BATTERY WORKFORCE CHALLENGE

Software Requirements Document

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Revision 5

Managed by Argonne National Laboratory

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FOR THE U.S. DEPARTMENT OF ENERGY

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A General Requirements

A-1 Purpose

This document defines the Core Software Requirements Document for the battery management system for Competition Organizer's BEV application. The purpose of this document is to describe the software that will be required by the Team. The scope of this document includes algorithms and processes that all teams are obligated to fulfill as well as algorithms and processes that are solely related to the battery pack assembly and its control module. All specifications are assumed to be understood unless specific and detailed questions are asked. This core software requirements document provides the best attempt to define up front to the Team the requirements for the BPCM (Battery Pack Control Module) software.

A-2 Definitions

The word "shall" is used to state binding requirements of the component defined by this document. These requirements shall be verifiable. The word "must" states requirements of other components and/or subsystems whose definitions are outside the scope this document. The word "will" is used to state conditions that result from immutable physical laws or conditions that result from adherence to other stated, binding requirements. The words "are" and will state definitions and facts that do not require verification. The word "withstand" will be defined as "Maintains design-intended functional and structural integrity while being subjected to the specified conditions." The flowcharts used in this document are meant to facilitate the meaning and logic of the written requirements. The flowcharts themselves should not be construed as the requirements.

A-3 Application

Battery system related requirements, such as performance, interfaces, and hardware, are contained in Battery System Specifications and their referenced documents. Stellantis uses the terminology BPCM to designate the ECU used in this application. It is the responsibility of the Team to conform to these requirements and terminology in all documentation. This includes all presentations, diagrams, and conversations shared with Competition Organizers. The software shall be contained in the BPCM (Battery Pack Control Module), which is part of the battery pack system.

A-4 Standards and Other Specifications

In addition to the defined Battery System Specifications, Competition Organizers Specifications and Industry Standards shall be considered part of the BPCM requirements. The BPCM requirements contain BPCM Architecture, as well as corresponding requirements for PowerNet (Vehicle Architecture) applications for all regions.

The Team shall verify compliance to Industry Standards as provided in the Auxiliary (Excel) Specifications Table; which will be part of BMS core software requirements document included in the Source Package.

Each Specification in the Auxiliary (Excel) Specification Table shall be an item in the Software Compliance Matrix Sheet (All features Mapped out), as defined by the core software requirement BMS Support Document. Each specification will be considered a software compliance line item.

A-5 California Air Resource Board Regulation Implementation

Not Applicable for Student Competition

For reference only:

The California Air Resource Board Regulations represent a Market and a time of sale. In this sense the BMS supported by this software requirements document shall require the ability to transition through the series of SAE J1979, SAE J1979-2, and SAE J1979-3, documents.

A-6 CARB and SAE J1979 Implementation for Model Year 2026

Not Applicable for Student Competition

For reference only:

For Model Year 2026, the BMS shall communicate with the vehicle's OBD and test equipment based on SAE J1979 communication protocols. The communication is defined by an Open Systems Interconnection model, SAE J1979 and ISO 15031-5.

Through the implementation of SAE J1979 and ISO 15031-5, which include additional specifications for the successful implementation of CARB requirements for Model Year 2026, the BMS shall meet the requirements set by CARB standards, allowing the vehicle in which this battery management system is installed to be sold in the CARB regulation state of California and section 177 states who choose to adopt CARB rules for this time and marketplace.

A-7 CARB and SAE J1979-2 Implementation for Model Year 2027 and after

Not Applicable for Student Competition

For reference only:

For Model Year 2027 and after, the BMS shall communicate with the vehicle's OBD and test equipment based on SAE J1979-2 communication protocols. This specification defines the communication protocol and Open System Interconnect model layers which will allow the incorporation of OBD on UDS and the successful conformity to CARB requirements.

Through the implementation of SAE J1979-2 and ISO 14229-1, which include additional specifications for the successful implementation of CARB requirements for Model Year 2027 and beyond, the BMS shall meet the requirements set by CARB standards, allowing the vehicle in which this battery management system is installed to be sold in the CARB regulation state of California and section 177 states who choose to adopt CARB rules for this time and marketplace.

A-8 CARB and the Advanced Clean Car II (ACC II) Implementation

Not Applicable for Student Competition

For reference only:

For Model Year 2026 and after, the Team shall support the implementation of ACC II requirements. ACC II compliance is required to enable the PHEV and BMS system to obtain Zero Emission Vehicle Credits (ZEV) as identified in ZEV/Emissions Requirements.

