be separated using an appropriate maintenance disconnect plug.
- Do not make calibration changes when the inverter pulse width modulation (PWM) is enabled.

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Electrical Safety Insulation Monitoring

The high voltage system in an electric vehicle is designed to be ungrounded (floating) with respect to the vehicle chassis (frame). Insulation faults can cause electric shock, personal injury and even death. An insulation monitoring device (IMD) must be used to protect against these faults. See Bender https://www.benderinc.com/ for more information. Please see the Insulation Monitoring Device (IMD) 27 section for VCU calibration options.

Supported Application Overview

AEM EV VCU firmware versions are developed to support specific features. Standard support exists for the following devices, however please see the Supporting Firmware 9 section for information specific to this firmware version.

Standard Supported CAN Modules	**Description**
AEM PDU-8 (pn 30-8300)	AEM Eight Channel Power Distribution Unit (PDU-8)
Battery Management System	AEM EV BMS-18 or Orion BMS-2
Digial Current and Voltage Sensor	Isabellenhuette IVT-S Sensor
AEM CAN Keypad (pn 30-8400)	AEM EV 8-Button CAN Keypad
Cooling Pump	WP29 / WP32 BRUSHLESS ELECTRIC WATER PUMP
AEM CD Carbon Digital Dash	AEM CD Carbon Digital Dash/Logging Displays

Non CAN controlled supported hardware interface modules are identified in the following table.

Supported Hardware Module	**Description**
Analog Current Sensor	LEM DHAB S/137
Tesla Model S Parking Brake Controller	https://www.pantera-electronics.com/epbcontroller.htm

Supporting Firmware Version

The features described in this document apply to a specific firmware version. AEM EV VCU firmware versions have a file extension of *.aemecudef*. When you install AEMCal, firmware release versions included in that build will be installed to the *C:\ProgramData\AEM\Ecudef* folder on your PC. New versions can be manually installed by dragging and dropping the *.aemecudef* file onto an open AEMCal layout page.

Supported applications for this firmware include:

Supporting Firmware Version	VCU200_04_A1_7XX.aemecudef
Inverters	Tesla Large Drive Unit with AEM EV LDU Inverter Control Board, Cascadia PM Series
Chargers*	Thunderstruck TSM-2500, Dilong 6.6Kw OBC/DCDC Combo

Direct support when used in conjunction with the AEM EV BMS-18.

For indirect charger support when using the Orion BMS, please refer to the Orion documentation.

Hardware Overview

AEM EV Part Number	30-8000
Microprocessor	NXP MPC5607B
Clock Speed	64 MHz
Environmental	IP6k7 Compliant
Operating Temperature	-40°C to +105°C
Operating Voltage	9 – 16V 16V is the absolute maximum rating. ***The module is not designed for use with 16V battery systems as they typically require ~18V to charge.***
Overvoltage Protection	16V
Current Draw: Off-State Current	1 mA
Wake Switch Power-on threshold	3.7V minimum
Wake Switch Power-down threshold	1.5V maximum
Communication Channels	CAN1, 500k, Internally Terminated, PC Comms
	CAN2, 500k, Internally Terminated, Peripheral Device Comms
	CAN3, 500k, Internally Terminated, Peripheral Device Comms and Data Transmit
	CAN4, 500k, Internally Terminated, Peripheral Device Comms
Internal Logging Memory	None - External logging possible with AEM Dash units with logging capability and other compatible 3rd party CAN displays and CAN data loggers.

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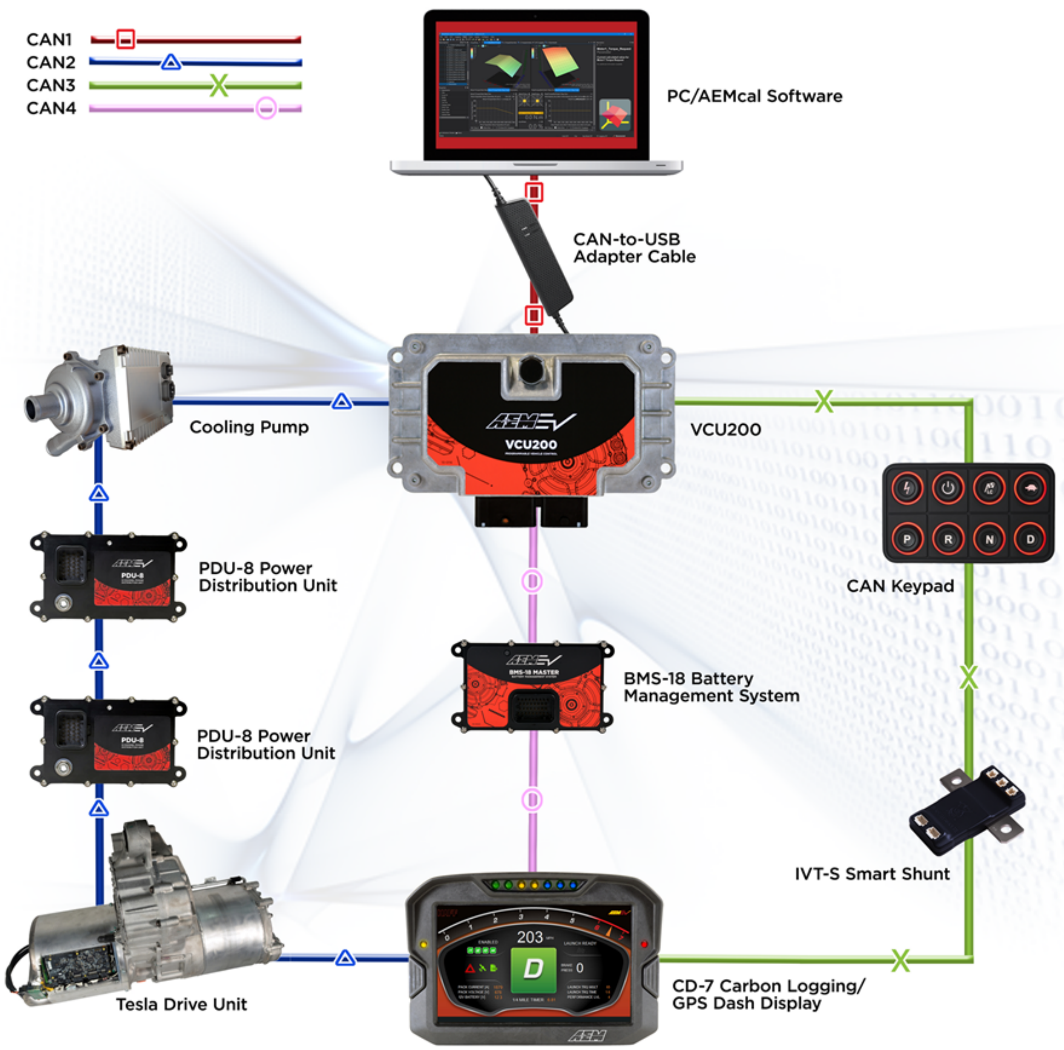
CAN Network Configuration

The following diagram describes the basic network requirements. Four separate CAN networks are represented. The network channel assignment for each device is not reconfigurable by the end user. All CAN channels in the VCU200 are internally terminated. The VCU must always be located at the physical end of a bus. All busses must be terminated with a 120 ohm resistor at the physical end. CAN network wiring should be accomplished by a skilled harness builder familiar with vehicle networking.

Network Summary

CAN1 – PC communication with AEMCal
CAN2 – Inverter, EMP Pump(s), PDU-8(s), AEM CD Dash Port 1
CAN3 – CAN Keypad, Orion BMS2, VCU Data Transmit, AEM CD Dash Port 2, IVT-S
CAN4 – AEM CD Dash Port 2, AEM EV BMS-18, Chargers (for direct control)



PC Communication With AEMCal

The VCU communicates with the PC over the CAN1 network. A CAN to USB converter device is required. For best performance, AEM recommends the Kvaser Leaf Light HS v2.
https://www.kvaser.com/product/kvaser-leaf-light-hs-v2/

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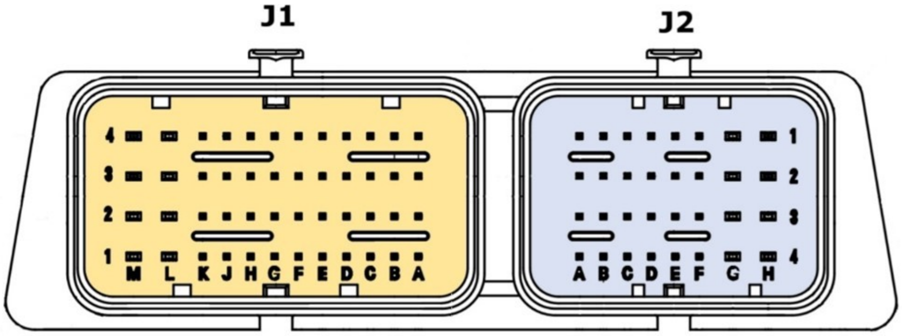
Hardware Pinout



Pin #	Pin Function	Range	Conditioning	Type	Application Notes
J1-A1	Ground				
J1-A2	Sensor Power1			5V Supply	100mA max
J1-A3	Ground				
J1-A4	Sensor Power2			5V Supply	100mA max
J1-B1	Ground				
J1-B2	Sensor Power3			5V Supply	50mA max
J1-B3	Ground				
J1-B4	Sensor Power4			5V Supply	50mA max
J1-C1	Manual Regen Lever 2	0 – 5V	1.3k Pullup	Analog	
J1-C2	Ground				
J1-C3	Output 21			Low Side	500mA max, RESERVED
J1-C4	Cooling Pump 2 Control			Low Side	500mA max
J1-D1	Negative Contactor FB	0 – 5V	10k Pullup to 4.3V	Analog	Switch to ground
J1-D2	Ground				
J1-D3	Drive System Fan			Low Side	500mA max
J1-D4	Battery System Fan			Low Side	500mA max
J1-E1	Enable Switch	0 – 5V	10k Pullup to 4.3V	Analog	Switch to ground
J1-E2	Ground				
J1-E3	Battery System Heater			Low Side	500mA max
J1-E4	Output 8			Low Side	RESERVED
J1-F1	Coolant Temp 1	0 – 5V	2k Pullup to 4.3V	Analog	
J1-F2	Ground				
J1-F3	Output 5			Low Side	RESERVED
J1-F4	NOT USED				
J1-G1	Parking Lamp Switch Ambient Temp	0 – 5V	2k Pullup to 4.3V	Analog	Dual function pin. Use one or the other. Switch to ground if using as a switch.
J1-G2	Ground				
J1-G3	HVIL Main Output			Low Side	100mA max, 100Hz, 50% DC
J1-G4	Cooling Pump 1/2 PWM Output			Low Side	100mA max

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Pin #	Pin Function	Range	Conditioning	Type	Application Notes
J1-H1	Head Lamp Switch AC Evap Temp	0 – 5V	2k Pullup to 4.3V	Analog	Dual function pin. Use one or the other. Switch to ground if using as a switch.
J1-H2	Ground				
J1-H3	Cooling Fan 1/2 PWM Output			Low Side	100 mA max
J1-H4	Safety Light Relay Driver			Low Side	500 mA max
J1-J1	LIN1				RESERVED
J1-J2	CAN1+				PC Comms
J1-J3	Output 17			High Side	500mA max, RESERVED
J1-J4	NOT USED				
J1-K1	Cooling Pump 1 Control			Low Side	500 mA max
J1-K2	CAN 1-				PC Comms
J1-K3	Cooling Pump 2 Wake			High Side	500 mA max
J1-K4	Cooling Pump 1 Wake			High Side	500 mA max
J1-L1	Pre-Charge Contactor Driver			High Side	3.3 A max
J1-L2	Positive Contactor Driver			High Side	3.3 A max
J1-L3	Inverter 12V Power Relay Driver			Low Side	3.3 A max
J1-L4	Oil Pump Relay Driver			Low Side	3.3 A max
J1-M1	12V Battery Power (Permanent)				
J1-M2	12V Battery Power (Permanent)				
J1-M3	Ground				
J1-M4	Negative Contactor Driver			Low Side	3.3 A max
J2-A1	CAN 2-				Peripheral Comms
J2-A2	Ignition Switch	0 – 12V	3.3k Pulldown	Digital	Switch to Batt, 12V = ON
J2-A3	Wake Input 2	0 – 12V	3.3k Pulldown	Digital	RESERVED
J2-A4	Wake Input 1	0 – 12V	3.3k Pulldown	Digital	Switch to Batt, 12V = ON
J2-B1	CAN 2+				Peripheral Comms
J2-B2	IMD Input	0 – 12V	3.3k Pulldown	Digital	Switch to Batt, 12V = ON
J2-B3	Brake Switch 2	0 – 12V	3.3k Pulldown	Digital	Switch to Batt, 12V = ON
J2-B4	Wake Input 3	0 – 12V	3.3k Pulldown	Digital	RESERVED
J2-C1	CAN 3-				VCU Data Transmit
J2-C2	Park Switch	0 – 12V	3.3k Pullup	Digital	Switch to ground
J2-C3	Reverse Switch	0 – 12V	3.3k Pullup	Digital	Switch to ground
J2-C4	Brake Switch 1	0 – 12V	3.3k Pullup	Digital	Switch to ground
J2-D1	CAN 3+				VCU Data Transmit
J2-D2	Neutral Switch	0 – 12V	3.3k Pullup	Digital	Switch to ground
J2-D3	Drive Switch	0 – 12V	3.3k Pullup	Digital	Switch to ground
J2-D4	Input 23	0 – 12V	3.3k Pullup	Digital	RESERVED
J2-E1	CAN 4-				RESERVED
J2-E2	Input 28	0 – 12V	3.3k Pullup	Digital	RESERVED

Pin #	Pin Function	Range	Conditioning	Type	Application Notes
J2-E3	Input 27	0 – 12V	3.3k Pullup	Digital	RESERVED
J2-E4	Start Switch	0 – 12V	3.3k Pullup	Digital	Switch to ground
J2-F1	CAN 4+				RESERVED
J2-F2	Accel Pedal 2	0 – 5V	10k Pulldown	Analog	
J2-F3	Accel Pedal 1	0 – 5V	10k Pulldown	Analog	
J2-F4	AC Switch	0 – 12V	33k Pulldown	Analog	Switch to Batt, 12V = ON
J2-G1	LEM Pack Current Low Range	0 – 5V	100k Pulldown	Analog	Used with AEM BMS-18 System
J2-G2	LEM Pack Current High Range	0 – 5V	100k Pulldown	Analog	Used with AEM BMS-18 System
J2-G3	Manual Regen Lever 1	0 – 5V	100k Pulldown	Analog	
J2-G4	Brake Pressure / AC Pressure	0 – 5V	10k Pulldown	Analog	Dual function pin. Use one or the other.
J2-H1	Non-Driven Wheelspeed	0 – 5V	10k Pulldown	Frequency	20 – 2000 Hz
J2-H2	Driven Wheelspeed	0 – 5V	10k PU/PD	Frequency	20 – 2000 Hz
J2-H3	Input 30	0 – 5V	10k PU/PD	Frequency	20 – 2000 Hz, RESERVED
J2-H4	HVIL Main Input	0 – 5V	10k PU/PD	Frequency	20 – 2000 Hz

Vehicle Integration Steps

This section will serve as a high level outline describing the basic steps of successful VCU/vehicle integration. The task is complex and requires skilled technicians who fully understand both low voltage (LV) and high voltage (HV) vehicle systems and wiring.

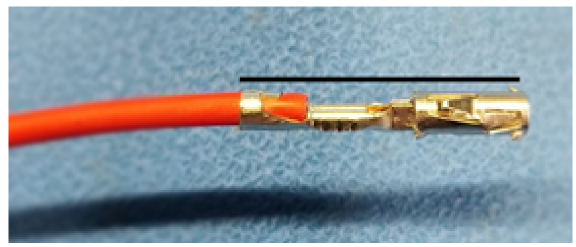
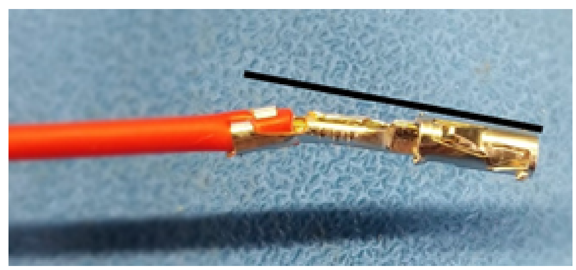
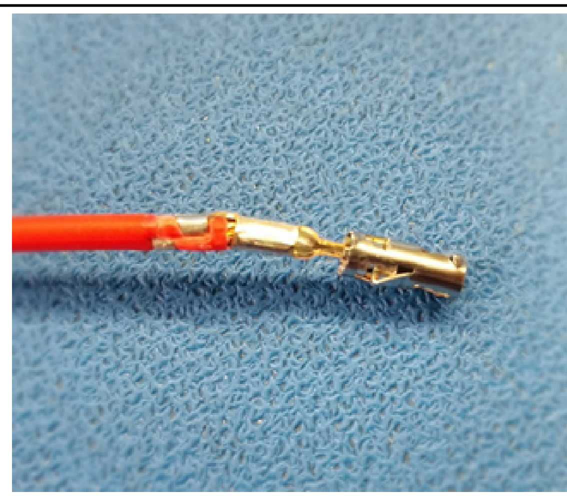
Step #	Step Name	Step Description
1	Planning	No complex project is ever successful without a plan. Building an electric vehicle (EV) from scratch or converting an internal combustion engine (ICE) vehicle is challenging. This summary guide is not intended to identify and describe every unique step along the way to project completion but it should provide a good overview, highlighting each major step. Some steps are required before others. For example, common sense dictates that you must have proper low voltage power and ground inputs before you can establish PC communications with the VCU. Other steps may be completed in a different order if necessary.
2	Low voltage power and ground busses	See the Minimum Required Inputs 20 section. A permanent 12 volt battery supply must be provided.
3	Wake Switch	See the Minimum Required Inputs 20 section. The wake switch tells the VCU to wake and begin logic processing.
4	CAN Networking & VCU PC Communication	See the PC Communication With AEMCal 10 section. At its core, the VCU is a CAN networking and logic processing hub. Up to four independent CAN networks may be required.
5	Accelerator Pedal	See the Minimum Required Inputs 20 section. A reliable pedal with dual redundant 0-5V analog signals is necessary.
6	Brake Switch	See the Minimum Required Inputs 20 section. The brake switch input is critical for safety and proper functionality.
7	Ignition Switch	See the Minimum Required Inputs 20 section. The ignition switch is a critical VCU input used to initiate inverter pre-charge and other important processes.
8	PRND Inputs	See the Minimum Required Inputs 20 section. Critical and used for Drive Mode arbitration.
9	HVIL	See the Minimum Required Inputs 20 section. A completed High Voltage Interlock (HVIL) is required for proper functionality and safety.
10	IMD	See the Optional Inputs 25 section. Although technically optional, a reliable insulation monitoring device is highly recommended for safety.
11	High Voltage Bus	See the Contactors 35 section. The high voltage bus system is dependent on the overall vehicle design and requirements. It should be planned for, designed and installed by technicians experienced with high voltage electric vehicle systems.
12	Battery Management (BMS)	See the Battery Management Systems 40 sections.
13	Cooling Pump(s)	See the Cooling Pumps & Fans 37 and Thermal Control 66 sections.
14	Cooling Fan(s)	See the Cooling Pumps & Fans 37 and Thermal Control 66 sections.
15	Power Steering	See the Power Steering 72 section.

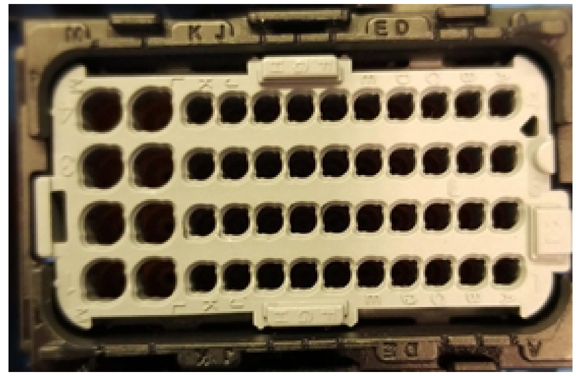
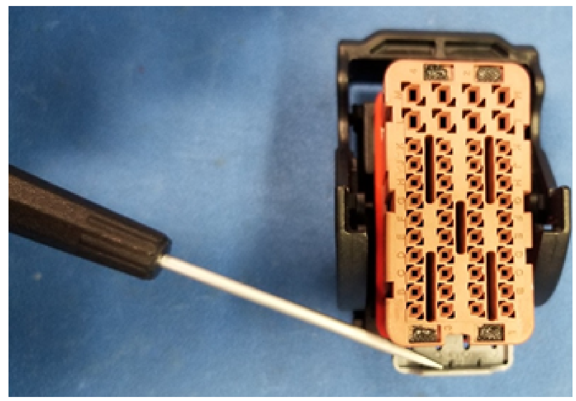
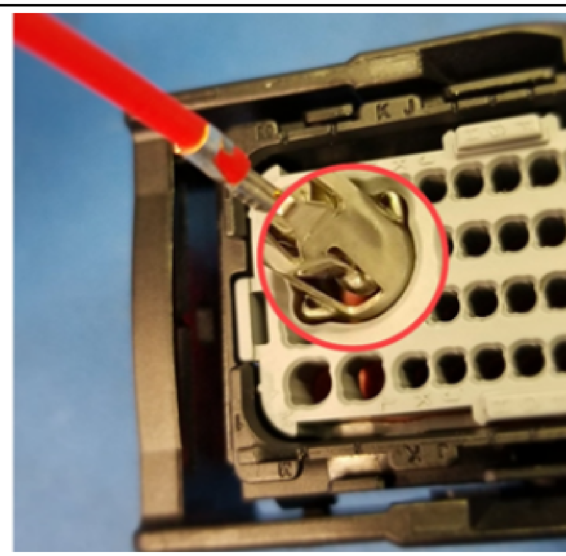
16	Brake Vacuum	See the Brake Vacuum 73 section.
17	Parking Brake	See the Parking Brake Control 72 sections.
18	Low voltage wire harness design, assembly and installation	Result of planning and implementation of each step. A properly designed low voltage wiring harness assembly is critical for performance, safety and reliability. It should be planned for, designed and installed by technicians experienced with complex vehicle electrical systems. Use a multi-meter to verify proper connectivity between all components.
19	Torque Management	See Torque Control 66 section.
20	Initial Spin Test	See Initial Spin Test 74 section. The vehicle must be raised with the drive wheels off the ground, preferably with the wheels/tires removed from the hubs. This initial checkout must be performed by an experienced EV technician.

Harness Connectors and Required Tools

A mating Plug & Pin Kit is available from AEM under PN 30-3709. Following is a list of Molex recommended tools and best practices for working with these connector assemblies. There may be similar and/or compatible tools available in the market. However, AEM will not be responsible for connector housing damage caused by misuse or use of improper tools. See the Reference Files and Documents 6 section for a list of associated specification sheets. ***Read these documents completely***. If you are not comfortable working with high density connector housings, please seek help from an experienced automotive harness builder. A properly planned and assembled harness is critical for performance and safety.

Tool	**Molex Part Number**
Large Terminal Crimp	063811-8900
Small Terminal Crimp	063811-9100
Large Terminal De-pinning	063813-2300
Small Terminal De-pinning	063813-2400

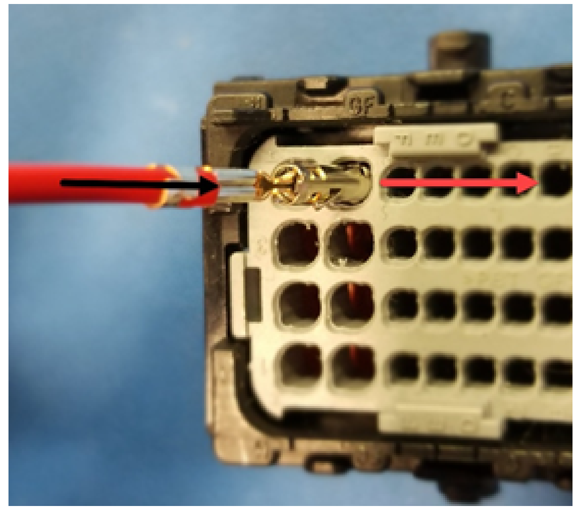
AEM highly recommends the correct Molex CMC crimp tools be used for terminal crimping. Should a universal crimp tool be used, be aware of the following possible crimp issues. Using a universal crimp tool may result in bent and deformed terminals that may inhibit terminals insertion or cause terminals to become stuck in the connector housing.	 
Using a universal crimp tool may cause the wire insulation to bulge and may inhibit terminal insertion. In all cases, be sure to use appropriately sized wire for the terminal size being used. Thin jacketed TXL wire or better is recommended.	

Connector pinout is marked on the back and front of the connector. Pay close attention to the cavity location to avoid installing a terminal in the wrong location.	
The CMC connector housing has a sliding terminal position assurance (TPA) lock that must be slid open before inserting or removing terminals. It can be slid open with a small screwdriver as shown.	
Terminal cavities have two keying slots. The terminal must be correctly aligned with the key slots before it can be inserted.	

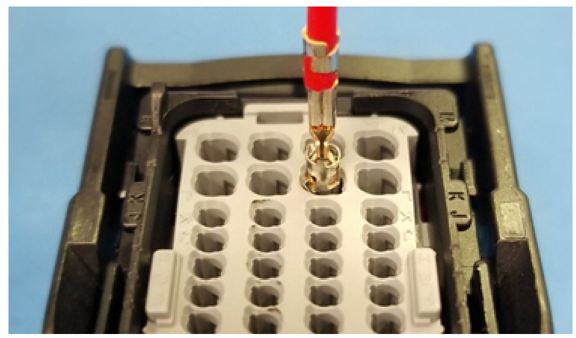
Depending on the wire lay orientation, the terminal can go in one way or be flipped 180°.

Do NOT rotate the terminals at any point during insertion otherwise damage to the terminal or connector housing is possible.

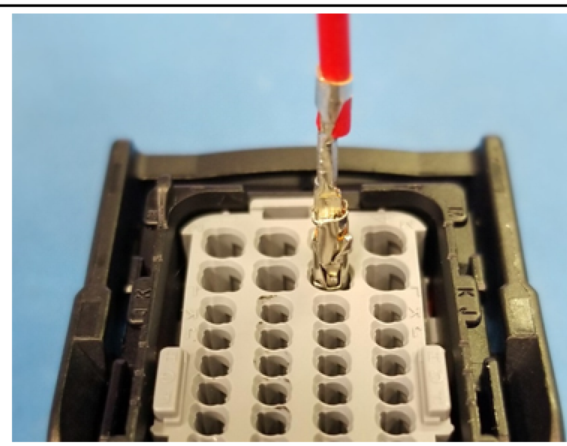
Note that that conductor crimp can only be aligned with the numbered rows and can NOT be aligned with the lettered columns. The conductor crimp can point either left or right, but not up or down.



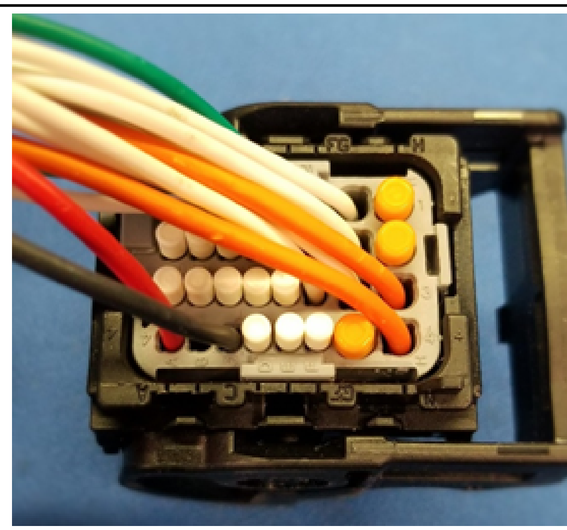
Correct Alignment

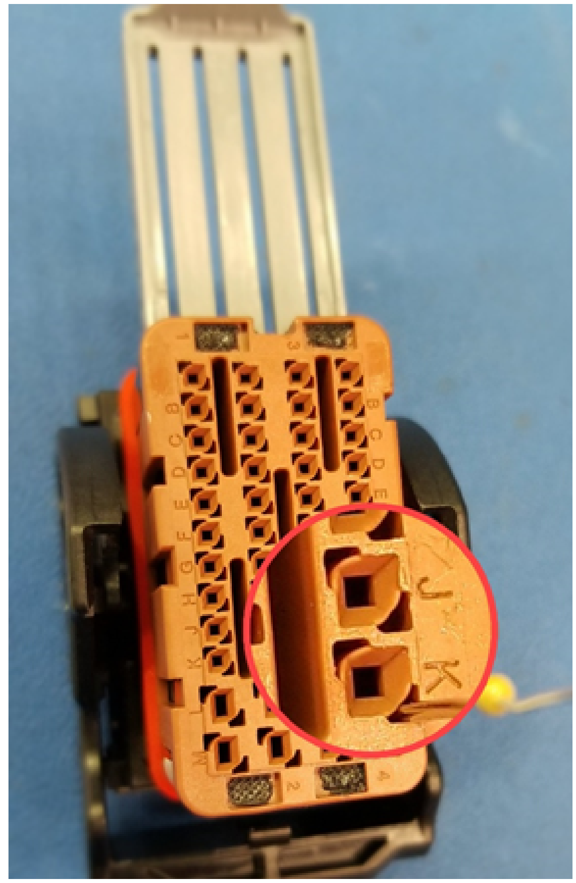


Incorrect Alignment



Sealing plugs must be used in any empty cavity within the connector housing.



To remove terminals from the connector housing, first slide the TPA open. AEM recommends the specific Molex depinning tools be used. Should they not be available, terminals can be released from the housing by carefully inserting a modified paper clip or similar tool into one of the two triangle shaped release ports. ***The terminal is released from one port or the other so if it does not release, try releasing from the other port.***	

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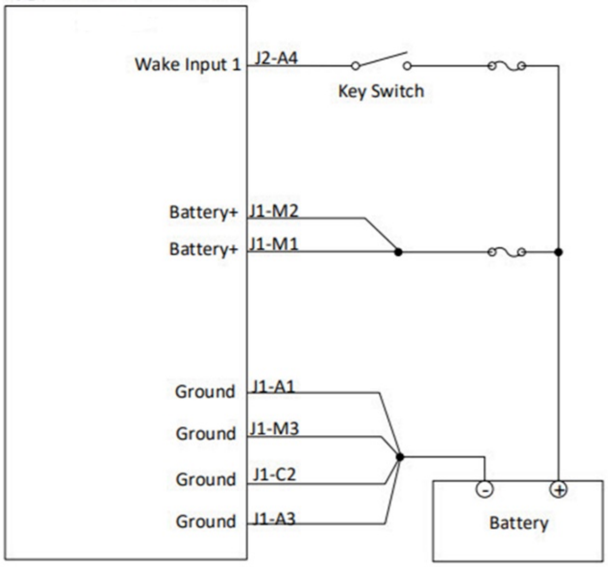
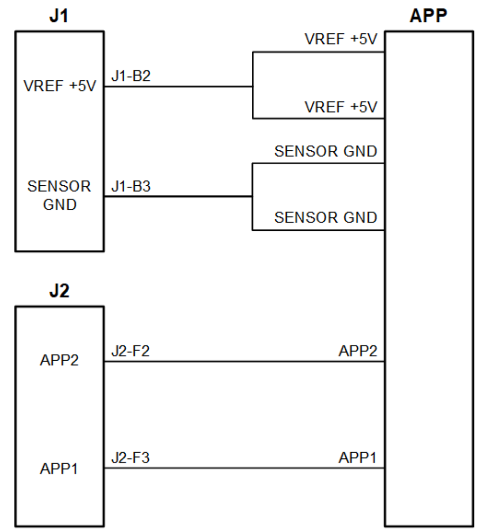
Inputs

Minimum Required Inputs

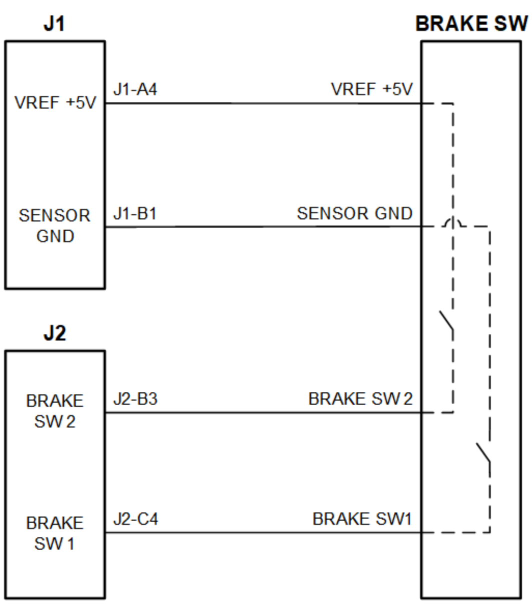
The following tables describe the minimum required inputs for proper VCU control.



WAKE AND POWER GROUND INPUTS

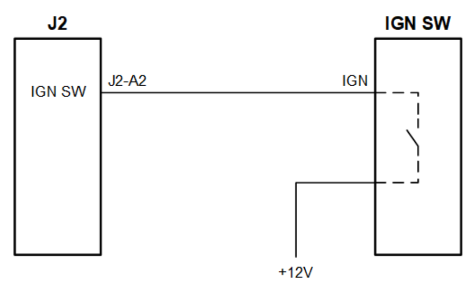


ACCELERATOR PEDAL POSITION (APP)



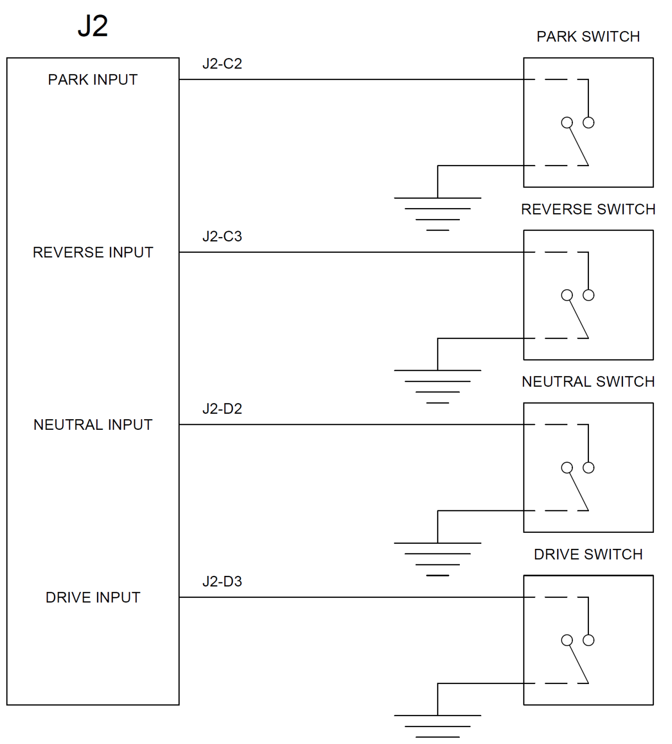
Signal polarity selectable to support both N.O. and N.C. switches
Choice between AND or OR logic

BRAKE SWITCH INPUT



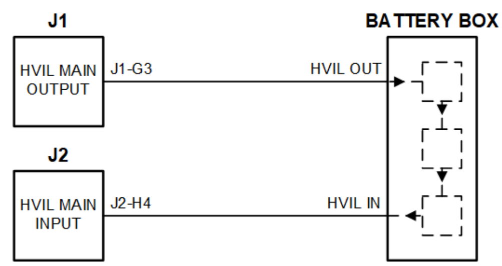
Optionally inputted by AEM 8 Button CAN Keypad for direct drive applications

IGNITION SWITCH INPUT



Optionally inputted by AEM 8 Button CAN Keypad for direct drive applications

PRND INPUTS



HVIL INPUT

VCU Power and Ground

The VCU power and ground inputs are used for powering internal components, such as the microprocessor, logic circuitry, RAM and high side outputs. The current usage will depend on how these circuits are used in the application. ***A good starting point for the 12V Battery+ input fuse is 10 amps.***

<u>Channels</u>

Battery_Voltage: VCU's internal supply voltage measurement

VCU Wake and Ignition

The wake switch input is not a switched 12v power supply for the VCU. It is better described as a logic switch. When the input is high, the VCU will begin processing. When the input goes low, the VCU will continue to process and will initiate a shut down sequence when appropriate. The VCU will store nonvolatile data after the wake signal goes low. This may take a few seconds. If all power is removed from the VCU before the shutdown sequence completes, memory corruption may occur. AEMCal communications with the VCU is only possible when the wake switch is high. ***A good fuse value for the wake switch input is 3 amps.***

<u>What is the difference between the Wake Switch & Ignition Switch?</u>

Traditionally in a standard ICE vehicle, the Ignition Switch has always been the primary enabler that essentially turns the vehicle on, allows the engine to be started and the vehicle to be driven. In this case when the Ignition Switch is off, everything on the vehicle is also off.

With an EV, there will be times when the vehicle is off or not being actively operated but there are active functions such as charging or battery thermal management that must still be controlled. With the AEM VCU, it can be on and actively managing these functions while the vehicle is essentially off and not being operated. The on/off state of the VCU has been separated from the vehicle's operation on/off state and is labeled as its "wake" state. The VCU is essentially always powered on and if actively controlling functions on the vehicle it is "awake" and if it's in an idle or inactive state, it's "not awake" or is "asleep".

With the VCU the concept of Ignition Switch has been relegated to specifically indicate the driver's desire to actively operate the vehicle. This means closing HV contactors to power up the inverter/motor and readying for a drive direction command (forward or reverse). When the vehicle is done being operated, the Ignition Switch is turned off, the inverter voltage is discharged and the contactors are opened. Because of the distinct functional difference between Wake & Ignition states, there must always at least be the primary connection of a Wake Switch input. While the VCU can actually be configured to tie the Ignition Switch state to the Wake Switch state, in most instances, the Ignition Switch will be a separate input from the Wake Switch input.

Options

IgnSwSource: Source option for ignition switch input, either discrete switch or AEM CAN keypad

IgnSw_Polarity: Used to invert detection logic

Channels

KeySw_Bgnd: Indicated state of the wake switch input

IgnSw: State of the discrete ignition switch input

IgnSwState: Final state of the ignition switch input

Accelerator Pedal Position (APP)

Dual APP sensor inputs are required for safety. Connect according to the basic schematic diagram above.

Options

APPX_Polarity: Option to invert the voltage slope polarity

APPX_Min: Sensor voltage calibration minimum

APPX_Max: Sensor voltage calibration maximum

APPX_Lo_Thresh: Voltage threshold for low sensor fault detection

APPX_Hi_Thresh: Voltage threshold for high sensor fault detection

APPXCheckThreshold: This is the allowable difference between the calculated APP1 and APP2 position. If the difference is greater than this limit, it will be considered a sensor or wiring error which can trigger fault actions

APPXCheckTimeThreshold: Maximum allowable time for APP1-APP2 cross check error to exist. When a cross check error is present for longer than this time a fault will be triggered

Where X = 1 or 2 depending on the APP input signal

Channels

APP1_Volts: Raw voltage from the APP1 input

APP2_Volts: Raw voltage from the APP2 input

AccelPedal: Final calculated pedal position in %

Calibration Process

1. With the pedal closed, monitor the channel *APPX_Volts* vs the option *APPX_Min*. Set *APPX_Min* = *APPX_Volts*.
2. With the pedal fully open, monitor the channel *APPX_Volts* vs the option *APPX_Max*. Set *APPX_Max* = *APPX_Volts*.
3. Set the *APPX_Hi_Thresh* and *APPX_Lo_Thresh* slightly outside these calibration limits. These will be your fault detection thresholds.

Brake Switch

Dual brake switch inputs are recommended for safety. Connect according to the schematic diagram above. Brake Switch state may also be triggered by Brake Pressure value – see optional configuration settings below.

Options

BrakeSwitchDetectOption: Switch **AND**, switch **OR** or **BrakePress** options for arbitration. AEM recommends using the Switch **AND** option for safety.

BrkSw1_Polarity: Used to invert detection logic

BrkSw2_Polarity: Used to invert detection logic

Channels

BrkSw1_Raw: State of brake switch 1 input

BrkSw2_Raw: State of brake switch 2 input

BrakeSwitch: Final state of brake switch input

Optional Brake Pressure Switch Configuration

Options

BrkPress_Lo_Thresh: Voltage threshold for low sensor fault detection

BrkPress_Hi_Thresh: Voltage threshold for high sensor fault detection

BrkPressOfst: Offset for linear transfer function

BrkPressGain: Gain for linear transfer function

Tables

BrkPressSwThresh: 1D table for using brake pressure for brake switch detection, 0 = On above setpoint, 1 = Off below setpoint

Channels

Break_Pressure: Indicated measured brake pressure (*BrkPressGain**(volts))+(*BrkPressOfst*)

PRND

The park, reverse, neutral and drive inputs for direct drive applications may be inputted as either discrete switch inputs or with the AEM CAN Keypad 25 (pn 30-8400).

Options

DirectDrivePRNDInput: Select between discrete switch inputs or AEM CAN Keypad as input for Drive Mode

PrkSw_Polarity: Used to invert park switch detection logic

RevSw_Polarity: Used to invert reverse switch detection logic

NtrlSw_Polarity: Used to invert neutral switch detection logic

DrvSw_Polarity: Used to invert drive switch detection logic

DriveMode_Speed_LoThr: Vehicle speed must be below this value to allow transition between neutral, drive and reverse

DriveMode_Speed_ZeroThr: Vehicle speed must be below this value to allow transition to park

Channels

PrkSw: State of the discrete park switch input

RevSw: State of the discrete reverse switch input

NtrlSw: State of the discrete neutral switch input

DrvSw: State of the discrete drive switch input

Drive_Mode: Final state of the drive mode arbitration logic

High Voltage Interlock Loop (HVIL) I/O

Use of the HVIL loop detection is a highly recommended safety feature. The HVIL circuit is a low voltage continuous loop that starts at the VCU and typically connects through each HV device's HV connector (inverter, DCDC, charger, etc). The purpose of the HVIL circuit is for the VCU to be able to detect if a HV connection has been broken or removed thus preventing the enabling of HV battery contactors to prevent possible shorting or other damage/injury. The VCU generates a 100Hz, 50% duty digital signal on its HVIL output pin and looks to receive this same signal back on its HVIL input pin. When the input frequency equals the output frequency, the HVIL loop is detected.

It's very important to note that the VCU's HVIL circuit is low voltage only and does NOT connect directly to any HV circuits! Connecting the VCU to any HV circuits will result in severe equipment damage and possible electrical shock injury!

Options

HVILMainBypass: User option to bypass the main HVIL loop detection

Channels

HVILFreqIn1: Measured input frequency

HVILFreqOut1: Control output frequency

HVIL_Main_State: Final state of the main HVIL loop

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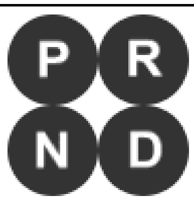
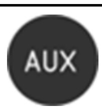
Optional Inputs

AEM 8-Button CAN Keypad

The VCU200 currently interfaces with the AEM 8-Button CAN Keypad (PN 30-8400) for direct drive configurations only.

Icon(s)	Function
	Direct Drive Park, Reverse, Neutral, Drive inputs Radio Button functionality
	Ignition Switch Input OFF = Contactors Open YELLOW = PreCharge in process GREEN = High Voltage Contactors Are Closed YELLOW = Active Discharge in process (if supported) RED = ERROR - PreCharge failed, Contactors are open
	Performance Level Loop Toggle 1-4, on while pressed
	Slip Target (reserved for future use) Loop Toggle
	Aux Function User programmable PDU output

<u>Keypad CAN Configuration:</u>

VCU CAN channel: CAN 3
Baud Rate: 500k

Coolant Temperature

An optional coolant temperature sensor may be installed in the vehicle's thermal conditioning system. Note that for specific temp references such as inverter temp, motor temp, etc., these channels values are typically reported over CAN by the specific device itself.

Options

CoolTemp1_Hi_Thresh: Voltage threshold for high sensor fault detection

CoolTemp1_Lo_Thresh: Voltage threshold for low sensor fault detection

Tables

CoolTemp1_Table: Coolant temperature sensor calibration table, sensor resistance vs temp

Channels

CoolTemp1_Res: Raw measured resistance from Coolant Temp input

Coolant_Temp1: Final calculated value

Coolant Temperature is discussed in detail in the Thermal Control 66 section.

Insulation Monitoring Device (IMD)

The high voltage system in an electric vehicle is designed to be ungrounded (floating) with respect to the vehicle chassis (frame). Insulation faults can cause electric shock, personal injury and even death. An insulation monitoring device (IMD) must be used to protect against these faults. Suggested IMD is Bender IR155-32xx with high side (+12v) status output. Output is high when NOT faulted and goes low when insulation fault is detected. Connect IMD output to VCU pin J2-B2.

Options

IMD_Polarity: Option to invert the detection logic polarity. Set to **Lo = Off** to disable the IMD function, otherwise set to **Lo = On** if using an IMD

IMD_LoTimeThresh: Time threshold for detecting the low state for signal debounce

IMD_HiTimeThresh: Time threshold for detecting the high state for signal debounce

IMD_Detect_Thresh: Time threshold in seconds to filter the IMD state after VCU wake to accommodate the IMD measurement delay; suggested to start with a value of **20** and adjust as necessary

IMD_Contactor_Enable_Input: Option to inhibit initial contactor closing based on either raw or filtered IMD fault state; to not inhibit contactor closing, set to **Ignore**

IMD_State_Store_Reset: Option to clear insulation fault flags from VCU memory

Channels

IMD_Raw: Reports the state of the digital input pin; pin low (0v) = 0, pin high (12v) = 1

IMD: Reports the raw or live IMD fault state without filtering; no insulation fault detected = Off, insulation fault detected = On

Fault_IMD: Reports the IMD fault state after delay timer expires; no insulation fault detected = 0, insulation fault detected = 1; also reported over CAN

IMD_State_Store: Flag indicating that an IMD fault has occurred and has been committed to VCU memory; can be cleared by toggling option *IMD_State_Store_Reset*

Calibration Process

VCU pin J2-B2 has a pull down resistor so when an IMD is not used, the IMD input will be pulled low. The IMD function can be disabled by setting option *IMD_Polarity* to **Lo = Off**. If using an IMD, set *IMD_Polarity* to **Lo = On**. Channel *IMD_Raw* is the state of the digital input pin. *IMD_Raw* will be 0 when the pin is pulled low (0v) and will be 1 when the pin is pulled high (12v). Use options *IMD_Hi/LoTimeThresh* for signal debounce.

Channel *IMD* is the "raw" fault state from the IMD. *IMD* will be **OFF** when no insulation fault is detected and will be **ON** when an insulation fault is detected. The IR155 can take a few moments before it can successfully measure the HV insulation resistance. Because of this, it may be necessary to filter or delay any fault triggers during periods of uncertainty. An optional filter delay timer is applied with option *IMD_Detect_Thresh*.

If channel *IMD* is **ON** after the *IMD_Detect_Threshold* timer expires, channel *Fault_IMD* will =1. When channel *Fault_IMD* becomes **1**, this fault flag is saved to memory. Channel *IMD_State_Store* will = **1** when an IMD fault flag is saved to memory. The IMD fault flags can be cleared from memory using option *IMD_State_Store_Reset*.

Option *IMD_Contactor_Enable_Input* can be used to inhibit initial contactor closing based on either raw or filtered IMD fault state. This would prevent the contactors from closing initially when the Ignition Switch is turned on. *IMD_Contactor_Enable* can also be set to **Ignore** and contactor closing will not be inhibited based on IMD fault state. Note that once contactors have closed, an IMD fault will not cause the contactors to open.

The IMD is referenced in the Pre-charge Contactor 36, Control Modes 57, and VCU Faults 76 sections.

Pack Current and Voltage

Battery pack current and voltage sensors must be installed by experienced technicians.

The VCU can monitor battery pack current from three different sources; analog inputs from the DHAB series by LEM, or CAN transmitted messages from either the IVT-Series by Isabellenhuette or an Orion BMS.

Pack voltage can be transmitted via CAN from the IVTS, Orion BMS, or AEM BMS-18. ***The LEM sensor is used for measuring pack current only.***

Options

PackCurrentSource: Set to either **IVTS**, **Orion**, or **BMS18** if using the LEM sensor (this is because the AEM BMS18 logic is used to interpret the analog signals)

PackCurrentPolarity: Can be used to invert the signal polarity. Discharge current (out of the pack) must be a positive value and charging current (into the pack) must be a negative value

PackVoltageSource: Selects the source of the HV battery pack voltage reference; set to **IVTS**, **Orion**, or **BMS18**

Channels

BattPackCurrent: Final battery pack current value

BattPackVoltage: Final battery pack voltage value

Channels - BMS-18

PackVoltage_AEMBMS: Calculated pack voltage as reported by the AEM BMS-18 system

BattPackCellMax: Maximum cell voltage across entire pack

BattPackCellMin: Minimum cell voltage across entire pack

PackCellMinMaxDelta: Voltage difference between the minimum and maximum cell values across entire pack

PackCellAvg: Calculated average pack cell voltage

IVTS

If using the IVT-S sensor from Isabellenhuette, connect it to the CAN3 network, and configure the following options:

Options

IVTS_CurrentMsgTimeoutThr: Fault timeout in seconds for IVTS CAN signal. If the VCU does not receive the CAN signal within this timeframe, the VCU will consider the connection lost and override the value. Set to a value greater than **1** second
IVTS_CurrentDfltVal: Default pack current to be used as an override in the event of a CAN timeout

Channels

IVTS_Current: Pack current signal as reported over CAN from the IVTS
IVTS_Voltage_U1: Pack voltage as reported over CAN from the IVTS

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LEM Sensor

If using a LEM sensor, connect it according to the Hardware Pinout 11 section and configure the following options:

To increase sensitivity at low current measuring ranges, the DHAB sensors have two measurement signals within one housing. The VCU will blend between the two ranges in both positive (discharge) and negative (charge) current ranges.