The requirements defined here and additions to the requirements, including development needed to implement these changes throughout the program shall be covered by ED&D.

The ACC II requirements shall pertain to the following software criteria and systems to support the procurement of ACC II credits. Supporting regulations to be found in SAE J1979-3.

The Team shall implement the Standardized Data requirements for ZEV credit vehicles, associated with the reporting of BMS parameters on the instrument cluster, DIC, etc.

The Team shall support and provide software (if required) for PHEV High Powered US06 Cold Start Requirements. This may require software improvements to support hardware.

The Team shall support and provide software (if required) for PHEV battery SOH in-use reporting and CARB in-use confirmatory for SOH accuracy and range retention.

The BMS shall meet the requirements set by CARB ACC II standards, allowing the vehicle in which this battery management system is installed to obtain ACC II ZEV credits in the state of California and section 177 states who choose to adopt CARB rules for this time and marketplace.

B Regulatory Compliance

B-1 Responsibility for Compliance

Not Applicable for Student Competition

For reference only:

It is responsibility of the Team to understand conformity measures and to recommend any changes to the specifications that are needed to meet regulations. Should it be determined for governmental compliance that post launch software is need; the Team will provide software changes in fully validated format within the normal time allotted.

After program launch, all software algorithms shall comply with all federal and state mandating rules.

In the event it is determined that the battery is not compliant with governmental regulations, the Team shall make all efforts to resolve this issue per interpretation of the regulations.

C Component Purpose

This document outlines the requirements for the BPCM. The BPCM monitors and reports battery pack cell voltages, battery pack and cell temperatures, cooling inlet and outlet temperatures, and battery pack current. The BPCM also calculates and reports power limits, state of charge, state of health, current and voltage limits. The functions, performance, reliability, and validation required for this component are outlined in this document. The basic function of the BPCM is the management of the battery pack cells and modules. The BPCM usually consists of a central electronic board and local cell supervising electronics for single cell supervision. BPCM functionality includes (but is not limited to) the measurement of battery current and battery voltage values during charge and discharge of battery and also protection from damage, such as overcharge, over discharge, and over/under temperature. It also provides HVIL monitoring and isolation measurement.

D Document Control

The information contained in this specification is considered to be Stellantis Confidential. ‘Stellantis Confidential’ is a designation for information, which has competitive value that, if disclosed, would have adverse consequences to Stellantis. As such, Stellantis intends to protect this information from disclosure to third parties (i.e. persons outside of Stellantis without a ‘need to know’).

D-1 Document Security

The Stellantis Information Security Practices and Procedures relating to the handling of Stellantis Confidential materials shall be followed.

D-2 Document Format

Sections, paragraphs, and sub-paragraphs of this specification will be uniquely numbered as a subset of the category and sub-category of the section into which they fall. Each lower level requirement will bear the same number as its higher-level requirement and will be uniquely identified by the addition of necessary decimal places in the numbering scheme.

D-3 Change Authority

Competition Organizers shall approve all changes to the format and/or content of this specification.

The final decision for any deviations from these requirements shall come from the Competition Organizers.

D-4 Applicable Documents

This document directly expands upon, and flows down from, the requirements specified in the battery pack performance specification. Other documents referenced form a part of this specification to the extent specified herein. Unless otherwise noted, this specification refers to the most recent version of a particular document.

D-5 Order of Precedence

In the event of a conflict between the text of this BMS core software requirement specification and any other Competition Organizers specification, the order of precedence are the other specifications, unless they are explicit to the battery pack software.

Those cases where a requirement fails to meet or exceed an applicable law or regulation or where a conflict occurs between requirements in documents referred to within this specification shall be reviewed by Competition Organizers and any changes to the specification shall be approved by Competition Organizers.

E Independent Monitoring of the BPCM

It will be suggested to have an independent method of assessing the integrity of the BPCM. When the integrity of the BPCM has been compromised, the appropriate action will be taken which may include the shutdown of the system.

E-1 Functional Safety - not required for Battery Workforce Challenge

For reference only:

> *The requirements for independent monitoring of the BPCM shall be determined by jointly conducting a functional safety analysis by the supplier. The final design configuration shall require Stellantis's approval.*
>
> *Basic functional safety analysis can be proposed and reviewed with Stellantis.*
>
> *Any discrepancies shall be brought forth to Stellantis for resolution.*
>
> *Routines and DIDs which allow the verification of the functional safety requirements shall be available for vehicle testing.*

F CAN COMMUNICATIONS

Refer to the specifications provided in the Specifications Table for complete CAN specifications.