Options

PackCurr_HiLo_BlendPoint: Maximum value of the sensor's low measurement range
PackCurr_HiLo_BlendPoint_Neg: Minimum (negative) value of the sensor's low measurement range
PackCurr_BlendStartRatio: Percentage of overlap between the low and high measurement ranges.
PackCurrLEM_FiltTC: Filter time in seconds for the low range signal
PackCurrLEM_Hi_Thresh: High threshold for fault detection. Refer to LEM datasheet for maximum voltage
PackCurrLEM_Lo_Thresh: Low threshold for fault detection. Refer to LEM datasheet for minimum voltage
PackCurrLEMSensitivity: Output sensitivity of the low range signal in mV/A. Refer to LEM datasheet for sensitivity value
PackCurrLEM1_FiltTC: Filter time in seconds for the high range signal
PackCurrLEM1_Hi_Thresh: High threshold for fault detection. Refer to LEM datasheet for maximum voltage
PackCurrLEM1_Lo_Thresh: Low threshold for fault detection. Refer to LEM datasheet for minimum voltage
PackCurrLEM1Sensitivity: Output sensitivity of the high range signal in mV/A. Refer to LEM datasheet for sensitivity value

Channels

PackCurrLEM: Filtered signal from the low range LEM current sensor
PackCurrLEM1: Filtered signal from the high range LEM current sensor
PackCurrBlendRatio: Will be between 0 and 1 within the blending window

Calibration Process

For our calibration example, we will use values for the LEM DHAB S/137 sensor capable of measuring +/- 75A on the low current range, and +/- 1000A on the high current range, suitable for a Tesla LDU system. If using this sensor, the calibration is configured with appropriate default values.

Performance Data channel 1						
Primary current, measuring range	$I_{PM\ channel\ 1}$	A	−75		75	
Primary nominal DC or rms current	$I_{PN\ channel\ 1}$	A	−75		75	@T_A = 25 °C
Offset voltage	V_O	V		2.5		@ U_C = 5 V
Sensitivity	G	mV/A		26.67		@ U_C = 5 V
Resolution		mV		2.5		@ U_C = 5 V
Output clamping voltage min [1]	V_{SZ}	V	0.2	0.25	0.3	@ U_C = 5 V
Output clamping voltage max [1]	V_{SZ}	V	4.7	4.75	4.8	@ U_C = 5 V
Performance Data channel 2						
Primary current, measuring range	$I_{PM\ channel\ 2}$	A	−1000		1000	
Primary nominal DC or rms current	$I_{PN\ channel\ 2}$	A	−1000		1000	@ T_A = 25 °C
Offset voltage	V_O	V		2.5		@ U_C = 5 V
Sensitivity	G	mV/A		2		@ U_C = 5 V
Resolution		mV		2.5		@ U_C = 5 V
Output clamping voltage min [1]	V_{SZ}	V	0.2	0.25	0.3	@ U_C = 5 V
Output clamping voltage max [1]	V_{SZ}	V	4.7	4.75	4.8	@ U_C = 5 V

1. Set the *PackCurr_HiLo_BlendPoint_Neg* and *PackCurr_HiLo_BlendPoint* according to the measuring range of the low current channel, e.g. **-75A** and **75A**.
2. Set the *PackCurr_BlendStartRatio* to a starting value of **25%**. The VCU will start transitioning to the high current measurement range at about 56A.
3. Configure the options in the *LEMSensor_LoRange* section and *LEMSensor_HiRange* section to suit your sensor using the information from the datasheet.
4. Once configured, monitor the internal 5V reference channel *VREF*. If necessary, an optional user offset for zero point adjustment is available. Set option *LEM_VSense_Ref_Option* to **UserCal** and adjust option *LEM_VSens_UserCal* to the measured *VREF* value to adjust the zero offset of the sensor.

5. Software filters are available to smooth the display of both LEM sensor inputs. Use the options *PackCurrLEM_FiltTC* and *PackCurrLEM1_FiltTC* to adjust the filter time constants for the low range and high range inputs respectively. Larger values will increase the filtering; smaller values will decrease the filtering.

Orion

For Orion BMS configuration, please see the 3rd Party BMS 55 section.

Enable Switch

An optional enable switch input feature is available. This can be used to override the switched power to the inverter allowing the calibrator to manually control the inverter power state. This can be helpful for initial setup and troubleshooting.

Options

EnableSwitchRequired: If **True**, the Enable Switch input can be used to override the Inverter Switched 12V Power

EnableSwHiADCThresh: Digital sensor state high ADC threshold in counts

EnableSwLoADCThresh: Digital sensor state low ADC threshold in counts

EnableSwLoTimeThresh: Time threshold for detecting the low state

EnableSwHiTimeThresh: Time threshold for detecting the high state

EnableSwPolarity: Option to invert the detection logic polarity

Channels

EnableSw: State of the enable switch input

Manual Regen Lever

An optional manual regen lever input function with dual analog inputs is available for commanding regenerative brake torque separately from the main pedal torque command map and brake pressure regen braking torque command map functions.

Options

ManualRegenX_Polarity: Option to invert the voltage slope polarity

ManualRegenX_Min: Sensor voltage calibration minimum

ManualRegenX_Max: Sensor voltage calibration maximum

ManualRegenX_Lo_Thresh: Voltage threshold for low sensor fault detection

ManualRegenX_Hi_Thresh: Voltage threshold for high sensor fault detection

Where X = 1 or 2 depending on the ManualRegen input signal

Channels

ManualRegen1_Volts: Raw voltage from the ManualRegen1 input

ManualRegen2_Volts: Raw voltage from the ManualRegen2 input

RegenLeverPosition: Final calculated position in %

Calibration Process

1. With the lever closed, monitor the channel *ManualRegenX_Volts* vs the option *ManualRegenX_Min*. Set *ManualRegenX_Min* = *ManualRegenX_Volts*.

2. With the lever fully open, monitor the channel *ManualRegenX_Volts* vs the option *ManualRegenX_Max*. Set *ManualRegenX_Max* = *ManualRegenX_Volts*.
3. Set the *ManualRegenX_Hi_Thresh* and *ManualRegenX_Lo_Thresh* slightly outside these calibration limits. These will be your fault detection thresholds.

Vehicle Speed

The VCU has 3 vehicle speed channels: Vehicle Speed, Ground Wheel Speed & Drive Wheel Speed. For direct drive applications like Tesla, vehicle speed can be calculated from motor speed, drive gear ratio and tire diameter. Ground & Wheel Speed are based on direct wheel speed sensor inputs – see Hardware Pinout 11 for wiring connections.

Options – Vehicle Speed

VehicleSpeed_InputSelection: Input selection to reference for vehicle speed channel; for Tesla drive units, select **VSS_DirectDrive**

DriveGearRatio: Final drive gear ratio

DriveTireDiameter: Tire diameter in inches

VehicleSpeedFilt: Vehicle speed signal filter; the larger the value, the more filtering is applied

Channels – Vehicle Speed

Vehicle_Speed: Speed in miles per hour

Options – Wheel Speeds

GroundWheelSpeedScaling: Scaling factor multiplied by the raw frequency to calibrate in miles per hour for non-driven wheel speed

GroundWheelSpeedFilterLevel: Filter to reduce noise. The higher the value the more dampening

DriveWheelSpeedScaling: Scaling factor multiplied by the raw frequency to calibrate in miles per hour for driven wheel speed

DriveWheelSpeedFilterLevel: Filter to reduce noise. The higher the value the more dampening

Channels – Wheels Speeds

GroundWheelSpeed: Non-driven wheel speed in miles per hour

DriveWheelSpeed: Driven wheel speed in miles per hour

Odometer

When the vehicle speed options are properly configured, the VCU will automatically calculate a total odometer value and trip odometer value. The measurement parameters *VehOdmtr* and *VehTropOdo* can be used to monitor each signal respectively. Accumulated odometer data is reset when the VCU firmware is updated. Use the calibration option *VehOdmtrInitVal* to set an initial value.

Lamps

The VCU has switch inputs for head and park lamps. The VCU lamp switch input pins are analog inputs (0-5v) thus the lamp switch input must connect to ground. The lamp switch input pins will not tolerate 12v – see Hardware Pinout 11 for more info. The lamp outputs are only supported via AEM PDUs – see PDU 33 section for more info.

Options

HeadLampSwHiADCThresh: Digital sensor state high ADC threshold in counts

HeadLampSwLoADCThresh: Digital sensor state low ADC threshold in counts

HeadLampSwLoTimeThresh: Time threshold for detecting the low state

HeadLampSwHiTimeThresh: Time threshold for detecting the high state

HeadLampSwPolarity: Option to invert the detection logic polarity

ParkLampSwHiADCThresh: Digital sensor state high ADC threshold in counts

ParkLampSwLoADCThresh: Digital sensor state low ADC threshold in counts

ParkLampSwLoTimeThresh: Time threshold for detecting the low state

ParkLampSwHiTimeThresh: Time threshold for detecting the high state

ParkLampSwPolarity: Option to invert the detection logic polarity

Channels

HeadLampSw: State of the headlamp switch input

ParkLampSw: State of the headlamp switch input

Outputs

AEM Power Distribution Units (PDUs)

The VCU output capabilities can be expanded with the addition of up to two AEM PDU-8 modules (pn 30-8300). The PDU-8 is a high current, lightweight module that is designed to be mounted near the devices requiring power. Its design philosophy is for multiple units to be part of a vehicle installation and to distribute the power throughout the vehicle rather than having it concentrated in a central area.

The PDU-8 is not a stand-alone device. It is designed to be operated as a satellite unit and controlled via CAN by either an AEM Vehicle Control Unit or a programmable 3rd party device that can generate the required CAN control messages. As such, the PDU-8 module itself is not programmable in any way and only carries out commands issued by other devices. When used with the VCU200, some output pins will offer limited user settable function assignments.

Specific PDU's are identified by grounding different combinations of configuration pins on the PDU connector. For proper function with the VCU200, the PDU-8 units must be configured as follows.

Unit ID	Config 1, Pin 24	Config 2, Pin 16	Config 3, Pin 10	Tx Msg 1 Address	Tx Msg 2 Address	Rx Msg 1 Address	Rx Msg 2 Address
1	O/C	O/C	O/C	0x000A0610	0x000A0611	0x000A0620	0x000A0630
2	Gnd	O/C	O/C	0x000A0612	0x000A0613	0x000A0621	0x000A0631

Phone (8am-5pm M-F PST): 310-484-2322
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AEM PDU-8 / VCU Functional Pin Assignments

Unit ID 1

Pin	PDU Pin Name	VCU Function	Notes
1 2	High Side Driver 1	Negative Contactor Driver	20 Amp Max
3	CAN-	VCU/PDU comms	Unterminated, VCU CAN2
4	CAN+	VCU/PDU comms	Unterminated, VCU CAN2
5	Ground		
6 7	High Side Driver 5	Peripheral switched 12V Supply Power (Inverter, Keypad, Dash)	20 Amp Max, software selectable function, See calibration option *EnableSwitchRequired*
8 9	High Side Driver 2	PreCharge Contactor Driver	10 Amp Max
10	Config 3	Leave unterminated	
11	Ground		
12 13	High Side Driver 6	High Voltage Safety Light ***or*** Drive Safe Timer ***or*** Brake Lamps Control	10 Amp Max, software selectable function, See calibration option *PDU1-Ch6_Option*
14 15	High Side Driver 3	Positive Contactor Driver	10 Amp Max
16	Config 2	Leave unterminated	
17	Not Used		
18 19	High Side Driver 7	PreCharge Contactor Driver ***or*** Parking Brake Controller	10 Amp Max, software selectable function, See calibration option *PDU1_Ch7_Option*
20 21	High Side Driver 4	Cooling Pump 1 Power ***or*** ON if Ign Sw ON ***or*** ON if Wake Sw ON	20 Amp Max, software selectable function, See calibration option *PDU1_Ch4_Option*
22	Not Used		
23	Not Used		
24	Config 1	Leave unterminated	
25 26	High Side Driver 8	Cooling Pump 1 Power	20 Amp Max

Unit ID 2

Pin	PDU Pin Name	VCU Function	Notes
1 2	High Side Driver 1	Head Lamps Driver ***or*** Drive Cooling Fan Power	20 Amp Max, software selectable function, See calibration option *PDU2_Ch1_Option*
3	CAN-	VCU/PDU comms	Unterminated, VCU CAN2
4	CAN+	VCU/PDU comms	Unterminated, VCU CAN2
5	Ground		
6 7	High Side Driver 5	Drive Cooling Fan Power	20 Amp Max
8 9	High Side Driver 2	Park Lamps Driver ***or*** DCDC Power	10 Amp Max, software selectable function, See calibration option *PDU2_Ch2_Option*
10	Config 3	Leave unterminated	
11	Ground		
12 13	High Side Driver 6	Battery Cooling Fan Power ***or*** ON if Wake Sw ON	10 Amp Max, software selectable function, See calibration option *PDU2_Ch6_Option*
14 15	High Side Driver 3	Brake Lamps Driver ***or*** ON if Ign Sw ON	10 Amp Max, software selectable function, See calibration option *PDU2_Ch3_Option*
16	Config 2	Leave unterminated	
17	Not Used		
18 19	High Side Driver 7	Oil Pump Power ***or*** Cooling Pump 1 Power ***or*** Battery Cooling Fan Power	10 Amp Max, software selectable function, See calibration option *PDU2_Ch7_Option*
20 21	High Side Driver 4	Reverse Lamps Driver ***or*** ON if Ign Sw ON ***or*** Cooling Pump 2 Power	20 Amp Max, software selectable function, See calibration option *PDU2_Ch4_Option*
22	Not Used		
23	Not Used		
24	Config 1	Ground for Unit ID 2	
25 26	High Side Driver 8	Auxiliary Power from Keypad ***or*** Cooling Pump 2 Power	20 Amp Max, software selectable function, See calibration option *PDU2_Ch8_Option*

Contactors

The VCU has outputs to control the main HV battery supply contactors including a negative contactor, inverter pre-charge contactor and positive contactor.

Note that parallel control logic exists for both the VCU's direct hardware output pins and the AEM PDU-8. See PDU Function Assignment 33 ***section.***

Negative Contactor

The negative contactor can be configured to close immediately after the VCU is in the wake state. Alternatively, the negative contactor may also be configured to only close once the pre-charge process is triggered via the Ignition input.

The VCU offers a negative contactor feedback input to check that contactor has closed. Some contactors have an AUX low current circuit that closes with the main circuit. For example, the Gigavac GXSA16BEB has this on a Deutsch DT connection on the contactor. This AUX circuit is used to send a ground signal to the VCU Negative Contactor FB input (see Hardware Pinout 11 section) to let the VCU know that the negative contactor has closed, since there is no way to detect that this actually happened. This is because the negative contactor closes first and there will be no voltage on the HV DC bus, whereas when the pre-charge or positive contactor closes, the VCU sees the HV DC bus come up to pack voltage, confirming proper contactor closure.

Options

NegContactorOption: Select **VCU_Pwr_Seq** to allow the VCU to enable the negative contactor only as part of the pre-charge process. Select **Default_On** to enable the negative contactor immediately at power up

Inverter1_NegFBRequired: Option to toggle negative contactor feedback requirement before inverter pre-charge may commence

NegContactorFBPlrty: Option to invert the detection logic polarity

Pre-Charge Contactor

The pre-charge feature adds a resistor and another contactor across the main positive contactor. When the ignition switch is turned on, the VCU will confirm the negative contactor is closed, then close the pre-charge contactor. The rate of change of DC voltage into the inverter is monitored using CAN data reported from the inverter. When the rate reduces sufficiently, the VCU closes the positive contactor. Finally, after a brief settling time, the VCU will open the pre-charge contactor. At this point, the pre-charge process is complete. Optionally, the calibrator may select to use direct pack voltage measurement as a comparison to inverter voltage for pre-charge voltage detection.

For successful control, the following pre-conditions are required:

1. No inverter faults or lockouts
2. *Fault_IMD* must be 0
3. *HVIL_Main_State* must be 1
4. *ChgPlugDetect* must be 0

Options - Standard

Inverter1_PreChargeBypassed: Option to disable the VCU pre-charge control if using an external controller

Inverter1_PreChgDetectSource: Option to use either BMS pack voltage or Inverter voltage rate detection to determine pre-charge completion

Inverter1_HVDetectPartialThr: Voltage threshold above which the VCU will consider the pre-charge process initiated. If the voltage does not exceed this value within a certain time, the pre-charge process will fail and a fault will be declared

Inverter1_HVDetectThr: Used when pre-charge control based on BMS pack voltage. Value above which high voltage is considered fully detected. Must be set below the lowest voltage the pack is expected to provide during normal operation

Inverter1_HVDetectDeltaThr: Used when pre-charge control based on BMS pack voltage. The inverter DC bus voltage must be within this delta of pack voltage for proper function

Inverter1_HVNoDetectThr: Used when pre-charge control based on BMS pack voltage. Value below which high voltage is considered not detected

PumpCheckBypassed: Optional cooling pump error check. Typically set to **Bypassed**. See Description in AEMcal for more info

Options – Advanced

Inverter1_PreChgCntrlDelayTime: Delay after closing the negative contactor

Inverter1_PreChgRetryDelayTime: Minimum delay before initiating a second pre-charge attempt

Inverter1_PreChgRetryWaitTime: Pre-charge retry wait time after an unsuccessful retry event

Inverter1_PreChgMxAttempts: Maximum number of pre-charge attempts allowed; reattempts only occur if reported inverter voltage is > *Invert1_HVDetectPartialThr* value; if no inverter voltage present after first attempt, reattempts will not occur

Inverter1_PreChgCntrlHoldTime: Hold time after closing the positive contactor. Allows voltage to settle before initiating other control processes

Inverter1_FaultTimeout: Fault timeout after pre-charge contactor closes

Inverter1_PreChgMxAttempts: Maximum number of pre-charge attempts allowed; reattempts only occur if reported inverter voltage is > *Inverter1_HVDetectPartialThr* value; if no inverter voltage present after first attempt, reattempts will not occur

Tables

Inverter1_PreChgDeltaVThresh: 1 x 2 table that defines the hysteresis values for threshold rate detection in volts/s

Channels

MC1ContEnable: If set to 1, indicates all pre-charge contactor pre-conditions are satisfied

Inverter1_NegFB: State of negative contactor feedback detection

Inverter1PreChgDeltaVDetect: Will be 1 if the delta threshold is satisfied

Inverter1_HVNoDetect: Will be 1 if high voltage is not detected

Inverter1_HVDetectPartial: Will be 1 if partial high voltage is detected

Inverter1_HVDetect: Will be 1 when high voltage is fully detected

MC1_PreChgComplete: Will be 1 when the pre-charge process is complete

Coolings Pumps and Fans

The VCU200 supports 3 different main thermal management configurations with options for different types of coolant pump and cooling fan controls. Pumps & fans may be powered by VCU triggered relays or optionally with AEM PDUs.

This section will define the different relevant software options, tables and channels but due to the numerous possible thermal management configurations, specific settings will be covered in the Thermal Control section 66.

Options – Temp Reference

InvTempRefOption: Selects either **TeslaLDU** (internal housing temp sensor before inverter) or Cascadia **PMSeries** inverter internal temp

CoolPump1TempReference: Selects cooling pump reference to be either the drive system or battery pack temp for variable speed control

Options – Cooling Pumps

CoolingPumpWakeDelay: Sets time delay in seconds between providing high current power to pump and triggering VCU low current pump wake output signal

PumpPWMOption: Selects which pump output to drive with variable PWM control

PumpCntrlFrequency: Sets variable pump drive PWM frequency in Hz

Pump1DutyTarget_Charging: Sets variable pump PWM duty to apply while HV charging is active

Pump1SpdTarget_Charging: Sets variable pump speed target to apply while HV charging is active; applies to EMP WP29/32 CAN pumps only

PDU1_Ch4_Option: Sets output function to be on with Wake Switch or Ignition Switch or Cooling Pump 1

PDU2_Ch4_Option: Sets output function to be on with Ignition Switch or Reverse Lamps or Cooling Pump 2

PDU2_Ch7_Option: Sets output function to be on with Oil Pump or Cooling Pump 1 or Battery Fan

PDU2_Ch8_Option: Sets output function to be one with Aux Power or Cooling Pump 2

CAUTION – do not use Cooling Pump 1 output from PDU 2, channel 7 to power an EMP pump!

Tables – Cooling Pumps

CoolingPumpXDutyTarget: 1 x 10 table that defines the variable pump PWM duty output based on reference temperature

CoolingPumpXSpeedTarget: 1 x 5 table that defines the variable pump speed target in rpm based on reference temperature; applies to EMP WP29/32 CAN pumps only

Where X = 1 or 2 depending on the cooling pump

Channels – Cooling Pumps

CoolingPumpXReq: Indicates the cooling pump control is requested ON; tied to status of pump wake control output pin

CoolingPumpXOn: Indicates the cooling pump high current drive command is enabled; tied to the status of pump power control (either VCU lowside output pin or PDU highside output)

PumpXSpdCntrlTempRef: Indicates the live temperature value that the pump control is referencing

CoolingPumpXTargetDuty_Out: Indicates the active variable pump PWM duty output value in percent

CoolingPumpXTargetSpeed_Out: Indicates the active variable pump speed target value in rpm

Where X = 1 or 2 depending on the cooling pump

Options – Cooling Fans

FanPWMOption: Selects which fan output to drive with variable PWM control

FanCntrlFrequency: Sets variable fan drive PWM frequency in Hz

FanDutyMax: Sets maximum allowed fan drive PWM duty in percent

PDU2_Ch1_Option: Sets output function to be on with Head Lamps or Cooling Fan (Fan 1, drive system)

PDU2_Ch6_Option: Sets output function to be on with Wake Switch or Battery Fan (Fan 2, battery system)

Tables – Cooling Fans

FanTempLimit: 1 x 2 table defines the drive system fan hysteresis on/off threshold; left cell (0) is on above value, right cell (1) is off below value

BatteryFan_TempLimit: 1 x 2 table defines the battery system fan hysteresis on/off threshold; left cell (0) is on above value, right cell (1) is off below value

FanXDutyTarget: 1 x 5 table that defines the variable fan PWM duty output based on reference temperature

Where X = 1 or 2 depending on the cooling fan

Channels – Cooling Fans

FanXReferenceTemp: Indicates the live temperature value that the fan control is referencing

FanX_State: Indicates if fan is on or off

FanXDuty_Target: Indicates the active variable fan PWM duty output value in percent

Where X = 1 or 2 depending on the cooling fan

Oil Pump

An oil pump for drive system cooling or lubrication can be controlled by the VCU. Oil pump activation is based on motor speed so anytime the motor is actively being driven, the oil pump will be turned on.

Options

OilPumpOnAbove: Sets motor speed threshold in rpm that live motor speed value must be above for oil pump to turn on

OilPumpOffBelow: Sets motor speed threshold in rpm that live motor speed value must be below for oil pump to turn off

OilPumpHiTimeThresh: Sets time in seconds that the live motor speed value must be above the on threshold before turning oil pump on

OilPumpLoTimeThresh: Sets time in seconds that live motor speed value must be below the off threshold before turning the oil pump off

Channels

OilPumpOn: Indicates the status of the oil pump function as being off or on

DCDC Converter

The VCU combined with the AEM BMS-18 allows the direct control of on-board chargers that also feature a built-in DC-to-DC converter. Check the specification of the particular VCU firmware build being used as OBC/DCDC control requirements may require varying control options.

Options

DCDC_Enable: Option to either enable or disable the VCU's DCDC control logic

DCDC_CurrentLimit: User defined current limit for DCDC; if current limit is exceeded, DCDC command output will turn off unless option *DCDCStateChkBypass* is on

DCDC_TempLimit: User defined temp limit for DCDC; if temperature limit is exceeded, DCDC command output will turn off unless option *DCDCStateChkBypass* is on

DCDCStateChkBypass: Option to ignore the state of channels *DCDC_State_OK* and *DCDC_Current_OK* and force the DCDC command output on

DCDCEff: User defined DCDC efficiency value

Battery Management Systems

A Battery Management System (BMS) is an electronic system that manages a rechargeable battery pack. When configured properly, it can protect the battery pack from unsafe operating conditions. A BMS can also communicate state variables, limit data and detailed information about individual cells.

The VCU supports the AEM EV BMS-18 40 or other 3rd party 55 battery management systems.

BMS Tech Tip

Using a battery management system is highly recommended however the VCU does offer basic current limiting protection features based on reported inverter current even if a BMS isn't being used. This is accomplished by setting the table *ItemSelect_BMS* for AEM BMS-18 and setting option *DCLCCLMethod* to **Temp Based** which will enable discharge current limit tables *DCL_PackTempHi* & *DCL_PackTempLo*. Set these tables with fairly high values to essentially disable them and then set the discharge current limit override options mentioned in Torque Limits – Inverter Current Limiting 64 in accordance to a battery pack's known current rating.

BMS-18

The AEM Battery Management System (BMS-18) is comprised of three components:

1. VCU
2. BMS-18 Master
3. BMS-18 Satellite(s)

The BMS is implemented as two different Module types: the BMS Master and the BMS Satellite. Each Module is capable of measuring up to 18 cells and 3 temperatures (thermistors) but the Master also contains the CAN communication interface and J1772 charging specific connections needed for each battery pack.

The VCU communicates with the BMS via the Master Module and all battery packs need at least one Master unit. The Satellites expand the capability of the Master by an additional 18 cells and 3 thermistors per additional Satellite connected. The Satellite Modules are connected to their Master via a high-speed serial interface (isoSPI) that allows additional units to be daisy chained together, adding up to 5 Satellites for a total of 6 Modules for the VCU200 and up to 11 Satellites for a total of 12 Modules for the VCU300.

The VCU is responsible for all BMS control logic and each individual BMS module is managed as a "group". All setup and calibration items can be modified using the AEMCal user interface.

For troubleshooting information, please see the BMS Troubleshooting Guide 85.

Basic Setup

All BMS modules have connections for 18 cell taps, 3 thermistors and the isoSPI channels. The Master module has additional connections for Power, CAN, and the J1772 charger connections. The Master receives its direction from the VCU over the CAN bus and it forwards them on to the Satellite units over a robust two-wire isoSPI datalink. The master only has an isoSPI output channel since it is the originator while the Satellites have both an input and an output channel.

Each Module can monitor from 4 to 18 cells wired in series. The cells that are monitored by one Module is called a Cell Group. The first module in the system is always a Master and referred to as Group 1. The next module in the system is called Group 2 and would be the first Satellite immediately downstream from the Master. The next Satellite would be Group 3 and so on. The

Group number assignment of a module is defined by the order in which they are attached to the Master while remembering that the Master is always Group 1.

Use the Module Enable options to enable the features for each group. *BMSM1G1Enable* will enable the Master Group 1 module. *BMSM1G2Enable* will enable the satellite Group 2 module and so on. Once the Module Enables are configured, complete the basic setup by setting the *PackData* & *CellData* options.

Table
ItemSelect_BMS: Selects the BMS configuration to be used; set right most cell to **1** to enable BMS-18

Options
PackCurrentSource: Selects the source of the HV battery pack current reference; set to **BMS18**

PackVoltageSource: Selects the source of the HV battery pack voltage reference; set to **BMS18**

BMSM1GXEnable: Option to enable each BMS module/group being used; select up to 6 for VCU200

PackMaxCapacity: Define the pack maximum capacity in Watt Hours; typically cell Amp Hours X Max Pack Voltage

PackTempFaultMax: Option to set a pack max temperature threshold; will set the status channel flag

BMS_FS_MaxPackTempFault

CellUnderVoltFaultLimit: Option to set a minimum allowed cell voltage; will set the status channel flag

BMS_FS_M1GXX_MinCellVoltsFault and is reported over CAN as *Fault_M1GXX_CellV_Min*

CellOverVoltFaultLimit: Option to set a maximum allowed cell voltage; will set the status channel flag

BMS_FS_M1GXX_MaxCellVoltsFault and is reported over CAN as *Fault_M1GXX_CellV_Max*

Voltages

Cell Voltages

Individual cell voltages are measured by each BMS module/group which are then transmitted by isoSPI to the Master BMS unit which then transmits all cell voltages on the CAN bus to the VCU.

Channels
BMSM1_GXX_CellYY: Instantaneous cell voltage where XX = group number and YY = cell number

M1GXX_CellAvg: Average cell voltage for group XX

M1GXX_SumOfCells: Sum of all individual cell voltages for group XX. Used for pack voltage calculation

M1GXX_MinIdx: Index of the minimum cell voltage value for group XX

M1GXX_Max: Maximum cell voltage value for group XX

M1GXX_MaxIdx: Index of the maximum cell voltage value for group XX

Pack Voltage

The VCU adds all series cell voltage measurements to calculate a net pack voltage and other pack stats.

Options
PackVoltageSource: Selects the source of the HV battery pack voltage reference; set to **BMS18**

Channels

PackVoltage_AEMBMS: Calculated pack voltage as reported by the AEM BMS-18 system

BattPackVoltage: Alias for *PackVoltage_AEMBMS*

BattPackCellMax: Maximum cell voltage across entire pack

BattPackCellMin: Minimum cell voltage across entire pack

PackCellMinMaxDelta: Voltage difference between the minimum and maximum cell values across entire pack

PackCellAvg: Calculated average pack cell voltage

Temperatures

External Thermistors

The resistance of 3 thermistor inputs are sampled by each BMS module/group which are then transmitted by isoSPI to the Master BMS unit which then transmits all resistance values on the CAN bus to the VCU.

It is important that the external thermistors be used since the VCU adjusts the max allowable current (both discharge and charge) based on the cell temperatures as well as alerts the user of a critical over-temp event is occurring. The thermistors supplied with each BMS module is the Vishay NTCLE413E2103F102L. Other thermistors may be substituted so long as the temperature-to-resistance calibration values are known and enter them in the VCU software. The only limitation is that all the thermistors used in the BMS must have the same calibration.

Tables

ExtTherm_Table: Calibration table for converting external thermistor resistance to temperature

Options

ExtTherm_DefaultValue: Default value used when the temperature probe is faulted. Typically set to **25** degrees C

ExtTherm_FaultHi_Thresh: High threshold for external temp sensor resistance data. Readings above this value will cause a fault flag to be set. The measured temperature data will be overridden by the *ExtTherm_DefaultValue*

ExtTherm_FaultLo_Thresh: Low threshold for external temp sensor resistance data. Readings below this value will cause a fault flag to be set. The measured temperature data will be overridden by the *ExtTherm_DefaultValue*

ExtTherm_FaultTime_Thresh: If the fault condition is true for this amount of time, the fault flag will be set

Channels

BMSM1_GXX_ThermY: Measured resistance value for external thermistor Y of group XX

M1GXX_ExtThermY: Calibrated temperature for external thermistor Y of group XX

PackTempMin: Calculated minimum temperature between all external thermistor, BMSM1_GXX_ThermY signals

PackTempMax: Calculated maximum temperature between all external thermistor, BMSM1_GXX_ThermY signals

Unused External Thermistors

In some cases, not all BMS external thermistor inputs will be used. Unused (disconnected) temperature probe inputs may indicate a fault state. Calibration options are available to mask these fault flags so they aren't transmitted over the CAN bus. ***Faults for unused probes will still display within AEMCal - this is normal.***

Options

M1GXX_ExtThermXX_FaultEnable: Set to Enabled for all external thermistor probes that are in use

Internal Temperatures
The temperature of the circuit board and microcontroller for each BMS modules/group are reported.

<u>Channels</u>
BMSM1_GXX_PCBThermY: Measured resistance value for PCB thermistor Y of group XX

M1GXX_PCBThermY: Calibrated temperature for PCB temperature Y of group XX

BMSM1_GXX_ICTemp: Reported microcontroller temperature of group XX

Pack Thermal States and Control Modes

The VCU uses the external thermistor temperature data along with user calibration settings to determine the thermal state of the pack.

<u>Tables</u>
PackTempStateThreshold: 1 x 2 table that defines a transition threshold with hysteresis. If both the *PackTempMax* and *PackTempMin* are above this threshold, the pack is considered warm. If both the *PackTempMax* and *PackTempMin* are below this threshold, the pack is considered cold. If the pack is warm, the *PackTempMax* value is used as the reference. If the pack is cold, the *PackTempMin* is used as the reference

PackActiveCoolThresh: 1 x 2 table that defines a transition threshold with hysteresis. If the reference pack temperature is above this threshold, the system is in active cooling mode

PackActiveHeatThresh: 1 x 2 table that defines a transition threshold with hysteresis. If the reference pack temperature is below this threshold, the system is in active heating mode

<u>Channels</u>
PackTempState: Cold or Warm as determined by the PackTempStateThreshold table

PackThermMode: Either Normal, Heating or Cooling. If the state is Normal, no active heating or cooling is required

Cell Open Circuit Voltage

At first look, the concept of battery open circuit voltage, or OCV, seems obvious and intuitive. Simply put, a battery's voltage is measured while in an open circuit where there is no load on the cell so there is nothing to influence the cell voltage up or down. OCV is also known as the cell's "resting" voltage.

Knowing a battery's OCV is an important part of battery management because it's representative of the battery's capacity. Battery OCV is analogous to knowing the fuel level in a fuel tank. By knowing where between 100% capacity and 0% capacity a fuel tank is, one can roughly estimate how far a vehicle can be driven if fuel consumption rate is known.

It is very easy to quantify fuel level in a fuel tank because it is directly measured and typically changes at a slow and steady rate. The difficulty in knowing a battery's OCV is that OCV can only be directly measured when there is no load but it is important to try and track the battery's OCV at all times – even when under load and being discharged or charged.

The VCU uses two methods for finding a battery cell's OCV:
1) By directly sampling the cell voltage when there is little to no load being applied
2) Calculating a cell's OCV using a predictive algorithm

By default, the BMS logic will quickly sample all cell OCVs at wake on as this is the best time to assume the pack is at rest or very nearly so. The values are also updated as part of the charging process when pack current is closely controlled.

Once the pack is under load, the BMS calculates and adjusts the cell OCV data over time as charge leaves or enters the pack. Accurate OCV data under load is important for discharge and charging current limit calculations (DCL/CCL) as well as State of Charge or SOC.

The following equations are used to predict cell open circuit voltage while under load:

Cell OCV Max = Instantaneous Max Cell Voltage + (Pack Current * Min Cell Resistance)
Cell OCV Min = Instantaneous Min Cell Voltage + (Pack Current * Min Cell Resistance)

The quality of the predicted OCV data while under load is dependent on the accuracy of the resistance data for each individual cell which is described in the next section.

Channels

M1GXX_CellOCVXX: Measured individual cell open circuit voltage values

BMSM1_G01_CellOCV_Min: Calculated minimum cell open circuit voltage

BMSM1_G01_CellOCV_Max: Calculated maximum cell open circuit voltage

Cell Resistance

Temperature corrected, individual cell resistance data is used to track the health of the pack and to calculate charge and discharge current limits during run time. Cell resistance values are calculated real time during the charging cycle when pack current is relatively steady and within a specified range. If real time calculated cell resistance data is not available, the BMS logic uses a nominal resistance value.

Tables

CellRNomTable: 7x7 2D table that defines nominal cell resistance in milliohms as a function of pack temperature and state of charge

CellRCorrFactorTable: 7x7 2D table that defines a correction factor for calculated cell resistance as a function of pack temperature and state of charge

Options

CellRPackCurrHi: Used with *CellRPackCurrLo*. Pack current must be greater than CellRPackCurrLo and less than CellRPackCurrHi in order to update the internal cell resistance values

CellRPackCurrLo: Used with *CellRPackCurrHi*. Pack current must be greater than CellRPackCurrLo and less than CellRPackCurrHi in order to update the internal cell resistance values

CellRKFactor: Weighting factor for cell resistance estimation. CellR = (Previous CellR * CellRKFactor)+((1-CellRKFactor)*New CellR)

Channels

M1GXX_CellRXX: Individual cell resistance values in milliohms

M1GXX_CellRMin: Group minimum cell resistance

M1GXX_CellRMinIdx: Index of group minimum cell resistance

M1GXX_CellRMax: Group maximum cell resistance

M1GXX_CellRMaxIdx: Index of group maximum cell resistance

M1GXX_CellRSum: Sum of group cell resistance values

PackCellRMax: Maximum cell resistance across the entire pack

PackCellRMin: Minimum cell resistance across the entire pack

PackCellRMinMaxDelta: Difference between the pack min and pack max cell resistance

PackResistance: Total pack resistance

Cell Resistance Sampling

If you know a cells OCV and you can measure the pack current and instantaneous individual cell voltages, you can calculate each cells individual resistance using Ohm's Law where I = V/R or by rearranging this equation, R = V/I. The cells individual resistance is equal to the voltage change divided by the current. To get the most accurate data, the BMS logic calculates these resistances when the pack is being charged and the current is relatively steady. To do this, the BMS logic must know when to make this calculation during charging.

Use the options *CellRPackCurrHi* and *CellRPackCurrLo* to define this range. Remember that charging current is defined as a negative value. If your measured charging current is 8 amps for example, set these two values to -3.0 and -15.0 respectively to ensure reliable capture during charging. The BMS will only make this individual resistance calculation during charging. New cell resistance values are determined using a weighted averaging algorithm. The option *CellRKFactor* can be used to adjust this weighting. A value of 0.01 will result in 1% of the new value being combined with 99% of the previous value. A value of **0.01** is a good starting point for *CellRKFactor*.

There are two 2D tables that can be used to further define your pack cell resistance behavior. The *CellRNomTable* can be used to define a starting point for the cell resistance data. If you do not know your cell resistance value, a good starting point is something between **0.9** and **1.0** milliohms. Cell resistance will also vary vs temperature. An optional *CellRCorrFactor* table is included if you want to further optimize the system. A value of 1.00 will result in no correction. A value greater than 1.00 will increase the calculated resistance. A value of less than 1.00 will decrease the calculated resistance.

Cell Resistance Fault – Note that during initial BMS use, the system will indicate that there is a cell resistance fault. Because cell resistances are only sampled while charging, the fault will be active until a charging has commenced at which point the fault state will reset.

Bus Bar Compensation

If bus bars or other high voltage interface cables are used to connect distributed battery modules, bus bar compensations may be necessary. These adjustments apply an offset equal to the added resistance of each interconnect bar or cable when a single BMS module is used to span more than one battery module. Up to two bus bar compensations are available for each BMS-18 module.

Options

M1GX_BusBarComp1Idx: [1 – 18] cell index where the first compensation is applied

M1GX_BusBarComp2Idx: [1 – 18] cell index where the second compensation is applied

M1GX_BusBarResComp1: Resistance compensation in milliohms. Applied to the cell index defined by *M1GX_BusBarComp1Idx*

M1GX_BusBarResComp2: Resistance compensation in milliohms. Applied to the cell index defined by *M1GX_BusBarComp2Idx*

The raw voltage channels transmitted on the CAN bus from the BMS-18 Master will not reflect the bus bar compensation values as they're only applied in post-processing in the VCU. This means that the instantaneous cell voltages, average cell voltages and sum of cell voltages from all BMS groups will show an uncompensated value in either a live dash display or data log.

Channels

M1GXX_Min: Minimum cell voltage value for group XX

M1GXX_Max: Maximum cell voltage value for group XX

Current Limits

Another important aspect of battery management is the tailoring of charge and discharge current limits to control state of charge or depth of discharge to prevent either a cell over- or under-voltage condition.

Discharge Current Limits

High power output e-propulsion drivetrains can apply incredibly high levels of load and draw hundreds of amps of current from a battery pack. The VCU offers two types or levels of current limit checks to control battery discharge. One can be thought of as an instantaneous or "short-term" discharge limit and the other a more "long-term" discharge limit where the discharge rate is reduced over time as the battery's capacity is depleted. This is done to observe a cell's depth of discharge limit and respect a cell's absolute minimum allowed voltage to prevent cell damage and maximize cell life.

The instantaneous or short-term current limit is applied and controlled through the inverter current limit subsystem. See the Torque Limits - Inverter Current Limiting 64 section. If the inverter's reported current is ever greater than the final battery DCL, the inverter current limiting ramp feature is used to reduce the live max motor torque allowed value in order to also reduce discharge current. Note that the inverter current limiting multiplier target and ramp rate options must be calibrated for optimal response.

Options

DCLCCLMethod: Setting to Temp Based will use the values of the *DCL_PackTempHi* & *DCL_PackTempLo* tables as the discharge current limit. The DCL table values will be applied as the actual live discharge current limit if less than option *BattDCL_cal*. Setting to **CellR** Based enables the long-term discharge current limit calculation using the VCU's predictive OCV algorithm and by knowing cell resistance.

Tables

DCL_PackTempLo: 1x5 table defining discharge current limits as a function of low pack temperature

DCL_PackTempHi: 1x5 table defining discharge current limits as a function of high pack temperature

CellR Based DCL

The long-term discharge current limit uses individual cell resistance data, cell open circuit voltage data and a cell under volt limit calibration option to calculate a discharge current limit based on Ohm's Law. Once every few seconds, the VCU calculates a cell's available voltage discharge capacity as the difference between the current OCV and the desired under volt limit. The discharge current available within the active calculation loop is found by dividing the cell's available voltage discharge capacity by cell resistance. It is very important to note that this value is based on a calculated discharge capacity and can result in a DCL that's much higher than a battery pack's max discharge limit – especially when cell/pack voltage is high. As the battery's capacity is depleted and OCV starts to decrease, the long-term calculated DCL will also decrease. When the long-term calculated DCL becomes less than option *BattDCL_cal* or any other lower DCL values, it will become the final live DCL target.

Options

CellUnderVoltLim: Limit minimum cell voltage for long-term DCL calculation

Channels

BattPackDCL: Masks either the discharge current limit from AEM BMS-18 or Orion BMS to be the observed DCL based on value of table *ItemSelect_BMS*; compared to option *BattDCL_cal* and the lower value becomes the final DCL

BattDCLFinal: Final pack discharge current limit; the lowest value from any DCL calculators is passed through as the final DCL

Charge Current Limits

The VCU uses the same strategies mentioned above for discharge current limiting for charge current limiting (CCL). If *DCLCCLMethod* is set to Temp Based, the values of the *CCL_PackTempHi* & *CCL_PackTempLo* tables as the charge current limit. The DCL table values will be applied as the actual live charge current limit if less than option *BattCCL_cal*. If *DCLCCLMethod* is set to **CellR** Based, the charge current limit calculations are made using the VCU's predictive OCV algorithm and by knowing cell resistance.

Tables

CCL_PackTempLo: 1x5 table defining charge current limits as a function of low pack temperature

CCL_PackTempHi: 1x5 table defining charge current limits as a function of high pack temperature

Options

CellOverVoltLim: Limit maximum cell voltage for long-term CCL calculation

Channels

BattPackCCL: Masks either the charge current limit from AEM BMS-18 or Orion BMS to be the observed CCL based on value of table *ItemSelect_BMS*; compared to option *BattCCL_cal* and the lower value becomes the final CCL
BattCCLFinal: Final pack charge current limit; the lowest value from any CCL calculators is passed through as the final CCL

Direct Inverter Current Control

This feature is an optional predictive algorithm that uses the parameters listed below to calculate a live theoretical electrical power limit. This power limit is then converted to a torque limit based on motor speed. Note that direct inverter current control should not be enabled until all standard BMS18 features are set up and functioning correctly.

Reference Channels

BattPackOCVolts: Reports the final battery pack open circuit voltage value

BattPackResistance: Reports the total additive battery pack resistance

Inverter1_MCL: Final inverter motoring current limit; reports the lower of (*BattDCLFinal-HVAccCur*) and *Inverter1_MCL_cal*; see Torque Limits - Inverter Current Limiting 64

Inverter1_GCL: Final inverter generating current limit; reports the lower of (*BattCCLFinal+HVAccCur*) and *Inverter1_GCL_cal*

Maps

Inverter1_MtrEffMap: Map that represents the efficiency of the inverter's DC input power and the motor's mechanical output power

Tables

Inverter1_ElecPwrLim: Table that reports the VCU's live calculated inverter power limit; ***NOT A USER EDITABLE TABLE***

Inverter1_TrqLim: Table that reports the VCU's live calculated inverter torque limit; live calculated inverter power limit and motor speed are referenced to find inverter torque limit; ***NOT A USER EDITABLE TABLE***

Motor1_TrqLimCur: Table that reports the VCU's final live calculated motor torque limit; live calculated inverter torque limit is modified by the *Inverter1_MtrEffMap* value to find final motor torque limit; ***NOT A USER EDITABLE TABLE***

Option

Motor1_TrqLimCurEnbl: Option to enable or disable the direct inverter current control function; do not enable until all standard BMS18 features are functioning as expected

Motor1_TrqLimCurMultp: Mutliplier to either increase or decrease the final calculated motor torque limit value; a value of 1 makes no change, 0.9 reduces the torque limit by 10% and 1.1 increases the torque limit by 10%

Channel

VehiclePower_Battery: Total battery electrical power in kW; *VehiclePower_Battery = BattPackVoltage* x *BattPackCurrent*

Energy Tracking

Accurate pack current data is critical for tracking energy in and out of the battery pack. An accumulator algorithm tracks this energy flow as a function of Battery Efficiency when the measured pack current is outside a specified dead band. Battery Efficiency is a broadly applied term and a complex subject. There are several ways to express it. One of the most significant factors affecting Battery Efficiency is current. As such, the Battery Efficiency data used by the BMS is a function of pack current.

Table

BatteryEfficiencyTable: 5 x 1 table defining Battery Efficiency as a function of pack current; generally, higher current values result in less efficient transfer and vice versa.

Options

PackMaxCapacity: Battery pack max capacity in Wh; used for energy consumption and state of charge calculations.

OCVNoLoadPackCurrHi: Used with *OCVNoLoadPackCurrLo*; pack current must be greater than *OCVNoLoadPackCurrHi* and less than *OCVNoLoadPackCurrLo* for the energy accumulator to start

OCVNoLoadPackCurrLo: Used with *OCVNoLoadPackCurrHi*; pack current must be greater than *OCVNoLoadPackCurrHi* and less than *OCVNoLoadPackCurrLo* for the energy accumulator to start

The options above define a dead band. Within the dead band, the load on the pack is considered very low (nearly zero) and during this time, cell open circuit voltages are allowed to be sampled. Outside of this range, the load on the pack is considered high enough to trigger the energy accumulator algorithm.

Channels

PackCapacityConsumed: Capacity consumed in kWh since last full charge. This value will increase during discharging and decrease during charging.

PackCapacityConsumed_Outing: Capacity consumed in kWh during the current VCU wake cycle. This value will increase during discharging and decrease during charging.

PackCapacityRemaining: Remaining pack capacity equal to (*PackMaxCapacity*/1000)-*PackCapacityConsumed*.

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Energy_Accum: Reports the accumulated energy in Wh since the last full charge; value will increase while discharging and decrease while charging (including during regenerative braking)

Energy_Accum_Outing: Reports the accumulated energy in Wh of the current outing; an outing is defined as a VCU wake on/off cycle; value will increase while discharging and decrease while charging (including during regenerative braking)

The Energy Tracking Process

Tracking energy in to and out of the pack is challenging. Losses and data inconsistencies can create errors. There's no one size fits all solution. The *BatteryEfficiencyTable* can be used to define the relationship between efficiency and pack current. Generally, the lower the current, the higher the efficiency and vice versa. The default settings for this table should represent a good starting point but diligent testing and trial and error is needed for the best results.

Charge tracking will never be accurate unless it is started from a known condition. That known condition is a fully charged pack. When the pack is fully charged, charge accumulators are reset and tracking can begin. Monitor the channels *Energy_Accum* and *Energy_Accum_Outing*. These reflect the accumulated energy in Wh since the last full charge and the current outing respectively. An outing is defined as a VCU wake on/off cycle. While discharging, these measurements should increase. While charging, these measurements should decrease. This includes periods of regenerative braking.

In an ideal world, the *Energy_Accum* counter will increase during periods of discharge to some value. When the charge cable is plugged in and the vehicle begins to charge, the counter will decrease and reach exactly zero at the exact point at which the pack is fully charged. This is rarely the case. However, backend VCU logic will not allow this counter to cross over and accumulate negative energy. It will always be clipped very close to zero. To optimize the tracking, monitor this behavior during charging cycles and adjust the *BatteryEfficiencyTable* until the *Energy_Accum* counter reaches zero as close as possible to the fully charged threshold. ***This will require trial and error.***

Once the energy accumulation settings are optimized, the VCU/BMS should be able to estimate the vehicle's range or distance remaining. See the Range Estimation 50 section for more information.

Energy Consumption Rates

Energy consumption rate data is calculated on a per trip (or outing) basis as well as a long-term value that is learned over time. A trip odometer value is used to calculate the short-term value. Total vehicle accumulated miles, or total odometer data is used for the long term learned consumption rate algorithm. Once enough long-term driving data is accumulated, the short-term data can be compared to see how well the vehicle is currently performing relative to the long-term data.

Options

VehTripOdoMin_Consumption: The minimum distance that must be driven before the short-term energy consumption rate data is updated; when any trip is started, the vehicle will always use a very high amount of energy to go a relatively short distance

VehicleMovingThreshold: Minimum speed above which the vehicle is considered to be moving

Channels

VehTripOdo: Distance traveled during the current outing or trip; is measured during the current VCU wake cycle

VehicleOdometer: Total distance traveled; odometer data is reset if the VCU firmware is upgraded

EnergyConsRate_LT: Long term energy consumption rate in Wh/mile; this data is a rolling average that is learned over time

PackConsumptionRate_Outing_Avg: Short term or outing-based energy consumption rate in Wh/mile

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Range Estimation

Estimated range data is determined based on several different sources. When energy consumption rate data is not available, a user calibration table is used by default. This table defines the range based on pack temperature and state of charge. Once energy consumption rate data is available, the range is determined based on either short- or long-term energy consumption data combined with a pack usable capacity ratio.

Table

Range_SOC_Cal_Table: User calibration table for range vs state of charge and pack temperature; table data will be used as default when energy consumption rate data is unavailable.

Options

PackUsableCapacityRatio: Percentage of total pack capacity available for estimating range
RangeConsumption_Type: Option for using either long-term or short-term consumption rate data for determining range

Channel

DistanceRemainingEst: Estimated remaining range

The Range Estimation Process

Once the energy accumulation settings are optimized, the VCU/BMS should be able to estimate the vehicle's range or distance remaining. Keep in mind that this is an estimate and should never be relied upon in critical situations. Use the calibration option *PackUsableCapacityRatio* to define a fraction of the pack's capacity available for range estimation. A value of 0.85 means you are allowing 85% of the total capacity for estimating range.

The option *RangeConsumption_Type* can be used to choose what type of consumption rate data to use for the range estimation. The options are Short Term or Long Term. Short Term consumption rate data can be tracked by monitoring the channel *EnergyConsRate_ST*. Long Term energy consumption rate data can be tracked by monitoring the channel *EnergyConsRate_LT*. The short term data resets for every outing. The long term data is learned over time and represents an average. AEM recommends using the long term data as the reference for range estimation.

When no learned data is available, the calibration table *Range_SOC_Cal_Table* will be used as a default. This table allows the calibrator to define a range estimate to define a range estimate as a function of SOC and pack temperature. Monitor the channel *DistanceRemainingEst* for the current range estimation.