F-1 Additional CAN Requirements

The BPCM shall have at least 3 high-speed CAN channels (two for communication with other vehicle controllers, one for communicating sensor and operation values inside the battery pack).

BPCM CAN Hardware Interfaces:

- Primary ePT
- Secondary ePT (redundant)

The Team shall implement the CAN messages using DBC and CMM files supplied by Stellantis.

All CAN signal mapping shall be verified to ensure the correct value is being broadcast in the correct signal

CANalyzer or similar CAN tool shall be used to collect data at both the vehicle and battery pack levels.

All the attributes of vehicle CAN in the. dbc file should be validated for default values transitioning to actual values during initialization by the Team.

F-2 Internal controller signal data capture

It is recommended for teams to implement either an additional internal CAN bus (debugging bus) or something like ETAS xETK with INCA for data capture and debugging both in real time and afterwards. This battery side connection should be available for when battery pack is on the bench or in the vehicle while driving. The teams may choose to create a wiring breakout harness to interface between the vehicle harness and the battery back.

Key data collected could be cell voltages, cell temperatures, coolant temperatures, feedback of individual contactor status, feedback from all current sensors, bus voltage, and any other internal variables that are needed for vehicle development.

G Power Up/Down, Initialization, Battery Conditioning

G-1 Power Up and Power Down

The BPCM shall follow the requirements below for Power Moding.

Hardware (HW) Wakeup control from Electric Vehicle Control Unit (EVCU)

- Don't set a nuisance DTC: In order to properly determine if the Service Disconnect is out after the HCP Shutdown Command, the BPCM shall be permitted to continue sourcing its internal HVIL loop. If the HVIL fails, then the isolation check shall be terminated so that a false isolation DTC is not set.

G-2 BPCM Initialization

The BPCM will control the actuation of the contactor when appropriate conditions and timing exist.

If the BPCM inhibits closing of the contactor or determines a fault condition, it shall set the applicable diagnostic code.

Once the BPCM has received the proper wake-up signals to begin its initialization process, the BPCM shall first perform functions that are essential to close contactor. These functions include:

- Performing essential voltage, current, and temperature measurements specific to computing and reporting the available discharge power
- Sourcing of HVIL
- Reading EEPROM specific to last isolation state and SOC from previous ignition cycle

The BPCM shall not exceed the timing in the following BPCM Wakeup Timing table:

		Closed via CAN	
No.	Event	Event Timing (ms)	Total Timing (ms)
1	Wake-up signal received (12V input line for wake-up)	0	0
2	HVIL is sourced	60	60
3	Remaining BPCM initialization processes--	100	160
4	All transmitted CAN signals are determined	40	200
5	BPCM transmits Contactor Status	20	220
6	Check that: Qualified Contactor Command = CLOSE and HVIL status = PASS Note: Timing assumes Contactor	20	240

	Command from Vehicle Controller is immediately received. This timing could be delayed if the BPCM waits for the HCP's Contactor Command (See Section I-1 Contactor Control).		
7	Precharge sequence and negative contactor/precharge relay closed	40	280
8	BPCM transmits Battery Contactor Status as "Precharging"	20	300
9	Precharge Process Time reaches 95% of pack voltage	100	400
10	BPCM Commands Positive Contactor Closed then commands Precharge sequence terminated	40	440
11	BPCM transmits Contactor Status as Closed	30	470

BPCM shall enable Loss of Communication diagnostics with EVCU independent of receiving the LOC Diagnostics Enable command from HCP. The diagnostic shall be set after 5000 ms of wake-up.

BPCM Power-Down Requirements

1) START: BPCM is awake (CAN Active & powered-up)

2a) If HV Contactors are Open, go to #3

2b) If HV Contactors are Closed
BPCM shall Open HV Contactors on receiving an "Open Contactors" command from HCP, then go to #3

3) BPCM shall initiate its Controller power-down sequence and be prepared to shutdown within TShtdwn(1200 ms) + 120 sec (maximum) of receiving the HCPShutDwnCmd = Initiate Powerdown command from the EVCU EPT-CAN communication shall remain active.

4) If EVCU sends a Cancel Power-down command
BPCM shall cancel its Controller power-down sequence and resume operation

5) Upon receiving the Disable LOC Diagnostics command from EVCU, BPCM shall disable its LOC diagnostics (on EPT-CAN network) Upon receiving the HCPShutDwnCmd = Shutdown Comm command, BPCM shall shutdown EPT-CAN communication within TShtComm(250 ms) of receiving this command - De-source HVIL

6) BPCM shall initiate its Pre power-down actions

7) BPCM shall continue to monitor the HW Wakeup line from EVCU for any transitions
Did the HW Wakeup line transition from High to low to High ?
Yes: BPCM shall re-start the power-up process
No: Go to #8

8) BPCM shall complete its **Pre power-down** actions

9) Is the HW Wakeup line from EVCU Low ?