State of Charge

Battery state of charge (SOC) cannot be directly measured. Many methods exist to estimate state of charge. The AEM BMS system relies on a hybrid method that combines energy accumulation, or Coulumb counting, with user calibration data. The Coulomb counting method measures the discharging current of a battery and integrates the discharging current over time in order to estimate SOC. This method alone works well but the data may diverge over time due to pack current measurement errors or slight offsets very close to zero amps. The hybrid method employs a user defined calibration table that allows direct SOC data entry versus pack temperature and the minimum pack open circuit voltage. The values from direct Coulomb counting measurement are combined with the entries in this table using a weighted averaging algorithm. This way, depending on the application requirements, the calibrator can decide whether to prioritize OCV measurements, Coulomb counting measurements or a combination of both.

Tables

PackSOC_KFactor: 1 x 6 table of weight factor data as a function of minimum cell open circuit voltage. Used to merge energy accumulated state of charge data with user calibration table data. This is a value between 0 and 1. The higher the value, the more weight is applied to the user calibration table data. The lower the value, the more weight is applied to the energy accumulated state of charge data.

SOC_Cal_Table: 6 x 6 table of user state of charge data versus minimum cell open circuit voltage and pack temperature. This data is also used by default when no energy accumulation data is available.

Channels

BattPackSOC: Masks either *PackSOC_Final* from AEM BMS-18 or *Pack_SOC* from Orion BMS to be the observed pack SOC based on value of table *ItemSelect_BMS*

PackSOCEst: Pack state of charge based purely on energy accumulation data.

PackSOC_Final: Weighted-averaged, estimated State of Charge (SOC). *PackSOC_Final* = (*SOC_Cal_Table***PackSOC_KFactor*)+((1-*PackSoc_KFactor*)**PackSOCEst*)

Cell Balancing

To minimize heat generation in the BMS modules, the 18 cell balancing circuits have been broken into three thermal regions. No more than 1 cell from each region can be balanced at one time. Each Module can balance up to 3 cells at once. The regions are cells 1-5, cells 6-11, and cells 12-18 for each group. In addition, cells 5 and 6 will never be balanced at the same time since the balancing resistors are physically near each other. A cell will never be balanced if its voltage is less than the *PackCellAvg* value. Balancing is only allowed during a charging cycle. VCU features ensure the system honors these limitations. Once cells are selected for balancing, they will be balanced for a 60 second cycle time. After that, the system will reset and select a new group of cells to balance.

Options

BalCellVoltThreshHi: Cell voltage must be over this value to allow balancing

BalCellVoltThreshLo: Cell voltage must be over this value to allow balancing. Generally, you don't balance a cell that is in the lower 50% of its capacity

BalPackVoltMin: Pack voltage must be above this value to allow balancing

BalGroupDeltaThresh: If the min/max pack cell voltage delta is within this range, balancing will stop

BalanceCmdCal: User calibration to enable/disable balancing

Channels

BMSM1_GXX_Balancing_CXX: If equal to 1, the cell is currently balancing

M1GXX_TZ1MaxCell: Thermal zone 1 max cell index

M1GXX_TZ1MaxCellVal: Thermal zone 1 max cell value

M1GXX_TZ2MaxCell: Thermal zone 2 max cell index

M1GXX_TZ2MaxCellVal: Thermal zone 2 max cell value

M1GXX_TZ3MaxCell: Thermal zone 3 max cell index

M1GXX_TZ3MaxCellVal: Thermal zone 3 max cell value

On Board Charger Support

CAN data from supported OBC and combo OBC/DCDC nodes is captured and processed by the VCU. The health and temperature states are continuously analyzed. If any parameter is abnormal or outside allowed limits, charging will be stopped or prevented from starting.

Options

Charger_TempLimit: Reported OBC on board temperature must be below this threshold to allow charge control functionality

DCDC_TempLimit: Reported DCDC on board temperature must be below this threshold to allow control functionality

DCDC_Enable: Used to Enable or Disable DCDC logic control

DCDCStateChkBypass: Can be used to bypass reported DCDC health state signals. ***Use with caution***

DCDC_CurrentLimit: Reported DCDC current must be below this threshold to allow control functionality

Channels

OBC_State_OK: Will indicate Yes when no fault flags are reported, otherwise will indicate No

OBC_Temp_OK: Will indicate Yes when reported charger on board temp is below the *Charger_TempLimit*, otherwise will indicate No

DCDC_State_OK: Will indicate Yes when no fault flags are reported, otherwise will indicate No

DCDC_Temp_OK: Will indicate Yes when reported charger on board temp is below the *DCDC_TempLimit*, otherwise will indicate No

DCDC_Current_OK: Will indicate Yes when reported charger current is below the *DCDC_CurrentLimit*, otherwise will indicate No

ChargePwrHold: When Enabled, this flag indicates the VCU power sequencing is being managed by the charging logic

DCDCPwrHold: When Enabled, this flag indicates the VCU power sequencing is being managed by the charging logic

Charge Management

The first step in charge management is determining the state of the J1772 plug or simply the “J plug”. The AEM BMS-18 Master module transmits the J1772 Proximity Voltage to the VCU. This signal is arbitrated and used to identify the J plug state. Once the J plug state is determined, this signal is combined with others to determine if the charging process should be allowed to commence.

Options

PackVoltage_FullyCharged: Sets the final pack voltage target to achieve while charging

FullChargedRangeDelta: Adjustment to account for certain on-board chargers that automatically reduce charging current near the setpoint; reduces *PackVoltage_FullyCharged* by the value set; high pack voltage threshold reported as channel PackChargeRefHi

PackVoltage_ChargeResetDelta: Defines a low pack voltage threshold to give charge allowed hysteresis; low pack voltage threshold reported as channel *PackChargeRefLo*

ChargeCurrTarget: Sets an override charge current value; final charging current is the minimum value of ChargeCurrTarget and tables CP_ChargeCurrLookup & *ChargeTargetTable*

PackChargingCellOverVoltLim: Sets the cell voltage high threshold to disable charging; if any individual cell exceeds this value, charging will be stopped

PackChargingCellUnderVoltLim: Sets the cell voltage low threshold to enable charging; if any individual cell is below this value, charging will not be enabled

ChargeRestTime: Defines the period of time for the system to pause/rest once the target charging voltage has been achieved and charging has stopped; charging will re-enable once timer expires

ChargeShutDownDelay: Defines the period of time for the system to pause once the target charging voltage has been achieved and charging has stopped; the charge process will completely stop once timer expires

ChargeTopBalance: Setting to allow automatic and continual pack charging "top off"; if enabled charging process will cycle and repeat each time charging is stopped after achieving target charge voltage; if disabled charging process will stop after achieving target charge voltage

Tables

CP_ChargeCurrLookup: 1 x 6 table of charge current versus CP Duty %; allows for the automatic detection of off-board charger current limitations

ChargeTargetTable: 7 x 7 table that provides the option of varying the charge current versus both pack voltage and pack temperature

Channels

J1772ProxState: Reports the current status of the J plug; will be Undefined, Disconnected, Proximity or Locked

CState1: Reports the OBC health and temperature states; will be 1 when OBC State is OK for charging otherwise will be 0

CState2: Currently reserved for future use; defaults to 1

CState3: Reports that the VCU Operating State is OK for charging; will be 1 if true otherwise will be 0; channel *OpState* must be 0, 1 or 14 to allow charging

CState4: Reports state of channel *PackChargeState_Full*; will be 1 if state is Yes otherwise will be 0; see options above for settings to adjust *PackChargeState_Full* conditions

CState5: Reports state of option *PackChargingCellOverVoltLim* condition threshold; will be 1 when there are no individual cell voltages above the limit otherwise will be 0

CState6: Reports state of option *PackChargingCellUnderVoltLim* condition threshold; will be 1 when there are no individual cell voltages below the limit otherwise will be 0

CState7: Reports state of pack thermal mode; will be 1 if pack thermal mode is Normal otherwise will be 0; channel *PackThermMode* must be Normal to allow charging

CState8: Reports state of J1772 Pilot Duty value to allow charging; will be 1 if Control Pilot Duty Cycle is within the normal range otherwise will be 0; VCU will inhibit charging is J plug is connected but offboard charger is disabled

PackChargeRefHi: Indicates the upper pack voltage charge threshold range; threshold set by option *PackVoltage_FullyCharged* minus option *FullyChargedRangeDelta*

PackChargeRefLo: Indicates the lower pack voltage charge threshold range; threshold set by channel *PackChargeRefHi* minus option *PackVoltage_ChargeResetDelta*

PackChargeState_Full: Indicates pack charge state; will be Yes when pack voltage >*PackChargeRefHi* and will be No when pack voltage <*PackChargeRefLo*; when Yes, resets the energy accumulation counter to zero

ChargingAllowed: If all charge allowed criteria is met, will be 1 otherwise will be 0

ChargingState: Indicates charging state as Off, On or Rest; will be Off if charging inhibited, On if charging active and Rest if charging is resting based on option *ChargeRestTime* once target voltage has been reached and charging has stopped

ChargeSum_Total: Reports the total accumulated charge in Amp Hours; will increase when discharging and decrease when charging; is adjusted by the *BatteryEfficiency* value

ChargeTime_Hours/Minutes: Reports the estimated time to charge completion based on *ChargeSum_Total* Amp Hour value and live pack current Amp value; *ChargeSum_Total [Ah]/PackCurrent [A]* = *ChargeTime_Hours* + *ChargeTime_Minutes*

The Charging Process

When the J1772 plug is connected, the charging process is initiated. If all State criteria above are met, the measurement channel *ChargingAllowed* will toggle to 1. The basic charging sequence is outline below:

1. Delay as pack load is checked and the VCU ensures the cell voltages are stable. After this check, all individual cell open circuit voltages are sampled.
2. EVSE Enable command is sent to the off-board charger. This will connect AC line voltage to the on-board charger.
3. VCU ensures the Pilot Duty Cycle is within the proper range.
4. Charging command is sent to the on-board charger along with target voltage and current. The charging current target is determined by finding the minimum from the following calibration sources:

- *CP_ChargeCurrLookup* - table
- *ChargeTargetTable* - table
- *ChargeCurrTarget* - option

5. Delay as the VCU waits for the charging current to stabilize. After this check, all individual cell resistances are calculated.
6. Charging will stop when the target voltage is reached. The measurement channel *ChargingState* will transition from On to Rest. The system will rest for a period of time defined by the calibration option *ChargeRestTime*. Once the *ChargeRestTime* timer expires, charging will begin again. *ChargingState* will transition from Rest to On. This cycle will continue indefinitely if the calibration option *ChargeTopBalance* is enabled. If *ChargeTopBalance* is disabled, the charging process will shut down after the *ChargeShutDownDelay* timer expires.

Detect System Faults

For additional troubleshooting information, please see the BMS Troubleshooting Guide 85.

Fault	Meaning	Calibration Options
BMS_FS_M1GXX_ExtThermX_InputHi	External thermistor resistance too high	*ExtTherm_FaultHi_Thresh* *ExtTherm_FaultTime_Thresh*
BMS_FS_M1GXX_ExtThermX_InputLo	External thermistor resistance too low	*ExtTherm_FaultLo_Thresh* *ExtTherm_FaultTime_Thresh*

BMS_FS_M1GXX_PCBThermX_InputHi	Internal thermistor resistance too high	*PCBTherm_FaultHi_Thresh* *PCBTherm_FaultTime_Thresh*
BMS_FS_M1GXX_PCBThermX_InputLo	Internal thermistor resistance too low	*PCBTherm_FaultLo_Thresh* *PCBTherm_FaultTime_Thresh*
BMS_FS_M1GXX_MinCellResFault *M1GX_CellRMinIdxDat*	Cell resistance too low …IdxDat will display which cell is currently faulted	*PackCellUnderResLim*
BMS_FS_M1GXX_MaxCellResFault *M1GX_CellRMaxIdxDat*	Cell resistance too high …IdxDat will display which cell is currently faulted	*PackCellOverResLim*
BMS_FS_M1GXX_MinCellVoltsFault *M1GX_MinIdxDat*	Cell voltage too low …IdxDat will display which cell is currently faulted	*CellUnderVoltFaultLim*
BMS_FS_M1GXX_MaxCellVoltsFault *M1GX_MaxIdxDat*	Cell voltage too high …IdxDat will display which cell is currently faulted	*CellOverVoltFaultLim*
BMS_FS_M1_SummaryFault	Internal fault detected by BMS Master	N/A
BMS_FS_M1_NumGroupsMismatchFault	Number of groups found does not match the number of enabled groups	*BMSM1GXEnable*
BMS_FS_BMS_12V_Supply_Fault	VCU measured 12 volt bus voltage below the fault threshold	*LVBusMinThresh*
BMS_FS_BMS_CAN_Fault	VCU to BMS Master CAN timeout exceeded	*MSG_0x01DD1000MsgTimeoutThr*
BMS_FS_PackCurrLEM_InputHi	Low range sensor input too high	*PackCurrLEM_Hi_Thresh* *PackCurrLEM_Hi_Time_Thresh*
BMS_FS_PackCurrLEM_InputLo	Low range sensor input too low	*PackCurrLEM_Lo_Thresh* *PackCurrLEM_Lo_Time_Thresh*
BMS_FS_PackCurrLEM_InputHi	High range sensor input too high	*PackCurrLEM1_Hi_Thresh* *PackCurrLEM1_Hi_Time_Thresh*
BMS_FS_PackCurrLEM_InputLo	High range sensor input too low	*PackCurrLEM1_Lo_Thresh* *PackCurrLEM1_Lo_Time_Thresh*
BMS_FS_ChargerFault	Fault state detected and reported by on board charger	N/A
BMS_FS_DCDCFault	Fault state detected and reported by DCDC	N/A
BMS_FS_MaxPackTempFault	Maximum pack temperature as measured by external thermistors above threshold	*PackTempFaultMax*

3rd Party BMS

Orion BMS

When an Orion BMS is used with the VCU200 the following features are possible:

- Inverter Pre-charge using measured battery pack voltage as a reference
- Torque request deratings based on battery pack discharge, pack high temp, pack low temp, cell voltage min, cell voltage max, pack state of charge % (SOC) and overall pack voltage.
-

For the VCU200 to communicate with the BMS properly, the following CAN configurations are required:

Orion BMS2

VCU CAN channel: CAN 3
Byte Order: Motorola
Baud Rate: 500k

Message: 0x6B0

Signal	Start bit	Length (bit)	Value Type	Factor	Offset	Min	Max
Pack_Current	8	16	Signed	.1	0	-3276.8	3276.7
Pack_Inst_Voltage	24	16	Unsigned	.1	0	0	6553.5
Pack_SOC	32	8	Unsigned	.5	0	0	127.5
MPI2_State	40	1	Unsigned	1	0	0	1
MPI3_State	41	1	Unsigned	1	0	0	1
MPO2_State	43	1	Unsigned	1	0	0	1
MPO3_State	44	1	Unsigned	1	0	0	1
MPO4_State	45	1	Unsigned	1	0	0	1
MP_Enable_State	46	1	Unsigned	1	0	0	1
MPO1_State	47	1	Unsigned	1	0	0	1
Discharge_Relay_State	48	1	Unsigned	1	0	0	1
Charge_Relay_State	49	1	Unsigned	1	0	0	1
Charger_Safety_State	50	1	Unsigned	1	0	0	1
MIL_State	51	1	Unsigned	1	0	0	1
MPI1_State	52	1	Unsigned	1	0	0	1
AlwaysOn_State	53	1	Unsigned	1	0	0	1
Is_Ready_State	54	1	Unsigned	1	0	0	1
Is_Charging_State	55	1	Unsigned	1	0	0	1

Message: 0x6B1

Signal	Start bit	Length (bit)	Value Type	Factor	Offset	Min	Max
Pack_DCL	8	16	Unsigned	1	0	0	65535
Pack_CCL	24	16	Unsigned	1	0	0	65535
Pack_High_Temp	32	8	Signed	1	0	-128	127
Pack_Low_Temp	40	8	Signed	1	0	-128	127

Message: 0x6B2

Signal	Start bit	Length (bit)	Value Type	Factor	Offset	Min	Max
Pack_Low_Cell_Voltage	8	16	Unsigned	0.0001	0	0	6.5535
Pack_High_Cell_Voltage	24	16	Unsigned	0.0001	0	0	6.5535
J1772_Plug_State	32	8	Unsigned	1	0	0	255

Once the Orion BMS has been configured accordingly, configure the VCU calibration according to the following settings:

Options

PackCurrentSource: Selects the source of the HV battery pack current reference; set to **OrionBMS**

PackVoltageSource: Selects the source of the HV battery pack voltage reference; set to **OrionBMS**

Tables
ItemSelect_BMS: Selects the BMS configuration to be used; set left most cell to **1** to enable Orion BMS

Channels
Pack_Current: Pack current as reported by the Orion BMS

Pack_Inst_Voltage: Pack voltage

Pack_Low_Cell_Voltage: Lowest reported cell voltage across the entire pack

Pack_High_Cell_Voltage: Highest reported cell voltage across the entire pack

Derate Features
The VCU has 7 Torque Limit Derate Multiplier tables that can derate either the motoring or generating torque command limit based on data transmitted by the Orion BMS - see Torque Limits - Inverter Current Limiting 64 section.

HV Charger
Because the Orion BMS handles the interfacing and controlling of the HV charger directly, the state of the charger isn't immediately known by the VCU. This results in the BMS and charger attempting to charge the HV battery even while the VCU is off. Additionally, this means that systems like contactor control and thermal management control will not be active thus HV contactors will not close and cooling pumps/fans will not run. ***It is suggested that while HV charging with an Orion BMS that the VCU's wake switch be turned on to support the charging process.***

Control Modes

OpState

The VCU operates as a state machine with specific status indicators for the startup and shutdown process. Safety logic inhibits transitions from one state to another unless certain conditions are true. The following list of channel values is very helpful for troubleshooting unexpected behavior.

Channels
Opstate: VCU startup and shutdown state:

1 = VCU On, Waiting...
2 = Negative Contactor Command
3 = Motor PWM Enable
4 = Direct Drive Start Safe
5 = Direct Drive Run
6 = Direct Drive Shutdown
7 = Indirect Drive Start
8 = Indirect Drive Run
9 = Indirect Drive Shutdown
10 = Indirect Drive Stop Command
11 = Motor PWM Disable
12 = Discharge Command
13 = Discharge Complete
14 = Motor Control Power Off
15 = Motor PWM Disable
16 = Discharge Command

Drive Mode

Drive mode arbitration logic exists for safety. A transition from park to any other drive mode is not allowed unless the brake pedal is depressed and detected by the brake switch input. Charge plug detection will also inhibit transitions between park and other drive modes.

Options

DriveMode_Speed_ZeroThr: Vehicle speed must be below this value to allow transition to park

DriveMode_Speed_LoThr: Vehicle speed must be below this value to allow transition between neutral, drive and reverse

Channels

ChgPlugDetect: Charge plug detection state

Drive_Mode: Final state of the drive mode arbitration logic

Start Safe

Start Safe arbitration logic exists for safety. Before a non-zero torque command is allowed, certain criteria must be met. Once State Safe is true, the driver may select DriveMode 1 (reverse) or 3 (drive) and non-zero torque commands can be sent to the inverter.

Options

APPStartSafeHiThresh: Maximum allowed pedal position for transition to run mode

APPStartSafeLoThresh: Minimum allowed pedal position for transition to run mode

Channels

Start_Safe: Will be 1 when all following criteria are met:

Fault_IMD must be 0

BrakeSwitch must be 1

ChgPlugDetect must be 0

Drive_Mode_State must be 0 or 2 (park or neutral)

AccelPedal must be in *APPStartSafe* threshold window

Run_Mode_State: Will go from 0 to 2 for direct drive run mode once *Start_Safe*=1

Torque Control

One of the main functions of a vehicle control unit is to provide a torque control request to the inverter over CAN. Generally, inverters or motor controllers have their own built in safety limits. These are defined for each applicable motor type and they are established during the complex process of motor calibration. Motor calibration is not the same as VCU torque request calibration. Motor calibration data is defined in the inverter control software and establishes much lower level control parameters. VCU torque request calibration is a much higher level task. The VCU calibrator uses the tools available in the VCU calibration software to define options and tables that result in a torque request at different operating conditions. This torque request is sent to the inverter over CAN. If the resultant signal is within the torque control limits of the inverter, it will be allowed and used for control.

The VCU has three primary levels or tiers of torque control (as well as some additional secondary controls). The first tier is to establish a base torque command based on the motors available torque per rpm and voltage per accelerator pedal position. This first torque command is checked against a max torque command limit or cap. The second tier is to control or limit the torque commands rate of change or how quickly (or slowly) a change in the torque command is allowed to occur. The third tier is to then apply a decreasing multiplier to "derate" the motors output based on some other condition.

The VCU treats motoring (motor consuming current and creating torque to propel the vehicle) torque control as positive or the high or "hi" torque command. Generating (motor creating current and absorbing torque for regenerative braking) torque control is treated as negative or the low or "lo" torque command.

Important torque command channels to monitor:

Motor1_TqLimMultHi: High torque (motoring) limit derate multiplier; values range from 0-1.00; 1.00 means no derating, 0.90 means a 10% reduction, etc., applied to *Motor1_TqLimHi*

Motor1_TqLimHi: Resultant motoring torque limit based on the active high torque limit multiplier value

Motor1_TqLimMultLo: Low torque (generating) limit derate multiplier; values range from 0-1.00; 1.00 means no derating, 0.90 means a 10% reduction, etc., applied to *Motor1_TqLimMultLo*

Motor1_TqLimLo: Resultant generating torque limit based on the active low torque limit multiplier value

Motor1_Torque_Request: The final torque command that is actively sent to the inverter; motoring torque commands are positive and generating torque commands are negative

Base Torque Command

Motoring and Generating

The first step in the torque control process is to establish a base motor torque command before applying any primary torque command caps, torque command rate of change limits or torque command derate multipliers. Additional torque command requests exist for specific drive modes such as creep and reverse.

Tables

Motor1TorqueTrimTable: Placeholder for eventual torque vectoring algorithms. The x-axis is motor speed. A value of 1.00 in this table is no change. A value of 0.50 in this table would cut the Base Torque Request in half

Maps

Motor1TorqueTable: The main table for defining the base motor performance characteristics. The x-axis is motor speed. The y-axis is inverter DC voltage and the table units are Nm. This information is typically provided by the motor manufacturer

PedalTorqueMultTableX: Commonly referred to as the pedal map; map is a percent multiplier vs motor speed on the x-axis and accelerator pedal position on the y-axis. ***Both positive and negative numbers are possible which allows for basic control of regenerative braking from within the same table***. There are four of these tables available where the X in the table name is 1 -4. Each table corresponds to a different Performance Level. The Performance Level driver input is selectable using the AEM CAN keypad.

Channels

Motor1TorqueTableOut: Raw torque request target from *Motor1TorqueTable*

PedalTqMult: Final pedal multiplier. Actual table output depends on Performance Level Selection

How quickly the motoring torque command is allowed to change is set by the Torque Command Rate of Change Limits 61

Creep and Reverse

The VCU has a user selectable creep mode that allows the vehicle to "creep" forward slowly after releasing the brake from a stop without applying the accelerator pedal similar to how an ICE vehicle with automatic transmission operates. There is also a separate torque request control based on accelerator pedal position when in reverse.

Options

CreepModeAllowed: User enable for creep mode

CreepModeAPPThresh: Maximum accelerator pedal position to allow creep mode

Tables

Motor1CreepTorqueTable: Motor torque request based on vehicle speed when creep mode is active; overrides the current base motoring torque command

CreepModeVehSpdThresh: Vehicle speed thresholds for creep mode; left cell sets off above setting and right cell sets on below setting to give hysteresis

Motor1ReverseTorqueTable: Motor torque request based on accelerator pedal position when the reverse drive direction is active; overrides the current base motoring torque command

How quickly the creep or reverse torque command is allowed to change is set by the Torque Command Rate of Change Limits 61

Regenerative Braking

The *PedalTorqueMultTable* map allows for both positive and negative values which allows for basic control of regenerative braking from within the same table. In most cases controlling both motoring and generating torque commands from the main pedal map is sufficient but there is an additional optional generating torque control function.

Options

RegenAllowedCal: User enable to make optional regen braking function active

BrakingTqAxisSelect: Selectable y-axis input for the *RegenBrakeTorqueMap*; maybe either brake pressure or manual regen lever position

BrakeSwRegenReq: Sets if brake switch is required for regen brake torque command to be active

RegenPedalThreshold: Sets maximum accelerator pedal position threshold for regen brake torque command to be active

RegenVSSThreshold: Sets minimum vehicle speed threshold for regen brake torque command to be active

Tables

Motor1_TrqLimMultpSpeed: 1x2 table gives hysteresis motor speed threshold to force regen torque to zero when below; left cell sets off above speed (regen torque allowed) and right cell sets on below speed (regen torque forced to zero)

Maps

RegenBrakeTorqueMap: Optional table for fine tuning the regenerative braking feature. The x-axis is motor speed and the y-axis is selectable from either Brake Pressure or the Manual Regen Lever input using option *BrakingTqAxisSelect*. Certain activation criteria must be true for this table to work:

1. Vehicle Speed must be greater than the calibration option RegenVSSThreshold
2. If the calibration option BrakeSwRegenReq is set to Yes, the Brake Switch input must be triggered

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3. The Accelerator Pedal Position must be less than the calibration option RegenPedalThreshold
4. The calibration option RegenAllowedCal must be set to Enabled

Channels
RegenBrakeTorqueMap_Output: The active regen torque command from the *RegenBrakeTorqueMap* in Nm

Torque Command Rate of Change Limits

The VCU's live torque command value is very dynamic and actively changing and with an electric motors capability of making large amounts of torque in less then one motor shaft revolution, the result can be an undesired roughness to the vehicle operation. To combat this, the VCU has user adjustable torque request rate of change limiters for both increasing and decreasing torque requests that allows for fine tuning of the torque delivery rate.