Yes: BPCM shall execute a controlled power-down
No: Go to #10

10) Did the HW Wakeup line transition from High to low to High ?
Yes: BPCM shall re-start the power-up process
No: BPCM shall set a DTC and execute a controlled power-down

H High Voltage Interlock Loop (HVIL)

The High Voltage Interlock Loop shall provide an indication of the integrity of the High Voltage Propulsion Bus. When there is a break in the HVIL, it indicates that a high voltage component may be compromised or disconnected.

The BPCM shall be the energy source and energy sink for the High Voltage Interlock Loop (HVIL) circuit.

There shall be two "HVIL type" loops in the battery pack. One HVIL loop (External HVIL) goes out through the High Voltage Propulsion Bus.

The other "HVIL loop" is actually not a loop, it is a separate 12V power feed for the contactors, going through a Remote High Voltage Disconnect and Lockout (HVDL) and ending into the battery pack.

H-1 HVIL Requirements

H-1.1 Sourcing External HVIL

The BPCM shall energize the HVIL circuit within Ke_t_HVILOnTimeout (Information: Default -60ms) when the following is TRUE:

- BPCM wake up from Sleep = TRUE (i.e. when the hardware wakeup line (ePT ECU Wakeup) is received) **OR** BPCM EPT Modes transitioning from OFF to ACCESSORY, RUN, or CRANK REQUEST

  NOTE: About 50ms (calibration value) delay may occur due to the initialization.

AND

- On Initialization, startup inhibit flag is not set.

Startup Inhibit Fault flag shall be set when ANY of the following conditions are true:

- BPCM Observed Impact Faults are TRUE on initialization
- BPCM Observed Loss of Internal Isolation Faults are TRUE on initialization
- BPCM Welded Contactor Faults are TRUE on initialization

H-1.2 De-Sourcing External HVIL

The BPCM shall de-energize the HVIL circuit (stop the PWM) when **ANY** of the following are TRUE:

- The Shutdown command – TRUE [HCPShutDwnCmd = Shutdown]
- When hardwired wakeup signal transitions from high to low AND Loss of Comm with HCP=TRUE
- When Contactors are OPEN AND ePT wakeup transitions from High to Low.
- BPCM Observed Impact Faults are TRUE, the BPCM shall desource the HVIL circuit

The BPCM shall set High Voltage Interlock Status to "Not Sourced"

H-1.3 De-Sourcing Internal HVIL

The BPCM shall de-energize the HVIL circuit (stop the PWM) when ALL the following are TRUE:

- Contactors are Opened (post weld check)
- Internal Isolation is Complete
- BPCM is transitioning to Sleep Mode

The BPCM shall de-energize the HVIL circuit when BPCM observed Impact Faults are TRUE.

H-2 Diagnostics to Determine High Voltage Interlock Status

The diagnostic to determine High Voltage Interlock Status shall be executed with at least a 100ms refresh rate (i.e. HVIL Fault should be detected in 100ms or less).

The diagnostic shall initially be executed within 100ms of the HVIL circuit becoming energized.

The BPCM shall set High Voltage Interlock Status to "Pass" when the BPCM senses the PWM frequency and duty cycle to be within range.

The BPCM shall set High Voltage Interlock Status to "Fail" and communicate that status to the vehicle system within 100ms via CAN HVBatIntrlkStat = Fail when the BPCM senses the PWM frequency and duty cycle to be out of range.

The BPCM shall set High Voltage Interlock Status to "Not Sourced" whenever the BPCM has not sourced HVIL or cannot measure the HVIL circuit (i.e. prior to initial measurement or due to a BPCM hardware failure), or when HVIL circuit has been de-asserted after receiving HCPShutDwnCmd = Shutdown.

The value of High Voltage Interlock Status shall be determined by using the following logic:

- UNDETERMINED (NOT SOURCED) – at the beginning of the BPCM wake up until the initial evaluation is complete or when HVIL circuit has been de-asserted after receiving the coordinated shutdown command.
- PASS when ALL the following are TRUE:
  - The test has run for a time equal to KeHVLR_t_HVILOpenSamplesDurationTime
  - The BPCM has not detected an electrical fault with the HVIL circuit (Shorted High, Shorted Low, Open for both External and Internal, OORL, OORH)
- FAIL when ALL the following are TRUE:
  - The test has run for a time equal to KeHVLR_t_HVILOpenSamplesDurationTime
  - The BPCM has detected an electrical fault with the HVIL circuit external or Internal to the battery (Open External, Open Internal, OORL, OORH)
- INVALID when ALL the following are TRUE:
  - The test has run for a time equal to KeHVLR_t_HVILOpenSamplesDurationTime
  - The BPCM has detected an electrical fault with the HVIL circuit External or Internal to the battery (shorted High, Shorted Low)

The BPCM shall perform Short to high, short to low and open circuit diagnostics on the external and internal HVIL line when the circuit is energized.

H-3 Calibrations Associated with HVIL

The following internal BPCM calibrations shall be associated with HVIL:

Calibration	Unit/Type	Description
Ke_t_HVILShortSamplesDurationTime	Time (s)	The duration of time for which HVIL must be measured to diagnose a short
Ke_t_HVILOpenSamplesDurationTime	Time (s)	The duration of time for which HVIL must be measured as open.
Ke_t_HVIL_Dly_Tim	Time (s)	The amount of time for which the HVIL Diagnostic will delay start to maturing post wake up
Ke_t_HVILOnTimeout	Time (s)	Expiry Time before which HVIL needs to be energized on startup

H-4 CAN Signals Associated with HVIL

HVBatIntrlk_InternalStat – BPCM shall detect internal current loop and transmit status on CAN as Not Sourced (N_S), Pass, Fail, or Invalid (INV).

HVBatIntrlkStat – BPCM shall report the vehicle high voltage interlock state as Not Sourced (N_S), Pass, Fail, or Invalid (INV).

I Contactor Control

The battery voltage is separated from the propulsion high voltage bus by two normally open, single pole contactors.

The contactor closing and opening process includes, but is not limited to, the following algorithms: command validity determination, bus capacitive precharging, shorted bus detection, welded contactor detection, and isolation detection.

The process for the closing and opening the contactors can be summarized by the vehicle controller sending a contactor command, the command being received by the BPCM, and the BPCM executing the command provided all the conditions for closing or opening the contactors are met.

I-1 General Contactor Control Requirements

I-1 General Hardwire PWM Contactor Control Requirements

I-1.1 During the LOC with Vehicle controller, BUS Off, or invalid CAN data active fault, the BPCM shall enable the power limit flag and step change power limits to +/- 3kW.

I-2 Internal Variables and Calibrations Associated with Main Contactor Control

The following internal variables and calibrations shall be used in main contactor control:

Calibration	Unit / Type	Description
Ke_I_ImpendingOpenLowBatteryCurrent	Current (A)	This calibration represents the amount of current that the BPCM considers to be low enough to open contactors when in an impending open situation.
Ke_t_BPCMContactorLowCurrentTime	Time (s)	This calibration represents the amount of time the BPCM has observed Ke_I_ImpendingOpenLowBatteryCurrent or less battery pack current before it can open the contactors when in the impending open situation.
Ke_t_BPCMContactorMaxDelayTime	Time (s)	This calibration is used by the BPCM as the overriding timer to get out of an impending open situation.
Ke_v_ContactorOpenControlledShutdownVehicleSpeed	Speed (km/h)	This calibration represents the vehicle speed at which the BPCM may open contactors in an impending open situation.
Ke_U_12VInputBPCMOverVoltage	Voltage (V)	This calibration represents the upper voltage threshold in which the BPCM will set the Request Open Command to Request Open.

Ke_U_12VInputBPCMUnderVoltage	Voltage (V)	This calibration represents the lower voltage threshold in which the BPCM will set the Request Open Command to Request Open.
Ke_t_12VInputBPCMUnderVoltageTime	Time (s)	If the 12V un-switched battery voltage is less than 12VInputBPCMUnderVoltage for longer than this time, the BPCM will open contactors.
Ke_T_HVBPMaxElementOverTemp	Temperature (C)	Indicates the maximum temperature that the BPCM will keep the contactors closed.
Ke_t_HVBPMaxElementOverTempTime	Time (s)	Indicates the time period that a high voltage battery pack element must exceed it's over temperature threshold before the contactors are requested open.
Ke_t_HighVoltageBusPrechargeTime	Time (s)	Indicates the amount of time in which the precharge function is expected to be complete.
Ke_t_CnctrCloseDebounce	Time (s)	Indicates the amount of debounce time in which the contactor is forced to stay open once a OPEN TO CLOSE command is triggered.
Ke_ P_LimpRegenPwr	Power (kW)	Indicates allowed regenerative power in Limp Mode
Ke_ P_LimpDischargePwr	Power (kW)	Indicates allowed discharge power in Limp Mode