Torque Rate Limits - Performance Level

One user tunable aspect of the Performance Level function is having the capability of having different motor torque request rate of change limits per Performance Level selection (1-4).

Tables
MtrTrqReqLimIncTblX: 1x5 table that sets the increasing motor torque command rate of change limit in Nm/sec based on vehicle speed; setting all tables to the same values will effectively "disable" this feature and will ensure that the torque command rate of change limit does not change regardless of the active Performance Level selection

MtrTrqReqLimDecTblX: 1x5 table that sets the decreasing motor torque command rate of change limit in Nm/sec based on vehicle speed; setting all tables to the same values will effectively "disable" this feature and will ensure that the torque command rate of change limit does not change regardless of the active Performance Level selection
Where X = 1, 2, 3 or 4 depending on the active Performance Level selection

The Performance Level function is always active even if an AEM CAN keypad is not being used. Check channel Performance_Level to verify the active Performance Level selection.

Torque Rate Limits - Creep and Reverse

Creep and reverse both use the same torque command rate of change limit values.

Tables
MtrTqReqLimIncTbl_RC: 1x5 table that sets the increasing motor torque command rate of change limit in Nm/sec based on vehicle speed when creep or reverse are active

MtrTqReqLimDecTbl_RC: 1x5 table that sets the decreasing motor torque command rate of change limit in Nm/sec based on vehicle speed when creep or reverse are active

Torque Limits

Once a base torque command value has been made, which represents the highest possible torque request that can be made in any one instance, the torque request value is checked against several limits or caps. Some limits are based on user selection for simple on-the-fly changes in motor torque output while others are based on other operating conditions to decrease or derate the motors performance as a safety factor.

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Torque Limits - Global

All base torque commands and possible derate limits are capped by a global torque command limit. The global torque limits will override and limit all other torque command limits.

Tables

Motor1_TrqLim_cal: 1x2 table that sets the absolute maximum allowed torque request; all other torque limits are limited by this table value; left cell sets the motoring/positive or high torque limit and the right cell sets the generating/negative or low torque limit in Nm

Torque Limits - Performance Level

One user tunable aspect of the Performance Level function is having the capability of having different motor torque limits per Performance Level selection (1-4).

Tables

Motor1TrqLim_CalTableX: 1x11 table that sets the maximum allowed torque command based on motor speed; setting all tables to the same values will effectively “disable” this feature and will ensure that the motor torque limit does not change regardless of the active Performance Level selection
Where X = 1, 2, 3 or 4 depending on the active Performance Level selection

Channels

Motor1_TrqLim_CalTableOutX: Reports the live motor torque command limit from the active motor torque limit table in Nm

The Performance Level function is always active even if an AEM CAN keypad is not being used. Check channel Performance_Level to verify the active Performance Level selection.

Torque Limits - Derate Multipliers

Dynamic torque limiters provide safety as well as performance optimization. All multipliers are compared and the ***minimum value is always chosen***. Derate multipliers either apply to the motoring/positive/high torque limit or the generating/negative/low torque limit. Generally, a value of 1.00 in a *TrqLimMultp* table means no change, 0.90 is a 10% reduction, 0.75 is a 25% reduction, etc. The motor rev limit function is also applied as a variable multiplier that’s applied or ramped in over time.

Tables – High Torque Limit Multiplier

MtrTrqLimMultpBattSOCLoTbl: 1x7 table sets maximum allowed motoring torque command based on battery state of charge

MtrTrqLimMultpPackVoltageTbl: 1x7 table sets maximum allowed motoring torque command based on battery voltage

MtrTrqLimMultpCellVoltMinTbl: 1x7 table sets maximum allowed motoring torque command based on battery’s lowest single cell voltage

MtrTrqLimMultpPackTempHiTbl: 1x7 table sets maximum allowed motoring torque command based on battery temperature when temps are high

MtrTrqLimMultpPackTempLoTbl: 1x7 table sets maximum allowed motoring torque command based on battery temperature when temps are low

MtrTrqLimMultpVehSpdHi: 1x7 table sets maximum allowed motoring torque command based on vehicle speed

Inverter1_TrqLimMultpTempTbl: 1x7 table sets maximum motoring allowed torque command based on the reported inverter temperature

Motor1_TrqLimMultpTempTbl: 1x7 table sets maximum motoring allowed torque command based on the reported motor temperature

Tables – Low Torque Limit Multiplier

MtrTrqLimMultpBattSOCHiTbl: 1x7 table sets maximum allowed generating torque command based on battery state of charge

MtrTrqLimMultpCellVoltMaxTbl: 1x7 table sets maximum allowed generating torque command based on battery's highest single cell voltage

MtrTrqLimMultpVehSpdLo: 1x7 table sets maximum allowed generating torque command based on vehicle speed

Most derate tables have two channels associated with them: a status channel and a table value channel. The status channel reports that any single derate is active whenever its live table values is <1.00. This is a handy and quick indicator of whether any derate functions are currently active.

Channels

LimMultBattSOCHi_Active
LimMultBattSOCLo_Active
LimMultPackVoltage_Active
LimMultCellVoltMax_Active
LimMultCellVoltMin_Active
LimMultPackTempHi_Active
LimMultPackTempLo_Active
LimMultVehSpdHi_Active
LimMultVehSpdLo_Active
MtrTrqLimMultpBattSOCHi
MtrTrqLimMultpBattSOCLo
MtrTrqLimMultpPackVoltage
MtrTrqLimMultpCellVoltMax
MtrTrqLimMultpCellVoltMin
MtrTrqLimMultpPackTempHi
MtrTrqLimMultpPackTempLo
MtrTrqLimMultpVehSpdHi
MtrTrqLimMultpVehSpdLo

The following diagram summarizes the logic flow:

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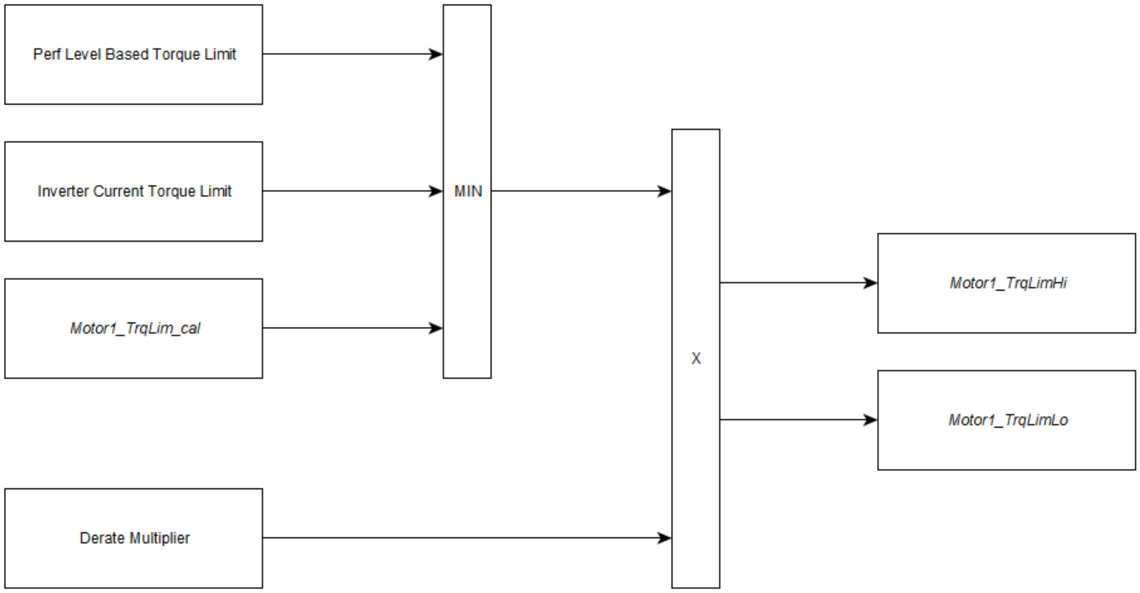

Motor Rev Limit

The VCU can apply a rev limit to prevent over speeding the motor or to limit the speed of the vehicle. The rev limiter function has two different operation types however only the ramping rev limit feature should be used with the Tesla's AC induction motors.

Options

MotorRevLimitCntrl: Set to **RampLimit** for all Tesla AC induction motors

MotorRevLimit: Sets the desired maximum motor speed to limit to

MotorRevLimitWindow: Sets the rpm threshold where the rev limit function starts to activate

RevLimMultRampRate: Sets the rate at which the rev limit derate multiplier is ramped in; a higher value will ramp in the derate multiplier more quickly and a lower value will ramp in more slowly

RevLimMultRampMax: Sets the maximum derate factor that the rev limit derate multiplier is allowed to ramp to; a lower value means larger torque reduction factor can be applied

Torque Limits - Inverter Current Limiting

The VCU200 has an inverter current limit ramp function that can reduce the inverter's motoring torque command to limit DC current draw in accordance with an observed Discharge Current Limit (DCL). The observed DCL may come from one of two sources: either as an internal calculation in the VCU itself if using an AEM BMS-18 or externally communicated over CAN from a third party BMS such as an Orion BMS 2. The inverter current limit ramp function becomes active anytime the inverter's reported DC current draw is greater than the live DCL value. There are optional current limit overrides that allow the user to supplant a calculated limit with user settable limits as a "backstop" should erroneous current limit values ever be calculated.

Channels

PackDCL: The VCU's calculated discharge current limit based on pack/cell data provided by the AEM BMS-18.

Pack_DCL: The discharge current limit transmitted to the VCU by an Orion BMS.

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BattPackDCL: Masks either *PackDCL* or *Pack_DCL* to be the observed DCL based on value of table *ItemSelect_BMS*; gets compared to option *BattDCL_cal* and the lower value becomes the final DCL

Pack_DCLim: The final pack discharge current limit

The live battery pack discharge current limit is reported as *Pack_DCLim*. With no correction for any additional current draw from HV accessories (DCDC, HV heater, HV A/C compressor, etc) and no current limit override values applied, the VCU's inverter current limit ramp function will reduce the inverter's motoring torque command anytime inverter DC current > *Pack_DCLim*.

Options

Inverter1_CurLimRampMultTarget: Sets the torque reduction multiplier target used when inverter current limit ramp function is active; a value of **0.5** has shown to work well

Inverter1_CurLimRampRate: Sets the change in ramp multiplier per internal loop time; a value of **0.001** has shown to work well

The inverter current limit ramp function reduces the inverter's motoring torque command by applying the option *Inverter1_CurLimRampMultiTarget* to the *Motor1_TqHiLimHi* value. This is a multiplier value that should be a number less than 1 in order to reduce the maximum allowed motoring torque command. The current limit is applied progressively or "ramped" in based on the option *Inverter1_CurLimMultiRampRate*. A higher *Inverter1_CurLimMultiRampRate* value will ramp in the derate multiplier more quickly and a lower value will ramp in more slowly. When the inverter current limit ramp function is no longer actively limiting, the derate multiplier will be ramped back out to a value of 1 at the same ramp rate.

Options

Inverter1_MCL_cal: User calibration for inverter motoring current limit in Amps

Channels

Inverter1_MCL: Final inverter motoring current limit; reports the lower of (*Pack_DCLim-HVAccCur*) and *Inverter1_MCL_cal*

The inverter current limit ramp function becomes active anytime inverter DC current is greater than the value of channel *Inverter1_MCL*. The *Inverter1_MCL* channel will report the lower value of either the "net" DC current available to the inverter for motoring based on *Pack_DCLim* minus additional current draw from HV accessories (DCDC, HV heater, HV A/C compressor, etc) or the override option *Inverter1_MCL_cal*. The override is useful in the case where HV accessory load may not be accurately reported and a lower inverter motoring current limit is desired.

Options

Inverter1_RampCurLimCal: User calibration for maximum allowed inverter DC current; compares this value to channel *Inverter1_MCL* and applies the lower as the current limit

The current limit ramp function itself has its own current limit override option. The value from channel *Inverter1_MCL* is compared to option *Inverter1_RampCurLimCal* and the lower value becomes the threshold for activating the inverter current limit ramp function. This override is useful in the case where a known inverter current limit is desired regardless of the observed discharge current limit.

Option

BattDCL_cal: User calibration for battery discharge current limit; compares this value to channel *BattPackDCL* and applies the lower as the battery's discharge current limit

The observed battery pack discharge current limit (The VCU's calculated long-term battery pack discharge limit) can be supplanted with a lower current limit using override option *BattDCL_cal*. The lower value between channel *BattPackDCL* and the option *BattDCL_cal* is passed through and reported as *Pack_DCLim*. This override is useful in the case where a lower known battery discharge current limit is desired regardless of what the observed discharge current limit might be. When using the BMS-

18, the VCU's long term calculated DCL based on cell OCV will typically start out at values much higher than a pack's realistic DCL. It is important to have a reasonable *BattDCL_cal* value as this will be the more "instantaneous" DCL applied until *PackDCL* decreases to be less than *BattDCL_cal* as the battery is discharged.

Thermal Control

The VCU200 supports 3 different main thermal management configurations with options for different types of coolant pump and cooling fan controls. Pumps and fans may be powered by VCU triggered relays or optionally with AEM PDUs. The 3 main configurations are as follows:

Thermal Management Configurations

1. Single coolant pump, drive system conditioning only 66. Coolant pump is assigned as Cooling Pump 2. This configuration would have a liquid cooled drive system but aircooled battery system components (battery, OBC, DCDC, etc).
2. Single coolant pump, drive and battery system combined in single conditioning loop 67. Coolant pump is assigned as Cooling Pump 1. This configuration would have liquid cooled drive and battery system components and assumes that all devices operate around a common acceptable temperature that a single conditioning loop can manage.
3. Two coolant pumps, drive and battery system in independent conditioning loops 69. The battery conditioning pump is assigned as Cooling Pump 1 and the drive system conditioning pump is assigned as Cooling Pump 2. This configuration would have liquid cooled drive and battery system components that operate at potentially very different temperatures thus requiring separate, independently controlled conditioning loops.

The VCU200 supports both variable pump speed control or standard on/off operation. Variable pump speed is done with either EMP WP29/32 pumps via direct CAN control or with PWM controlled pumps. The VCU can operate two variable speed EMP pumps via CAN however there is only a single output pin from the VCU to control a variable speed PWM pump.

The VCU's two pump control functions have both one lowside and one highside output pin assigned to them. For CAN or PWM pumps, the lowside output is used to trigger a relay to provide higher current pump power and the highside output is used as a low current pump "wake" signal. If using standard on/off pumps, either of these outputs can be used to trigger a relay for pump power.

Variable pump speed control via PWM assumes that a pump with integrated PWM control is being used.
While it may be possible to variably control a standard on/off type pump using a solid-state relay, setup and configuration of such an arrangement is beyond the scope of this document.

The VCU supports standard on/off operation of two cooling fans as well as variable speed control of a single cooling fan using PWM control. Variable PWM speed control could be accomplished using a fan speed controller such as a Calsonic Kansei controller or a solid-state relay, however setup and configuration of such an arrangement is beyond the scope of this document.

Single Loop - Drive System Only

Coolant pump is assigned as Cooling Pump 2 and is activated whenever the Ignition Switch is enabled. Cooling fan is assigned as Cooling Fan 1 with activation based on FanTempLimit table values.

On/Off Pump Without PDU

Use either pin J1-C4, Cooling Pump 2 Control (lowside) or pin J1-K3, Cooling Pump 2 Wake Control (highside) to trigger a relay to power the pump.

On/Off Pump With PDU

Cooling Pump 2 can be assigned to PDU 2, channels 4 & 8 (20A rating each – can be combined for 40A rating). Set options *PDU2_Ch4_Option* & *PDU2_Ch8_Option* to **CoolingPump2**.

PWM Pump Without PDU

Use either pin J1-C4, Cooling Pump 2 Control (lowside) or pin J1-K3, Cooling Pump 2 Wake Control (highside) to trigger a relay to provide high current power to the pump. Use pin J1-G4 as the PWM signal to the pump. Set option *PumpPWMOption* to **PumpDuty2** and set the *CoolingPump2DutyTarget* table pump duty values accordingly. Note that *CoolingPump2DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*.

PWM Pump With PDU

Cooling Pump 2 can be assigned to PDU 2, channels 4 & 8 (20A rating each – can be combined for 40A rating) to provide high current power to the pump. Set options *PDU2_Ch4_Option* & *PDU2_Ch8_Option* to **CoolingPump2**. Use pin J1-G4 as the PWM signal to the pump. Set option *PumpPWMOption* to **PumpDuty2** and set the *CoolingPump2DutyTarget* table pump duty values accordingly. Note that *CoolingPump2DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*.

EMP WP29/32 Pump Without PDU

Configure pump's CAN rx address to 0x18EF8BA3 (pump 2). The pump's high current power is wired directly to 12v battery positive through an appropriately sized fuse. Use pin J1-K3 (highside) as low current 12v wake signal to pump. Set the *CoolingPump2SpeedTarget* table pump speed values accordingly. Note that *CoolingPump2SpeedTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*.

EMP WP29/32 Pump With PDU

Configure pump's CAN rx address to 0x18EF8BA3 (pump 2). Cooling Pump 2 can be assigned to PDU 2, channels 4 & 8 (20A rating each – must be combined to power EMP pump) to provide high current power to the pump. Set options *PDU2_Ch4_Option* & *PDU2_Ch8_Option* to **CoolingPump2**. Use pin J1-K3 (highside) as low current 12v wake signal to pump. Set the *CoolingPump2SpeedTarget* table pump speed values accordingly. Note that *CoolingPump2SpeedTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*.

On/Off Fan Without PDU

Use pin J1-D3 (lowside) to trigger a relay to power the fan. Set *FanTempLimit* table drive system temp activation points accordingly.

On/Off Fan With PDU

Cooling Fan 1 can be assigned to PDU 2, channels 1 & 5 (20A rating each – can be combined for 40A rating). Set option *PDU2_Ch1_Option* & *PDU2_Ch5_Option* to **CoolingFan**. Set *FanTempLimit* table drive system temp activation points accordingly.

PWM Fan Without PDU

Use pin J1-D3 (lowside) to trigger a relay to provide high current power to the fan. Use pin J1-H3 as the PWM signal to the fan. Set option *FanPWMOption* to **FanDuty1** and set the *Fan1DutyTarget* table fan duty values accordingly. Note that *Fan1DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *Coolant_Temp1*.

PWM Fan With PDU

Cooling Fan 1 can be assigned to PDU 2, channels 1 & 5 (20A rating each – can be combined for 40A rating) to provide high current power to the fan. Set option *PDU2_Ch1_Option* & *PDU2_Ch5_Option* to **CoolingFan**. Use pin J1-H3 as the PWM signal to the fan. Set option *FanPWMOption* to **FanDuty1** and set the *Fan1DutyTarget* table fan duty values accordingly. Note that *Fan1DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *Coolant_Temp1*.

Single Loop - Drive and Battery System Combined

Coolant pump is assigned as Cooling Pump 1 and is activated when Ignition Switch or DCDC activation or EVSE (charging "J" plug) is enabled. Cooling fan is assigned as Cooling Fan 1 with activation based on *FanTempLimit* table values.

On/Off Pump Without PDU

Use either pin J1-K1, Cooling Pump 1 Control (lowside) or pin J1-K4, Cooling Pump 1 Wake Control (highside) to trigger a relay to power the pump.

On/Off Pump With PDU

If using lower current pump (<10A), Cooling Pump 1 can be assigned to PDU 2, channel 7. Set option *PDU2_Ch7_Option* to **CoolingPump1**. If using higher current pump (>10A), Cooling Pump 1 can be assigned to PDU 1, channels 4 & 8 (20A rating each – can be combined for 40A rating). Set option *PDU1_Ch4_Option* & *PDU1_Ch8_Option* to **CoolingPump1**.

PWM Pump Without PDU

Use either pin J1-K1, Cooling Pump 1 Control (lowside) or pin J1-K4, Cooling Pump 1 Wake Control (highside) to trigger a relay to provide high current power to the pump. Use pin J1-G4 as the PWM signal to the pump. Set option *PumpPWMOption* to **PumpDuty1** and set option *CoolPump1TempReference* to **DriveTemp** to make *CoolingPump1DutyTarget* table active temp reference the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*. Set the *CoolingPump1DutyTarget* table pump duty values accordingly. A different fixed pump duty target value to use while charging can be set with option *Pump1DutyTarget_Charging*.

PWM Pump With PDU

If using lower current pump (<10A), Cooling Pump 1 can be assigned to PDU 2, channel 7. Set option *PDU2_Ch7_Option* to **CoolingPump1**. If using higher current pump (>10A), Cooling Pump 1 can be assigned to PDU 1, channels 4 & 8 (20A rating each – can be combined for 40A rating). Set option *PDU1_Ch4_Option* & *PDU1_Ch8_Option* to **CoolingPump1**. Use pin J1-G4 as the PWM signal to the pump. Set option *PumpPWMOption* to **PumpDuty1** and set option *CoolPump1TempReference* to **DriveTemp** to make *CoolingPump1DutyTarget* table active temp reference the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*. Set the *CoolingPump1DutyTarget* table pump duty values accordingly. A different fixed pump duty target value to use while charging can be set with option *Pump1DutyTarget_Charging*.

EMP WP29/32 Pump Without PDU

Configure pump's CAN rx address to 0x18EF20A3 (pump 1). The pump's high current power is wired directly to 12v battery positive through an appropriately sized fuse. Use pin J1-K4 (highside) as low current 12v wake signal to pump. Set option *CoolPump1TempReference* to **DriveTemp** to make *CoolingPump1SpeedTarget* table active temp reference the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*. Set the CoolingPump1SpeedTarget table pump speed values accordingly. A different fixed pump speed target value to use while charging can be set with option *Pump1SpdTarget_Charging*.

EMP WP29/32 Pump With PDU

Configure pump's CAN rx address to 0x18EF20A3 (pump 1). Cooling Pump 1 can be assigned to PDU 1, channels 4 & 8 (20A rating each – must be combined to power EMP pump) to provide high current power to the pump. Set option *PDU1_Ch4_Option* & *PDU1_Ch8_Option* to **CoolingPump1**. Use pin J1-K4 (highside) as low current 12v wake signal to pump. Set option *CoolPump1TempReference* to **DriveTemp** to make *CoolingPump1SpeedTarget* table active temp reference the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*. Set the *CoolingPump1SpeedTarget* table pump speed values accordingly. A different fixed pump speed target value to use while charging can be set with option *Pump1SpdTarget_Charging*.

CAUTION – do not use Cooling Pump 1 output from PDU 2, channel 7 to power an EMP pump!

On/Off Fan Without PDU

Use pin J1-D3 (lowside) to trigger a relay to power the fan. Set *FanTempLimit* table drive system temp activation points accordingly.

On/Off Fan With PDU

Cooling Fan 1 can be assigned to PDU 2, channels 1 & 5 (20A rating each – can be combined for

40A rating). Set option *PDU2_Ch1_Option* & *PDU2_Ch5_Option* to **CoolingFan**. Set *FanTempLimit* table drive system temp activation points accordingly.

PWM Fan Without PDU

Use pin J1-D3 (lowside) to trigger a relay to provide high current power to the fan. Use pin J1-H3 as the PWM signal to the fan. Set option *FanPWMOption* to **FanDuty1** and set the *Fan1DutyTarget* table fan duty values accordingly. Note that *Fan1DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *Coolant_Temp1*.

PWM Fan With PDU

Cooling Fan 1 can be assigned to PDU 2, channels 1 & 5 (20A rating each – can be combined for 40A rating) to provide high current power to the fan. Set option *PDU2_Ch1_Option* & *PDU2_Ch5_Option* to **CoolingFan**. Use pin J1-H3 as the PWM signal to the fan. Set option *FanPWMOption* to **FanDuty1** and set the *Fan1DutyTarget* table fan duty values accordingly. Note that *Fan1DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *Coolant_Temp1*.

Dual Loop

The battery system conditioning loop's coolant pump is assigned as Cooling Pump 1 and the drive system conditioning loop's coolant pump is assigned as Cooling Pump 2. Cooling Pump 1 is activated when Ignition Switch or DCDC activation or EVSE (charging "J" plug) is enabled. Cooling Pump 2 is activated whenever the Ignition Switch is enabled. Cooling Fan 1 is used on the drive system conditioning loop and is activated based on *FanTempLimit* table values. Cooling Fan 2 is used on the battery system conditioning loop and is activated based on *BatteryFan_TempLimit* table values.

On/Off Pump Without PDU

Use either pin J1-K1, Cooling Pump 1 Control (lowside) or pin J1-K4, Cooling Pump 1 Wake Control (highside) to trigger a relay to power the battery conditioning pump. Use either pin J1-C4, Cooling Pump 2 Control (lowside) or pin J1-K3, Cooling Pump 2 Wake Control (highside) to trigger a relay to power the drive system conditioning pump.

On/Off Pump With PDU

If using lower current pump (<10A), Cooling Pump 1 can be assigned to PDU 2, channel 7. Set option *PDU2_Ch7_Option* to **CoolingPump1**. If using higher current pump (>10A), Cooling Pump 1 can be assigned to PDU 1, channels 4 & 8 (20A rating each – can be combined for 40A rating). Set option *PDU1_Ch4_Option* & *PDU1_Ch8_Option* to **CoolingPump1**. Cooling Pump 2 can be assigned to PDU 2, channels 4 & 8 (20A rating each – can be combined for 40A rating). Set options *PDU2_Ch4_Option* & *PDU2_Ch8_Option* to **CoolingPump2**.