Internal Signals:

Signal	Unit / Type	Description
Verified Contactor Command	Enumeration	The Verified Contactor Command represents the BPCM's interpretation of the contactor command received from the Vehicle Controller (as determined from either CAN Bus). This will be stored as an internal BPCM variable that can be observed via a DID or on the BPCM's internal CAN.
Qualified Contactor Command	Enumeration	The Qualified Contactor Command represents the BPCM's internal determination of what the contactor command needs to be based on it's own interpretation of the current state of the system. For example, if the BPCM determines that contactors need to be opened due to a diagnostic fault, the Verified Contactor Command from the vehicle might still be "CLOSED" but the Qualified Contactor Command should be "OPEN"

I-3 Battery Contactor Status

The value of the High Voltage Battery Contactor Status represents the driver state of the battery pack contactors at the time of signal transmission and is transmitted via CAN. The battery pack contains the following contactors: negative main, precharge and positive main contactor.

The value of Battery Contactor Status shall be determined by the following logic:

- OPEN – Positive Main and precharge contactors are de-energized because of any of the following items:
    - A transition from the CLOSED state
    - The commencement of an Operation Cycle (key on battery pack woken up from sleep) and BPCM Precharge Circuit Thermal Protection is DISABLED
- PRECHARGING – the Negative Precharge Contactor(s) are energized
- CLOSED – the Breaktor/Negative and Positive Main Contactors are energized
- PRECHARGE FAILED – all contactors are OPEN due to any of the following items:
    - Remaining in PRECHARGING state for a continuous duration of time more than Ke_t_HighVoltageBusPrechargeTime
    - BPCM Disconnected HV Bus Detected transitioning from FALSE to TRUE (HVIL open)
    - BPCM Precharge current too high Detected transitioning from FALSE to TRUE
    - A retry attempt within the PRECHARGING state
- PRECHARGE INHIBITED - all contactors are de-energized because of BPCM Precharge Circuit Thermal Protection transitioning from DISABLED to ENABLED (cool down period for precharge resistor to cool down)
- Otherwise, retain last known value

At wakeup, Battery Contactor Status shall remain in its initialized state until the BMS can initialize and detect the correct state of “HVBatCntctrStat” and transition accordingly.

The value of Battery Contactor Status shall be updated within two transmission cycles of the message containing it on the CAN bus.

If the Battery Contactor Status is set to PRECHARGEINHIBIT, then the BPCM shall set the appropriate Diagnostic Trouble Code (DTC) to FAIL.

Otherwise, the BPCM shall set the DTC to PASS. The specific DTC will be dependent upon the value of BPCM Disconnected Bus Detected.

I-4 Connecting to the Bus

Connection to the bus shall involve two sequential steps:

1. Precharge
2. Completion of the Circuit

I-5 Precharge

Precharging the HV bus (precharge relay closed until HV bus is charged) is defined as charging the HV bus voltage to a voltage that is within a predetermined voltage (calibratable, typically 95%) of the battery pack voltage in less than a predetermined amount of time.

Precharging the HV bus allows the battery pack voltage to be applied through the precharge resistor, which yields a “ramped-in” voltage waveform and avoids an uncontrolled high current.

The precharge contactor has a current limiting resistor in series for raising the propulsion bus voltage up to the battery pack voltage before the main contactors are closed.

I-6 Precharge Initiation

The precharge process shall occur by closing the precharge contactors (positive and negative) after the BPCM has completed the wake-up procedure.

After determining the Vehicle Controller is commanding the contactors closed, the BPCM shall precharge the HV bus (close the Precharge Contactors, but do not close the Main Contactors/Breaktor) when HVIL has been asserted and ALL the following are TRUE:

- HVIL continuity has been confirmed
- Qualified Contactor Command is equal to CLOSED
- Contactor close inhibit conditions are not present (Weld Check, Isolation etc.)

I-7 Precharge Complete Criteria

The BPCM shall determine the precharge completion by comparing the battery pack voltage to the bus voltage (also called the link voltage). The link voltage shall be within a calibrated percentage of the pack voltage.

If the BPCM is unable to connect to the HV bus, the following shall be completed:

- DTC shall be set TRUE determined by DTC matrix
- Precharge status shall be set to FAILED

The BPCM shall connect the main HV bus (close Positive Main Contactor) when ALL the following are TRUE:

- Vehicle Controller commands contactors to” CLS” (close)
- Precharge is complete

The BPCM shall send the CAN signal HVBatCntctrStat (Battery Contactor Status), within the next two CAN samples.

Precharge Time-Out and Circuit Thermal Protection

The BPCM shall terminate precharge if the precharge complete criteria has not been achieved after a prescribed time.

The BPCM shall allow sufficient time for the precharge circuitry to cool before reattempting precharge and provide a count down timer until next allowed attempt through the Precharge Penalty Timer Prchrgpnltytimer.

The Precharge Penalty Timer shall continue to count down independent of key position or wake/sleep state of the BPCM.

In the event of loss of 12V during precharge penalty timer BPCM shall restart precharge penalty timer after loss of 12V recovers.

Once the Precharge Penalty Timer reaches zero, the BPCM shall attempt Precharge once the Main High Voltage Contactor Command = Close.

When a precharge inhibit is not active, the BPCM shall retry attempts to precharge until cool down period is needed (enabling of Precharge Thermal Protection), as determined by the Team.

During the inhibit, the CAN signal HVBatCntctrStat shall indicate “Precharge Inhibited.”

After failing multiple attempts in a row (when only millisenconds between each precharge attempt), the CAN signal HVBatCntctrStat shall indicate transition between PRECHARGE and PRECHARGE FAILED.

I-8 Precharge Diagnostics

The BPCM shall determine if the precharge is successful.

The BPCM shall detect and communicate through DIDs or DTCs the following during the precharge sequence:

- Precharge into a short (Shorted Bus or current too high)
- Precharge too long
- Precharge too short

AND take appropriate actions as defined in the DTC Matrix.

Information:

- The internal variable for BPCM Shorted Bus Detected shall indicate whether the current decays sufficiently during the precharge process of the High Voltage Propulsion Bus.
- The battery current shall be monitored such that when the current does not decay, it is an indication that the High Voltage Propulsion Bus may have a short between its positive and negative terminals.

The BPCM shall communicate the status of precharge: precharging, precharge inhibited, precharge failed through CAN.

The diagnostic Precharge Time Too Short shall not set unless the starting link voltage is below a certain calibratable value (Ke_U_PrechargeDischargeLinkVoltage) when precharging to ensure the diagnostic does not falsely set in passive discharge conditions.

The BPCM shall store to EEPROM the result of precharge diagnostics and all associated FOMs.

I-9 Internal Variables and Calibrations Associated with Precharge

The following internal variables and calibrations shall be used with Precharge and shall be accessible via DIDs:

Calibration	Unit / Type	Description

Ke_n_FailedVoltageElementSensorFailNumber	Count	Represents the number of voltage sensors that must fail in the HV battery pack before the BPCM will set the High Voltage Battery Voltage Validity signal to invalid.
Ke_U_BusDisconnectThresholdVoltage	Voltage (V)	Represents the voltage threshold in which the propulsion bus voltage must be to have successfully performed a high voltage discharge.
Ke_t_HighVoltageBusPrechargeTime	Time (s)	Represents the amount of time that is allowed for precharging the HV bus (i.e. the amount of time the HV bus voltage must reach a predetermined voltage of the battery pack voltage).
Ke_t_BPCM_Precharge_Fail_Penalty_Time	Time (s)	Indicates how much time must elapse for the precharge resistor to return to its normal thermal operating range.
Ke_t_PrechargeFailCoolTime	Time (s)	The amount of time the precharge penalty timer is incremented each time the precharge contactor is energized.
Ke_t_HighVoltageBusPrechargeTime	Time (s)	The amount of time in which the precharge function is expected to be complete.
Ke_t_ExtraPrechargeFailCoolPenaltyTime	Time (s)	Indicates an additional amount of time that the precharge resistor may need to cool to return to normal operating temperature after a failed precharge has occurred.
Ke_t_PrechargeFailMaxPenalty	Time (s)	Indicates the time threshold that must be exceeded to transition to the Precharge Inhibit contactor state.
Ke_I_HighVoltageBusShortageCurrent	Current (A)	The current as seen on a shorted bus during precharge. If current hasn't risen to within this level after contactors are reported closed, then the Vehicle Controller will command the contactors open.
Ke_t_PrechargeDetectedBusShortPeriod	Time (s)	The amount of time the BPCM will wait to see the high voltage battery current decay below 50% of its initial value.
Ke_t_CnctrCloseDebounce	Time (s)	Indicates the amount of debounce time in which the contactor is forced to stay open once an OPEN TO CLOSE command is triggered.