PWM Pump Without PDU

When using two cooling pumps, the VCU can variably control one of them with PWM. Use either pin J1-K1, Cooling Pump 1 Control (lowside) or pin J1-K4, Cooling Pump 1 Wake Control (highside) to trigger a relay to power the battery conditioning pump. Use either pin J1-C4, Cooling Pump 2 Control (lowside) or pin J1-K3, Cooling Pump 2 Wake Control (highside) to trigger a relay to power the drive system conditioning pump. Use pin J1-G4 as the PWM signal to the pump being variably controlled. Option *PumpPWMOption* can be set to either **PumpDuty** 1 or **PumpDuty2**. If set to **PumpDuty1** to vary the battery cooling pump, set option *CoolPump1TempReference* to **PackTemp** and *CoolingPump1DutyTarget* table will reference the battery pack temperature as reported by the BMS. Set the *CoolingPump1DutyTarget* table pump duty values accordingly. A different fixed pump duty target value to use while charging can be set with option *Pump1DutyTarget_Charging*. If *PumpPWMOption* is set to **PumpDuty2**, *CoolingPump2DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*. Set the *CoolingPump2DutyTarget* table pump duty values accordingly.

PWM Pump With PDU

When using two cooling pumps, the VCU can variably control one of them with PWM. If using lower current pump (<10A), Cooling Pump 1 can be assigned to PDU 2, channel 7. Set option *PDU2_Ch7_Option* to CoolingPump1. If using higher current pump (>10A), Cooling Pump 1 can be assigned to PDU 1, channels 4 & 8 (20A rating each – can be combined for 40A rating). Set option *PDU1_Ch4_Option* & *PDU1_Ch8_Option* to **CoolingPump1**. Cooling Pump 2 can be assigned to PDU 2, channels 4 & 8

(20A rating each – can be combined for 40A rating). Set options *PDU2_Ch4_Option* & *PDU2_Ch8_Option* to **CoolingPump2**. Use pin J1-G4 as the PWM signal to the pump being variably controlled. Option *PumpPWMOption* can be set to either **PumpDuty** 1 or **PumpDuty2**. If set to **PumpDuty1** to vary the battery cooling pump, set option *CoolPump1TempReference* to **PackTemp** and *CoolingPump1DutyTarget* table will reference the battery pack temperature as reported by the BMS. Set the *CoolingPump1DutyTarget* table pump duty values accordingly. A different fixed pump duty target value to use while charging can be set with option *Pump1DutyTarget_Charging*. If *PumpPWMOption* is set to **PumpDuty2**, *CoolingPump2DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp*. Set the *CoolingPump2DutyTarget* table pump duty values accordingly.

EMP WP29/32 Pump Without PDU

The VCU200 can control two EMP WP29/32 CAN pumps. Configure one pump as Cooling Pump 1 for battery system conditioning and set its CAN rx address to 0x18EF20A3. Configure the other pump as Cooling Pump 2 for drive system conditioning and set its CAN rx address to 0x18EF8BA3. The pump's high current power is wired directly to 12v battery positive through an appropriately sized fuse. Use pin J1-K4 (highside) as low current 12v wake signal for Cooling Pump 1 and use pin J1-K3 (highside) as low current 12v wake signal for Cooling Pump 2. Set option *CoolPump1TempReference* to **PackTemp** and *CoolingPump1SpeedTarget* table will reference the battery pack temperature as reported by the BMS. Set the *CoolingPump1SpeedTarget* table pump speed values accordingly. A different fixed pump speed target value to use while charging can be set with option *Pump1SpdTarget_Charging*. *CoolingPump2SpeedTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp* – set pump speed values accordingly.

EMP WP29/32 Pump With PDU

The VCU200 can control two EMP WP29/32 CAN pumps. Configure one pump as Cooling Pump 1 for battery system conditioning and set its CAN rx address to 0x18EF20A3. Configure the other pump as Cooling Pump 2 for drive system conditioning and set its CAN rx address to 0x18EF8BA3. Cooling Pump 1 can be assigned to PDU 1, channels 4 & 8 (20A rating each – must be combined to power EMP pump) to provide high current power to the pump. Set option *PDU1_Ch4_Option* to **CoolingPump1**.

CAUTION – do not use Cooling Pump 1 output from PDU 2, channel 7 to power an EMP pump!

Cooling Pump 2 can be assigned to PDU 2, channels 4 & 8 (20A rating each – must be combined to power EMP pump) to provide high current power to the pump. Set options *PDU2_Ch4_Option* & *PDU2_Ch8_Option* to **CoolingPump2**. Use pin J1-K4 (highside) as low current 12v wake signal for Cooling Pump 1 and use pin J1-K3 (highside) as low current 12v wake signal for Cooling Pump 2. Set option *CoolPump1TempReference* to **PackTemp** and *CoolingPump1SpeedTarget* table will reference the battery pack temperature as reported by the BMS. Set the *CoolingPump1SpeedTarget* table pump speed values accordingly. A different fixed pump speed target value to use while charging can be set with option *Pump1SpdTarget_Charging*. *CoolingPump2SpeedTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *i1_Motor_Temp* – set pump speed values accordingly.

On/Off Fan Without PDU

Use pin J1-D3 (lowside) to trigger a relay to power the drive system cooling fan (Cooling Fan 1) and use pin J1-D4 (lowside) to trigger a relay to power the battery system cooling fan (Cooling Fan 2). For Fan 1, set *FanTempLimit* table drive system temp activation points accordingly. For Fan 2, set *BatteryFan_TempLimit* table battery system temp activation points accordingly.

On/Off Fan With PDU

Cooling Fan 1 can be assigned to PDU 2, channels 1 & 5 (20A rating each – can be combined for 40A rating). Set option *PDU2_Ch1_Option* & *PDU2_Ch5_Option* to **CoolingFan**. Cooling Fan 2 can be assigned to PDU 2, channels 6 & 7 (10A rating each – can be combined for 20A rating). Set options *PDU2_Ch6_Option* & *PDU2_Ch7_Option* to **BatteryFan**. For Fan 1, set *FanTempLimit* table drive system temp activation points accordingly. For Fan 2, set *BatteryFan_TempLimit* table battery system temp activation points accordingly.

PWM Fan Without PDU

When using two cooling fans, the VCU can variably control one of them with PWM. Use pin J1-D3 (lowside) to trigger a relay to power the drive system cooling fan (Cooling Fan 1). Use pin J1-D4 (lowside) to trigger a relay to power the battery system cooling fan (Cooling Fan 2). For Fan 1, set *FanTempLimit* table drive system temp activation points accordingly. For Fan 2, set *BatteryFan_TempLimit* table battery system temp activation points accordingly. Use pin J1-H3 as the PWM signal to the fan being variably controlled. Option *FanPWMOption* can be set to either **FanDuty1** or **FanDuty2**. If set to **FanDuty1**, the *Fan1DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *Coolant_Temp1*. Set *Fan1DutyTarget* table fan duty values accordingly. If *FanPWMOption* is set to **FanDuty2**, the *Fan2DutyTarget* table temp reference is **PackTemp** as reported by the BMS. Set *Fan2DutyTarget* table fan duty values accordingly.

PWM Fan With PDU

When using two cooling fans, the VCU can variably control one of them with PWM. Cooling Fan 1 can be assigned to PDU 2, channels 1 & 5 (20A rating each – can be combined for 40A rating). Set option *PDU2_Ch1_Option* & *PDU2_Ch5_Option* to **CoolingFan**. Cooling Fan 2 can be assigned to PDU 2, channels 6 & 7 (10A rating each – can be combined for 20A rating). Set options *PDU2_Ch6_Option* & *PDU2_Ch7_Option* to **BatteryFan**. For Fan 1, set *FanTempLimit* table drive system temp activation points accordingly. For Fan 2, set *BatteryFan_TempLimit* table battery system temp activation points accordingly. Use pin J1-H3 as the PWM signal to the fan being variably controlled. Option *FanPWMOption* can be set to either **FanDuty1** or **FanDuty2**. If set to **FanDuty1**, the *Fan1DutyTarget* table active temp reference is the higher of channels *i1_Housing_Temp_Inlet* and *Coolant_Temp1*. Set *Fan1DutyTarget* table fan duty values accordingly. If FanPWMOption is set to **FanDuty2**, the *Fan2DutyTarget* table temp reference is **PackTemp** as reported by the BMS. Set *Fan2DutyTarget* table fan duty values accordingly.

Additional Vehicle Integration

This section covers some additional vehicle integration information that may be pertinent to a user's particular vehicle application. This information is based on the setup of AEM EV's R&D test and development vehicle, a 2007 Ford Mustang GT with a Tesla LDU rear subframe grafted into the car's chassis. Following these guidelines will allow a user to implement these systems in the same way that was validated by AEM.

Parking Brake Control

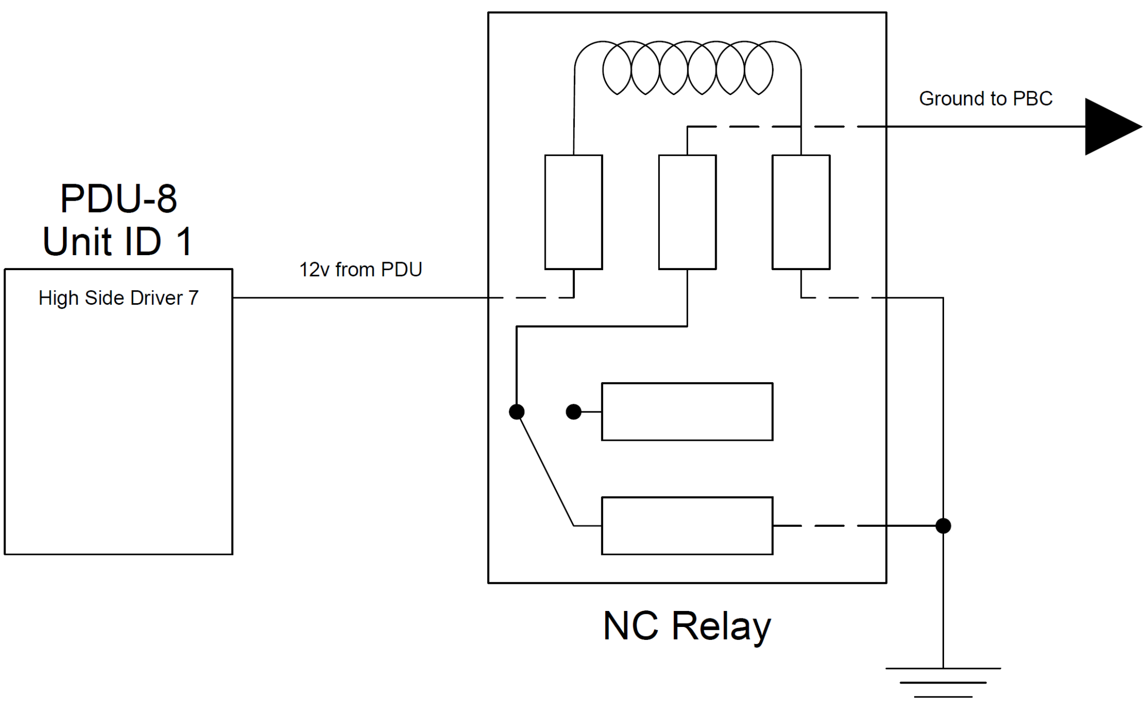
The VCU includes a parking brake control feature when combined with the AEM PDU-8. It will automatically toggle the output when the driver selects the Park Drive Mode. For use with Pantera Electronics hand lever type EBP that uses ground switch in when park brake is set on. Normally closed relay to ground is required to use PDU highside output to trigger - see schematic below.

<u>Options</u>

ParkBrakeLogicPolarity: Used to invert the control logic

<u>Channels</u>

ParkBrakeCntrl: State of the control output



Power Steering

An electric hydraulic power steering pump works well for keeping and using an already existing hydraulic power assist steering system. Electric power steering pumps from Ford/Mazda/Volvo work well. Donor vehicle applications include Mazda 3 & 5, Volvo C30, C70 & S40 and some European Ford cars.

The pump has high current, direct to 12v battery power and ground connections – protect with an appropriately sized fuse or breaker. There is also a low current connector that has a 12v pump-on logic trigger pin. This pin is trigged by a PDU output that turns on when the ignition state is active. Because the pump's turn on pin doesn't supply any circuit loading, the pins voltage will

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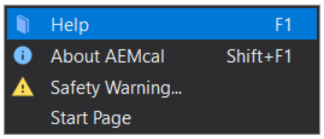
"float" when the PDU output is off therefore a pull down resistor must be used to force the pins voltage down to 0v when the PDU output is off. Use a ¼ watt rated 4.3kOhm resistor.

Power Brakes

An existing vacuum-assist power brake system can still be utilized by using an electric vacuum pump and vacuum reservoir. Many of these types of kits exist from numerous outlets. Typically the vacuum pump is controlled by a vacuum switch that turns a 12v relay on and off. For integration with a PDU, use an output pin that's on when the ignition state is active so that the vacuum pump is only on when the driver intends to operate the vehicle otherwise the pump may run excessively and be noisy. The PDU output can supply power to a relay that's still triggered on/off by a pressure switch.

Initial Spin Test

This section is a basic guide for how to complete a systems check after installation of an AEM Tesla LDU Control Board with a VCU200. It will also describe how to conduct a slow speed motor spin test. ***Read this section thoroughly and completely before attempting to proceed. Ensure that all components are correctly installed. Stop if the steps do not proceed as described below. These procedures assume the calibrator is already familiar with the basic functionality of AEMCal. If not, please review the Windows Help tool within AEMCal.***



If additional help is required, contact AEMEV Tech Support.

Step	Description
1	Open the high voltage battery service disconnect switch so the battery is disconnected from the drive system. Disconnect low voltage connections to contactors to prevent them from turning on. Place vehicle on lift or jack stands to lift drive wheels off the ground. ***Note - The Ignition Switch will not be turned on until after the initial check out has been completed***
2	Turn on wake switch and establish PC comms. Open Tesla LDU Check Out layout/tabs file. Load Tesla LDU supporting firmware into the VCU. After firmware has loaded, select the Disclaimer tab and review the warning message and set option *SafetyWarningAcknowledgement to* **Yes** only after reading and acknowledging the Safety Warning Text. ***During the VCU firmware upgrade process, battery cell segments must be separated using an appropriate service disconnect plug.*** The firmware will load with Tesla LDU check out test calibration already pre-loaded. The forward and reverse drive torque limits have been set to 1Nm to allow for slowly spinning the drive wheels. All BMS features are disabled.
3	Configure brake switch. Calibrate APP. If using keypad, press Neutral & Aux buttons while monitoring Raw Key States to ensure the keypad is functioning. If using discrete PRND switch inputs, toggle Park & Neutral switches and check their respective status channels. If using an IMD, configure it as described in the Insulation Monitoring Device section 27. Once this has been completed, turn off the VCU and reconnect low voltage connections to contactors but leave the HV battery service disconnect open.
4	Audibly monitor the negative contactor and turn the wake switch on. The negative contactor should click as it is closed (turned on).
5	Monitor the InverterPreCharge tab. The next step will be to activate the Ignition Switch (with either CAN keypad or switched input) and monitor the inverter precharge process. Because the HV battery is disconnected, the VCU will initiate but not be able to complete the precharge process. Enable the Ignition Switch and audibly monitor the precharge contactor for a click as it is closed (turned on). If it does not close, review the troubleshooting section below.

	If this checks out, turn off VCU and close the HV battery service disconnect switch.
6	Turn on VCU and in the TorqueRequest tab, monitor *OpState* & *Motor1_Torque_Request*. With foot firmly on brake pedal, enable the Ignition Switch. Now that the HV battery is connected, the precharge process will complete and the positive contactor will close thereby connecting the HV battery pack to the inverter. After precharge completes, *MC1_PreChgComplete* will be 1 and *OpState* will be 3.
7	With foot still firmly on brake pedal and Ignition Switch on and drive wheels off the ground, enable the Drive switch. There should be an audible high frequency electrical whine from the drive unit. With foot on brake, *Motor1_Torque_Request* should be 0. Release the brake and the wheels should not spin. Press on the accelerator pedal and the *Motor1_Torque_Request* should go to 1.0Nm and the wheels should start to slowly spin forward. Press the brake to enable the brake switch and *Motor1_Torque_Request* should go to 0.
8	Once wheels stop spinning and with foot on brake, enable the Neutral switch. The drive units' electrical noise should cease and *Motor1_Torque_Request* should be 0. Releasing the brake should have *Motor1_Torque_Request* stay at 0 and the wheels should not turn.
9	With foot on brake, enable the Reverse switch. The drive unit's electrical noise should return. With foot on brake, *Motor1_Torque_Request* should be 0. Release the brake and the wheels should not spin. Press on the accelerator pedal and the *Motor1_Torque_Request* should go to 1.0Nm and the wheels should start to slowly spin backward. Press the brake to enable the brake switch and *Motor1_Torque_Request* should go to 0.
10	This completes the basic systems check out and drive unit spin test. Additional systems to check before attempting to operate the vehicle include: cooling pumps/fans, brake power assist pump, power steering activation, DCDC, vehicle marking lights, etc.

Tesla Base LDU Base Calibration

A VCU200 base calibration is provided in the AEMcal Calibrations/Factory directory for the Tesla Base LDU. This base calibration is actually the calibration from AEM's LDU powered development car, the Testang. It is a refined calibration with considerable tuning time already put into it and should work as an excellent starting point for most vehicles and give good drivability with minimal additional tuning. Besides the standard input/output configuration, the following are calibration setup aspects that should be considered before attempting to use this base cal.

Safety Warning & Disclaimer: The option *SafetyWarningAcknowledgement* will be **No** by default; after reading and acknowledging the Safety Warning test, set to **Yes**

BMS Selection: Table *ItemSelect_BMS* sets which type of BMS is being used; the base cal has no BMS selected

Pack Current/Voltage Source: Options *PackCurrentSource* & *PackVoltageSource* are both set for an Issabellenhutte IVT-S smart shunt

IMD: An insulation monitoring device is highly recommended however the base cal is set with the IMD function disabled; set option *IMD_Polarity* to **Lo = On** to enable IMD protection

HVIL: Using the VCU's High Voltage Interlock Loop safety function is highly recommended however the base cal is set with HVIL turned off, set option *HVILMainBypass* to **Enabled** to turn on

Direct Inverter Current Control: The VCU has a direct invert current control function when used with a BMS-18; the base cal has this turned off; set option *Motor1_TrqLimCurEnbl* to **Enbl** to turn on

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VCU Faults

Fault	AEMCal Measurement Name	Description	Associated Calibration Option
WheelSpeed Direct Drive Spike	Fault_Wheel_Speed_DD_Spike	Maximum allowable speed change per second exceeded. If speed changes too quickly, it is assumed to be a wiring or sensor fault	*VSS_DirectDriveSpikeThresh*
WheelSpeed Driven Left Spike	Fault_Wheel_Speed_DL_Spike	Maximum allowable speed change per second exceeded. If speed changes too quickly, it is assumed to be a wiring or sensor fault	*DriveWheelSpikeThresh*
WheelSpeed Driven Right Spike	Fault_Wheel_Speed_DR_Spike	Maximum allowable speed change per second exceeded. If speed changes too quickly, it is assumed to be a wiring or sensor fault	*DriveWheelSpikeThresh*
WheelSpeed Non-Driven Left Spike	Fault_Wheel_Speed_NL_Spike	Maximum allowable speed change per second exceeded. If speed changes too quickly, it is assumed to be a wiring or sensor fault	*GroundWheelSpikeThresh*
WheelSpeed Non-Driven Right Spike	Fault_Wheel_Speed_NR_Spike	Maximum allowable speed change per second exceeded. If speed changes too quickly, it is assumed to be a wiring or sensor fault	*GroundWheelSpikeThresh*
Reverse Lamps	Fault_Reverse_Lamps	Minimum current threshold exceeded or other internal error. Assumes the output driver is AEM PDU8-2, Channel 4.	*ReverseLampsMinCurrThresh* Enter a negative value to disable fault detection
Manual Regen 1 Input High	Fault_Manual_Regen1_InputHi	Voltage input exceeds high threshold	*ManualRegen1_Hi_Thresh* *ManualRegen1_Hi_Time_Thresh*
Manual Regen 1 Input Low	Fault_Manual_Regen1_InputLo	Voltage input exceeds low threshold	*ManualRegen1_Lo_Thresh* *ManualRegen1_Lo_Time_Thresh*
Manual Regen 1 Spike	Fault_Manual_Regen1_Spike	Maximum allowable speed change per second exceeded. If voltage changes too quickly too many times, it is assumed to be a wiring or sensor fault	*ManualRegen1_VoltageSpikeThresh* *ManualRegen1_SpikeMax*
Manual Regen 2 Input High	Fault_Manual_Regen2_InputHi	Voltage input exceeds high threshold	*ManualRegen2_Hi_Thresh* *ManualRegen2_Hi_Time_Thresh*
Manual Regen 2 Input Low	Fault_Manual_Regen2_InputLo	Voltage input exceeds low threshold	*ManualRegen2_Lo_Thresh* *ManualRegen2_Lo_Time_Thresh*
Manual Regen 2 Spike	Fault_Manual_Regen2_Spike	Maximum allowable speed change per second exceeded. If voltage changes too quickly too many times, it is assumed to be a wiring or sensor fault	*ManualRegen2_VoltageSpikeThresh* *ManualRegen2_SpikeMax*
Park Lamps	Fault_Park_Lamps	Minimum current threshold exceeded or other internal error. Assumes the output driver is AEM PDU8-2, Channel 2.	*ParkLampsMinCurrThresh* Enter a negative value to disable fault detection
Regen Lever Cross Check	Fault_Regen_LeverXChk	Difference between signal1 and signal2 exceeds the max threshold	*RegenLeverXChkThr*
DC Voltage Safety Light	Fault_DCVoltage_SafeLight	Minimum current threshold exceeded or other internal error. Assumes the output driver is AEM PDU8-1, Channel 6.	*DCVoltageSafeLightMinCurrThresh* Enter a negative value to disable fault detection
Headlamps	Fault_Head_Lamps	Minimum current threshold exceeded or other internal error. Assumes the output driver is AEM PDU8-2, Channel 1.	*HeadLampsMinCurrThresh* Enter a negative value to disable fault detection

Fault	AEMCal Measurement Name	Description	Associated Calibration Option
Idle Target	Fault_Idle_Target	Applies to indirect drive transmission applications only. Difference between Idle Target and measured motor speed exceeds a threshold for too long.	*IdleTargetErrorThreshold* *IdleTargetErrorTimeThreshold*
Ignition Charge Plug Cross Check	Fault_IgnChgPlug_XCheck	Fault will be set if the charge plug is detected with the Ignition Switch ON.	
Inverter 1 Contactor	Fault_MC1_Contactor	Fault will set if: 1. Inverter voltage is detected after the negative contactor closes and before the pre-charge contactor closes 2. Inverter voltage does not increase above the partial threshold within a certain period of time after the pre-charge contactor closes 3. Inverter voltage does not satisfy the pre-charge criteria after successive attempts	*Inverter1_FaultTimeout* *Inverter1_PreChgMxAttempts* *Inverter1_HVDetectPartialThr* *Inverter1_PreChgRetryDelayTime* *Inverter1_PreChgRetryWaitTime*
Accelerator Pedal Position Cross Check	Fault_AccelPedal_XCheck	Difference between signal1 and signal2 exceeds the max threshold	*RegenLeverXChkThr*
Brake Lamps	Fault_Brake_Lamps	Minimum current threshold exceeded or other internal error. Assumes the output driver is AEM PDU8-2, Channel 3.	*BrakeLampsMinCurrThresh* Enter a negative value to disable fault detection
Brake Pressure Input High	Fault_Brake_Press_InputHi	Voltage input exceeds high threshold	*BrkPress_Hi_Thresh* *BrkPress_Hi_Time_Thresh*
Brake Pressure Input Low	Fault_Brake_Press_InputLo	Voltage input exceeds low threshold	*BrkPress_Lo_Thresh* *BrkPress_Lo_Time_Thresh*
Cooling Pump1	Fault_Cooling_Pump1	Minimum current threshold exceeded or other internal error. Assumes the output drivers are AEM PDU8-1, Channels 4 and 8.	*CoolingPump1MinCurrThresh* Enter a negative value to disable fault detection
Coolant Temp1 Input High	Fault_Cool_Temp1_InputHi	Voltage input exceeds high threshold	*CoolTemp1_Hi_Thresh* *CoolTemp1_Time_Thresh*
Coolant Temp1 Input Low	Fault_Cool_Temp1_InputLo	Voltage input exceeds low threshold	*CoolTemp1_Lo_Thresh* *CoolTemp1_Lo_Time_Thresh*
Accessory Power	Fault_Acc_Power	Minimum current threshold exceeded or other internal error. Assumes the output driver is AEM PDU8-1, Channel 5.	*AccPowerMinCurrThresh* Enter a negative value to disable fault detection
Accelerator Pedal Position1 Input High	Fault_AccPedal1_InputHi	Voltage input exceeds high threshold	*APP1_Hi_Thresh* *APP1_Hi_Time_Thresh*
Accelerator Pedal Position1 Input Low	Fault_AccPedal1_InputLo	Voltage input exceeds low threshold	*APP1_Lo_Thresh* *APP1_Lo_Time_Thresh*
Accelerator Pedal Position1 Spike	Fault_AccPedal1_Spike	Maximum allowable speed change per second exceeded. If voltage changes too quickly too many times, it is assumed to be a wiring or sensor fault	*APP1_VoltageSpikeThresh* *APP1_SpikeMax*
Accelerator Pedal Position2 Input High	Fault_AccPedal2_InputHi	Voltage input exceeds high threshold	*APP2_Hi_Thresh* *APP2_Hi_Time_Thresh*
Accelerator Pedal Position2 Input Low	Fault_AccPedal2_InputLo	Voltage input exceeds low threshold	*APP2_Lo_Thresh* *APP2_Lo_Time_Thresh*
Accelerator Pedal Position2 Spike	Fault_AccPedal2_Spike	Maximum allowable speed change per second exceeded. If voltage changes too	*APP2_VoltageSpikeThresh* *APP2_SpikeMax*

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Fault	AEMCal Measurement Name	Description	Associated Calibration Option
		quickly too many times, it is assumed to be a wiring or sensor fault	
IMD State Fault	Fault_IMD	Insulation Monitoring Device is indicating an insulation fault, time delay threshold is set too low, or detection polarity is inverted	*IMD_LoTimeThresh* *IMD_HiTimeThresh* *IMD_Polarity* *IMD_Detect_Thresh*

VCU Troubleshooting Guide

VCU operation states are tracked using the flag *OpState*. This operational state indicator should be monitored when troubleshooting unexpected system behavior. The summary below broadly describes the features assigned to each operational state.

OpState = 1
- 12V power and ground, AEMCal USB Comms
- Inverter power and CAN comms

OpState = 2 - 3
- Ignition switch and J1772 charge plug check
- Contactor enable conditions
- High voltage detect and pre-charge sequencing

OpState = 4
- Start safe criteria

OpState = 5
- Direct drive run criteria
- Torque request and torque request limits
- Drive mode transitions (brake sw, spd criteria, etc)
- Inverter enable/disable

OpState = 6 - 14
- Ignition switch or wake off, ChgPlug check
- Contactor opening
- Active discharge and VCU shutdown

<u>Operational State 1, *OpState = 1*</u>

The default power on state for the VCU is *OpState = 1*. As soon as the wake switch input is detected high, the VCU will transition to OpState 1.

Troubleshooting the following conditions is possible by understanding the features of OpState 1:

- No USB communications with AEMCal
- Negative contactor not working
- No inverter power or VCU/Inverter CAN communications

Problem	Items to Check
No USB communications with AEMCal	Check for permanent 12 volt battery power at terminals J1-M1 and J1-M2 Check for switched 12 volt power at terminal J2-A4. Power on threshold is a minimum of 3.7 volts. Power off threshold is a maximum of 1.5 volts.

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	Check for 12 volt battery ground at terminals J1-A1, J1-M3, J1-C2 and J1-A3 Make sure you are using a supported CAN to USB adapter and that the device drivers are properly installed.
Negative contactor not working	Check calibration option *NegContactorOption*. If set to *Default_On*, the negative contactor will immediately actuate when the VCU powers up. Otherwise, the negative will be controlled as part of the inverter pre-charge sequencing. If using the VCU to directly control the negative contactor, check wiring from low side output on VCU pin J1-M4. If using a PDU-8 to control the negative contactor, check wiring from pins 1 and/or 2 for High Side Driver 1. Check CAN network wiring. The PDUs must be part of the CAN2 network.
No inverter power or VCU/Inverter CAN communications	Generally, the VCU must be powered up before the inverter. Therefore it is important for the VCU to control 12 volt switched power to the inverter. If using the VCU low side driver, check the wiring for output pin J1-L3. This must drive a 12 volt relay that will supply switched 12 volt power to the inverter. Check wiring from the relay to the inverter. If using a PDU-8 to control switched 12 volt power to the inverter, check wiring from PDU-8 pins 6 and/or 7 for High Side Driver 5. The output from the PDU-8 can switch power to the inverter directly. Check CAN network wiring. The PDUs must be part of the CAN2 network. Check calibration option *EnableSwitchRequired* and VCU Enable Switch input pin J1-E1. The Enable Switch is optional and can be convenient in some cases to override the 12 volt power to the inverter for programming and/or other debugging scenarios. Check the CAN timeout thresholds. The inverter communicates data to the VCU using 10 individual CAN messages. The following calibration options must be set to a non-zero value. Default is 1.0 second. *i1_CurrentInfoMsgTimeoutThr* *i1_Fault_CodesMsgTimeoutThr* *i1_Internal_StatesMsgTimeoutThr* *i1_Motor_Position_InfoMsgTimeoutThr* *i1_Torque_And_Timer_InfoMsgTimeoutThr* *i1_Voltage_InfoMsgTimeoutThr* *i1_Temp_Set1MsgTimeoutThr* *i1_Temp_Set2MsgTimeoutThr* *i1_Temp_Set3MsgTimeoutThr* *i1_RW_Param_RespMsgTimeoutThr*

<u>Operational State 2 - 3, *OpState = 2 & 3*</u>
Inverter pre-charge sequencing is managed during *OpState = 2* and completes during *OpState = 3*. As soon as the ignition switch input is detected high, the VCU will transition to OpState 2.

Troubleshooting the following conditions is possible by understanding the features of OpState 2 & 3:

- No inverter pre-charge
- Main contactor opening after pre-charge is completed

Problem	**Items to Check**
No inverter pre-charge	Check measurement channel *IgnSwState*. This flag indicates the state of the ignition switch input to the VCU and must indicate *On* in order for contactor sequencing to commence. There are several options for the ignition switch input. Check calibration option *IgnSwSource* to configure. If using the AEM CAN Keypad, it must be connected to the CAN3 network. If using a discrete switch input, check wiring to VCU pin J2-A2. Check measurement channel *MC1ContEnable*. Certain conditions are required to enable this flag. These include: *IMD_MD* – Measured state of the IMD input. This flag must be 0 to allow contactor sequencing. *HVIL_Main_State* – Measured state of the high voltage interlock loop. This flag must be 1 to allow contactor sequencing. *ChgPlugDetect* – State of J1772 charging plug detection. This flag must be 0 to allow contactor sequencing. *i1_Run_Flt* – Inverter run fault. Must be 0 to allow contactor sequencing. *i1_Post_Flt* – Inverter power on self-test fault. Must be 0 to allow contactor sequencing. *i1_Inverter_Enable_Lockout* – State of inverter internal control lockout. Must be 0 to allow contactor sequencing. Check measurement parameter *i1_DC_Bus_Voltage*. This signal must increase toward the level of the pack voltage when the pre-charge contactor is closed. If using the VCU for direct contactor control, check wiring to pin J1-L1 for the pre-charge contactor driver and pin J1-L2 for the positive contactor driver. Note that these are both high side drivers. They switch 12 volts not ground. If using the PDU-8 for contactor control, ensure the pre-charge and positive contactors are connected to PDU-8 unit ID 1 and that all Config pins at the PDU-8 are unterminated. Check wiring to pin 8/9 for the PreCharge and pin 14/15 for the Positive contactor.
Main contactor opening after pre-charge is completed	If any inverter faults or lockouts are detected after the pre-charge process is completed, the VCU will open the main contactor when the measured motor speed is less than the calibration option *MotorStopThresh*. *i1_Run_Flt* – Inverter run fault. Must be 0. *i1_Post_Flt* – Inverter power on self-test fault. Must be 0. *i1_Inverter_Enable_Lockout* – State of inverter internal control lockout. Must be 0. Incorrectly assembled high voltage cables may cause high frequency noise that can result in the inverter resetting unexpected. When this happens, the *i1_Inverter_Enable_Lockout* flag may set. High frequency noise may also affect the CAN communications between the VCU and the inverter. Monitor the measurement channels *i1_DC_Bus_VoltageVld* and

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	i1_DC_Bus_Voltage. *I1_DC_Bus_VoltageVld* is a data validity flag. If this flag is toggling between 0 and 1 and the *i1_DC_Bus_Voltage* value is also toggling between some actual value and 0, then high frequency noise may be the cause.

Operational State 4, *OpState = 4*
A transition to *OpState = 4* is only allowed when conditions are safe to do so. As such, this may require troubleshooting for new setups.

Troubleshooting the following conditions is possible by understanding the features of OpState 4:

- No forward or reverse drive torque

Problem	**Items to Check**
No forward or reverse drive torque	Monitor the measurement channel *Start_Safe*. All criteria below must be met for *Start_Safe* to toggle. *ConfigDriveMode* – Calibration option, must be set to *DirectDrive.* *IMD_MD* – Measured state of the IMD input. This flag must be 0. *HVIL_Main_State* – Measured state of the high voltage interlock loop. This flag must be 1. *ChgPlugDetect* – State of J1772 charging plug detection. This flag must be 0. *AccelPedal* – Measured value of the accel pedal position. Must be less than *APPStartSafeHiThresh* and greater than *APPStartSafeLoThresh*. *BrakeSwitch* – Measured state of the brake switch. Must be On *Drive_Mode* – Arbitrated drive mode state. Must be either Park or Neutral

Operational State 5, *OpState = 5*
A transition to *OpState = 5* occurs when the driver selects either forward or reverse.

- No forward or reverse drive torque
- Unexpected forward or reverse drive torque
- No drive direction change

Problem	**Items to Check**
No forward or reverse drive torque	Check the calibration option *SafetyWarningAcknowldedgement*. Within AEMCal, go to the Warnings group and select the WarningStatement tab. Read and acknowledge the safety warning declaration. Check measurement channel *Motor1_Torque_Request*. If this value is not 0 and there is no response from the drive unit, the following items need review: - CAN communications between the VCU and inverter. The inverter must be on the CAN2 network. - Monitor the measurement channels *i1_DC_Bus_VoltageVld* and *i1_DC_Bus_Voltage*. - Re-check *OpState 1* & *OpState 2-3* criteria.
Unexpected forward or reverse drive torque	If *Motor1_Torque_Request* or the behavior from the drive unit is unexpected, review the following items:

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	Check calibration tables *Motor1_TrqLim_CalTable1-4*. Check calibration option *Motor1_TrqLim_cal*. Check calibration option *Motor1_TqReqGain*. This should be set to 10 for Cascadia PM series inverters and Tesla LDU control systems. There are many features that allow for dynamic torque limiting. The following measurement flags can be used to monitor behavior. If any of them are 1, that means dynamic torque limiting is active. *LimMultPackTempHi_Active* *LimMultPackTempLo_Active* *LimMultCellVoltMin_Active* *LimMultCellVoltMax_Active* *LimMultPackVoltage_Active* *LimMultBattSOCLo_Active* *LimMultBattSOCHi_Active* *LimMultVehSpdHi_Active* *LimMultVehSpdLo_Active* *LimMultOverrev_Active* *LimMultInv1Temp_Active* *LimMultMotor1Temp_Active* *LimMultMotor1SpdLo_Active* *LimMultRampInv1Curr_Active* Monitor the measurement channels *Motor1_TqLimMultLo* and *Motor1_TqLimMultHi*. If either of these are less than 1, dynamic torque limiting is active.
No drive direction change	The transition from either Park or Neutral to either Drive or Reverse will result in an OpState change. A transition from OpState 3 to OpState 5 requires going through OpState 4 and its associated *Start_Safe* criteria. A direct transition from OpState 5 back to OpState 3 is normal and does not require any other criteria be met. OpState 3 = Park or Neutral OpState 4 = *Start_Safe* gate OpState 5 = Drive or Reverse Park is the default drive mode. Transitions to other drive modes are arbitrated according to the following rules: <u>Park to Reverse</u> Reverse drive mode selection *ChgPlugDetect* – State of J1772 charging plug detection. This flag must be 0. *BrakeSwitch* – Measured state of the brake switch. Must be On <u>Park to Neutral</u> Neutral drive mode selection *ChgPlugDetect* – State of J1772 charging plug detection. This flag must be 0. *BrakeSwitch* – Measured state of the brake switch. Must be On <u>Park to Drive</u> Drive drive mode selection *ChgPlugDetect* – State of J1772 charging plug detection. This flag must be 0.

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	BrakeSwitch – Measured state of the brake switch. Must be On <u>Neutral, Drive, or Reverse</u> Neutral, Drive, or Reverse drive mode selection *Vehicle_Speed* less than *DriveMode_Speed_LoThr* <u>Reverse, Neutral or Drive to Park</u> Park drive mode selection *Vehicle_Speed* less than *DriveMode_Speed_ZeroThr* If using discrete switches for drive mode selection, check the wiring to VCU input pins: Park – J2-C2, *ParkSw* raw switch measurement channel Reverse – J2-C3, *RevSw* raw switch measurement channel Neutral – J2-D2, *NtrlSw* raw switch measurement channel Drive – J2-D3, *DrvSw* raw switch measurement channel The discrete raw PRND switch inputs are arbitrated as follows: Park = Park and Not Neutral Reverse = Reverse and Not Park, Neutral or Drive Neutral = Neutral Drive = Drive and Not Park or Neutral If using the AEM CAN Keypad for PRND drive mode selection, it must be connected to the CAN3 network. The measurement channel *KeypadDriveMode* can be used to monitor the raw drive mode selection from the CAN keypad. Use the calibration option *DirectDrivePRNDInput* to select between discrete switch inputs and the AEM CAN Keypad The raw drive mode input selection states can be monitored using the following measurement channels: *PRND_Park* *PRND_Reverse* *PRND_Neutral* *PRND_Drive* The calibration option *i1_DirChangeAllowed* must be set to Enable for direction changes to be allowed. The inverter's internal control logic will not allow direction changes unless it receives the proper sequence of CAN commands from the VCU. The inverter control logic requires the inverter PWM to be disabled before a direction change is allowed. The control sequence can be monitored using the following measurement channels: *i1_Direction_Commanded* – Feedback signal from the inverter indicating the current command direction. *i1_Inverter_Enable_State* – Feedback signal from the inverter indicating the current PWM enable state.

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Operational State 6 - 14, *OpState = 6 - 14*

A transition to *OpState = 6* from *OpState = 5* occurs when the driver turns off either the ignition switch or the wake switch. This transition will also occur if the J1772 charge plug is detected. Following this transition, several functions take place automatically:

OpState = 6: Zero torque command sent to inverter in preparation for shutdown. When motor speed less than stop threshold, open main contactor.
OpState = 11: Motor control PWM disable
OpState = 12: Active discharge command to the inverter
OpState = 13: Active discharge complete check
OpState = 14: Inverter power turned off followed by VCU power off if no power hold flags set

Troubleshooting the following conditions is possible by understanding the shutdown features:

- VCU power hangs and doesn't turn off
- Keypad ignition switch LED doesn't turn off
- No active discharge

Problem	**Items to Check**
VCU power hangs and doesn't turn off	If the VCU hangs at OPState = 11, check the calibration option *MotorDisableDelay*. This delay is intended to give the inverter time to disable PWM before requesting active discharge. If the VCU hangs at OpState = 12, check the calibration option *DischargeTimeout*. This timeout is used to override the requirement for a discharge feedback success signal from the inverter. If the VCU hangs at OpState = 14, check the measurement channel *PwrHold_State*. This will indicate Hold if either the on board charger or DCDC requires a power hold.
Keypad ignition switch LED doesn't turn off	The AEM CAN keypad LED control logic is designed to track the shutdown process and provide feedback to the driver by changing the ignition switch LED color during each state transition. The state of the active discharge process is monitored. If the keypad logic does not see the proper sequence of state change flags, this can lead to unexpected LED behavior. If active discharge is enabled, monitor the state of the measurement channel *DischargeComplete* during shutdown. This flag monitors the inverter DC bus voltage relative to the user calibration table *DischargeCompleteThreshold*. This table sets the threshold for determining when inverter DC bus voltage discharge is complete. If active discharge is not desired or is not supported by the inverter, set the calibration option *i1_Inverter_Discharge* to Disable. Monitor the result of this setting using the measurement channel *i1_DischargeBypassed*.
No active discharge	If the calibration option *i1_Inverter_Discharge* is set to Enable, the VCU will send the active discharge command to the inverter during OPState = 12. The inverter must be configured properly to enable this feature. See the inverter control board documentation for more details. Adjust the *DischargeCompleteThreshold* table to meet the application requirements.

BMS-18 Troubleshooting Guide

The VCU200 and BMS-18 system provide literally hundreds of channels that can be used to diagnose and/or troubleshoot unexpected behavior.

Unexpected Behavior	**Troubleshooting Help**
Pack voltage very low	Layout Group = *BMS18_Setup_Monitor* Layout Tab = *Basic* The measurement channel *BattPackVoltage* indicates a value that is excessively low. If the BMS logic does not see the correct number of connected BMS-18 modules, the pack voltage calculation will be wrong. Double check the following calibration options and make sure they are selected appropriately for the number of installed modules. *BMSM1G1Enable* *BMSM1G2Enable* *BMSM1G3Enable* *BMSM1G4Enable* *BMSM1G5Enable* *BMSM1G6Enable* Layout Group = *BMS18_Setup_Monitor* Layout Tab = *Faults* Check the state of fault flag *BMS_FS_M1_NumGroupsMismatchFault* If this fault is set, the wrong number of modules are being detected. Refer to the 30-8401M & 30-8401S Instruction Manual. Check the isoSPI satellite system wiring. If one interconnect cable is faulty, all downstream satellite modules will be undetectable.
• Pack voltage intermittently low • *BMS_FS_M1GX_MinCellVoltsFault* flag set • *BMS_FS_M1_Summary* fault flag set • *BMSM1_GXX_CellXX* values snapping to ~2.7 volts • Red status LED or blinking red status LED on Master BMS-18 module.	Layout Group = *BMS18_Setup_Monitor* Layout Tab = *Faults* Layout Group = *BMS18_Group_Data* Layout Tab = *GroupXData*  These conditions could be caused by a critical system failure. **PROCEED CAUTIOUSLY**. This may only occur when high voltage PWM is enabled to the motor. The inverter is enabled in Drive and Reverse and disabled in Park and Neutral. If this problem only occurs when the inverter is enabled: 1. Refer to the 30-8401M & 30-8401S Instruction Manual. Check the isoSPI satellite system wiring. Ensure the cables are high quality and constructed of twisted pairs. ***They must be twisted pairs***.  2. A second less likely scenario is an isolation problem. **PROCEED CAUTIOUSLY!** AEM has observed drive system failures that result in a short between the motor stator and the housing. This can induce high voltage, high frequency noise onto the chassis of the vehicle when the inverter is enabled, creating numerous system faults and failures.

Unexpected Behavior	**Troubleshooting Help**
BattPackDCL indicating 0.0	IF the calculated discharge current limit is 0.0 and the optional Inverter Current Control feature is enabled, the result will be a torque request limit of 0.0 Nm ***which basically means no power allowed!*** Check the calibration options *CellUnderVoltLim* and *DCLCCLMethod*. If *DCLCCLMethod* is set to *CellR Based* and the minimum cell open circuit voltage as indicated by the channel *BMSM1_CellOCV_Min* is less than *CellUnderVoltLim*, then the result will be *BattPackDCL* = 0.0. **PROCEED CAUTIOUSLY!** **The calibration option *CellUnderVoltLim* is intended to prevent cell damage caused by over discharge.**
• Charging doesn't initiate when the J1772 charge cable is plugged in • Pack voltage does not reach the fully charged target during charging	Layout Group = *BMS18_Setup_Monitor* Layout Tab = *Charging* Monitor the charging control states *CState1 – 8* *CState1* will indicate 1 if the charging operating state control allows charging. Criteria that must be true for *CState1* to trigger: *J1772ProxState* = 3 (Locked) *PackChargeState_Full* = 0 (not full) *OBC_State_OK* = 1 *OBC_Temp_OK* = 1 -1 > *Motor1TqReqDat* < 1 *CState2* is a reserved logic state and will always default to 1 *CState3* ensures the VCU is in the correct operational state for charging. Criteria that must be true for *CState3* to trigger: *OpState* = 0, 1 or 14 *CState4* will indicate 1 if the pack is not already fully charged. Criteria that must be true for *CState4* to trigger: *PackChargeState_Full* = 0 (not full) *CState5* will indicate 1 if the maximum pack cell voltage is within bounds. Criteria that must be true for *CState5* to trigger: *BattPackCellMax* less than or equal to *PackChargingCellOverVoltLim* **PROCEED CAUTIOUSLY!** **The calibration option *PackChargingCellOverVoltLim* is intended to protect cells from over charging. Over charging can lead to thermal runaway resulting in fire, vehicle damage, property damage, personal injury, or death.**

Unexpected Behavior	Troubleshooting Help
	CState6 will indicate 1 if the minimum pack cell voltage is within bounds. Criteria that must be true for *CState6* to trigger: *BattPackCellMin* greater than or equal to *PackChargingCellUnderVoltLim* **PROCEED CAUTIOUSLY!** **The calibration option *PackChargingCellUnderVoltLim* is intended to protect weak and/or damaged cells. Resolve this issue before attempting to charge the pack.** *CState7* will indicate 1 if the pack thermal state is within bounds for charging. Criteria that must be true for *CState7* to trigger: *PackThermMode* = 0 (Normal) **PROCEED CAUTIOUSLY!** **The *PackThermMode* logic should be configured to ensure the pack is always within a safe operating temperature for charging.** *CState8* will indicate 1 if the J1772 Pilot Duty Cycle is detected and not zero. Monitor with measurement channel *BMSM1_J1772PilotDutyFraction*.
When the charge cable is plugged in, charging does not immediately begin	This is normal and expected. One of the first steps in the charging sequence is to capture all cell open circuit voltage values. The BMS logic waits until all cell voltages are stable. Once stability is ensured, the unloaded or open circuit voltages of each cell are captured. This data is used to calculate the individual cell resistance values once the charging current ramps up to a stable value.
Changes to charging target voltage or current are not applied	Monitor the measurement channels: *ChgCurrTargetFinal* *ChgVoltTargetFinal* Changes to the target charging voltage and/or current will only be applied if the J1772 charging cable is not plugged in. If changes are made with the cable plugged in, remove the cable, wait 10 seconds and plug it back in.
Fresh installation – *BMS_FS_M1GX_MinCellResFault* flags set	This is normal. The BMS samples data and calculates individual cell resistance values during the early stages of the charging cycle. If the J1772 cable has never been plugged in, this process has not completed yet. As long as there are no other installation or charging system setup issues, these faults should go away after the first charging cycle. Note that *charging cycle* does not mean the pack must be fully charged. The charging cycle must initiate and the charging current must be within an appropriate range to allow resistance estimation. Once this is true, the cell resistance values will be updated and the faults should clear.
External thermistor probes installed and calibrated properly but *BMS_FS_M1GX_ExtThermX_InputHi* flags set in AEMCal	This is normal for unused temperature probes.

Unexpected Behavior	**Troubleshooting Help**
	It’s normal for these faults to display in AEMCal. However, the faults for unused probes can be masked from transmission over CAN for display and/or logging. Refer to calibration options *M1GX_ExtThermX_FaultEnable*. Disable these options if you don’t want fault status flags transmitted for unused probes.

Warranty

AEM Performance Electronics warrants to the consumer that all AEM Electronics products will be free from defects in material and workmanship for a period of twelve months from the date of the original purchase. Products that fail within this 12-month warranty period will be repaired or replaced when determined by us that the product failed due to defects in material or workmanship. This warranty is limited to the repair or replacement of the AEM Electronics part. This warranty applies only to the original purchaser of the product and is non-transferable. All implied warranties shall be limited in duration to the said 12-month warranty period. Improper use or installation, accident, abuse, unauthorized repairs or alterations performed by the user on any AEM Electronics products voids this warranty.

In no event shall this warranty exceed the original purchase price of the AEM Electronics part nor shall AEM Electronics be responsible for special, incidental or consequential damages or cost incurred due to the failure of this product.

AEM Electronics disclaims any liability for consequential damages due to breach of any written or implied warranty on all of its products.

Warranty returns will only be accepted by AEM Electronics when accompanied by a valid Return Merchandise Authorization (RMA) number and a dated proof of purchase. The product must be received by AEM Electronics within 30 days of the date the RMA is issued. Warranty claims to AEM Electronics must be shipped to us prepaid (we recommend a shipping service with package tracking capability). Once your package is received by our warranty and repairs department you will be notified and provided with updates.

PROCEDURES FOR ISSUANCE OF A RETURN MERCHANDISE AUTHORIZATION (RMA) NUMBER

Please note that before AEM Electronics can issue an RMA for any product, it is first necessary for the installer or enduser to contact our technical support team to discuss the problem. Most issues can be resolved over the phone. Under no circumstances should a system be returned, or an RMA requested before our support team is contacted. This will ensure that if an RMA is needed that our team is able to track your product through the warranty process.

You can reach our Tech Support Team for support on all AEM Electronics performance products by phone at 1-800-423-0046. To contact us by email for engine management systems, email us at emstech@aemelectronics.com. For all other products, email us at gen.tech@aemelectronics.com.

AEM Electronics will not be responsible for products that are installed incorrectly, installed in a non-approved application, misused, or tampered with. In the case of AEM Electronics Fuel Pumps, incorrect polarity (+&- wires crossed) will not be warranted. Proper fuel filtration before and after the fuel pump is essential to fuel pump life. Any pump returned with contamination will not be warranted.

PRODUCTS OUTSIDE OF WARRANTY PERIOD

Any AEM Electronics product, excluding discontinued products, can be returned for repair if it is out of the warranty period. There is a minimum charge of $50.00 for inspection and diagnosis of AEM Electronics parts. Parts used in the repair of AEM Electronics components will be extra. AEM Electronics will provide an estimate of repairs and must receive written or electronic authorization from you before repairs are made to a product.