Internal Signals:

Signal	Unit / Type	Description
BPCM Bus Voltage Source	Enumeration	Identifies the origin of the BPCM High Voltage Bus Voltage.
BPCM Precharge Pack Voltage	Voltage (V)	Represents the voltage on the battery pack side of the contactors during precharge. It can differ from the signal that is transmitted via CAN as High Voltage Battery Pack Voltage.
BPCM Precharge Circuit Thermal Protection	Boolean	Identifies when the precharge contactor cannot be energized to prevent damage to the precharge circuitry (contactor status of precharge is inhibited).
BPCM Precharge Pack Voltage Source	Enumeration	Identifies the origin of the BPCM precharge battery pack voltage.
BPCM Bus Voltage	Voltage (V)	Represents the voltage measurement of the High Voltage Bus using the BPCM Bus Voltage Sensor located on the vehicle side of the High Voltage Battery Pack Contactors. This variable is different than the voltage measurement sent on the CAN bus.
Prchrgpnltytimer	Time (s)	Indicates the amount of time to allow precharge circuitry to cool before reattempting precharge.

I-10 CAN Signals Associated with Precharge

HVInvRatVlt – The rationalized voltage that the BPCM uses as a backup for precharge in the event that the high voltage bus sensor read by the BPCM is providing non-credible data. It is the vehicle controller's measurement of the DC Propulsion Bus Voltage.

HVInvRatVltV – The vehicle controller's determination of the validity of its DC Propulsion Bus Voltage. The BPCM uses this to decide if precharge can be completed and the positive main contactor can be closed.

I-11 Contactors Opening or Prevented from Closing

The BPCM shall report all reasons for not closing the contactors when commanded, did not complete a precharge, or opened contactors while they were commanded closed. These strategies shall be defined in the DTC Matrix.

The BPCM shall close contactors when commanded and shall only prevent contactors from closing when in an faulted condition.

When the faulted condition is gone and if contactor close is not inhibited, the BPCM shall close contactors in the following key cycle (i.e. a contactor open command to a contactor closed command), provided conditions to close contactors are met.

No fault that prevents contactors from closing shall exist without a DTC.

If the contactors open when commanded closed, the condition shall be able to be traced back to a unique DTC that signifies the reason for why the contactors opened.

If the contactors are inhibited from closing, the DTC shall not clear in the same key cycle, even if a loss of 12V occurs.

Contactor inhibit and DTC shall be cleared through service control routine.

On Vehicle Controller contactor command signal MainHighVltCntctrCmd = Fast Open, then BPCM shall open contactors immediately and not allow diagnostic checks (such as weld or isolation) to delay the open.

The BPCM shall inhibit contactor closure until both internal and external HVIL are passing.

I-12 Contactor Weld Check Diagnostics

The BPCM shall monitor the bus voltage after the contactors have been opened to ensure that the voltage drops when the contactors have opened.

The BPCM shall populate HVBatCntrWeld_ImpdOpn = STUCK_CLOSED whenever a welded contactor has been detected.

On shutdown the BPCM shall check for individual contactor weld.

The DTC's shall be set according to DTC Matrix on how individual weld checks will be completed.

The BPCM shall desource HVIL with an active contactor weld diagnostic.

I-13 Conditions When to Perform Contactor Weld Check

The BPCM shall perform a voltage based weld check when ALL of the following are TRUE:

- Qualified Contactor Command has transitioned from CLOSED to OPEN

The BPCM shall NOT perform a voltage based weld check diagnostic if ANY of the following conditions are TRUE:

- Qualified Contactor Command is transitioning from IMPENDING OPEN to OPEN
- Qualified Contactor Command is OPEN while Vehicle Speed > Ke_v_WeldCheckEnableSpeed
- There is an impact (which will be communicated from the Vehicle Controller through the Contactor Command signal as IMPACT OPEN)

The BPCM shall be able to enable/disable the weld check diagnostic through the parameter Ke_b_WeldCheckEnabler using the following logic and this logic should only be used during development of the program and should be disabled in production:

- Ke_b_WeldCheckEnabler = 0 shall be interpreted as weld check diagnostic disabled
- Ke_b_WeldCheckEnabler = 1 shall be interpreted as weld check diagnostic enabled
- The Ke_b_WeldCheckEnabler shall be accessible through a DID.

I-14 Conditions to Interrupt Contactor Weld Check

The weld check diagnostics should be interrupted in the following conditions:

- Insufficient 12V supply
- Controller RAM / ROM / EEPROM Error, Micro-controller failure detected
- BPCM observes HW Wakeup line transitions from Low to High
- Welded Contactor Error Storage

The BPCM shall store the status of the Weld Check through a DID and a DTC.

On shutdown the BPCM shall implement a retry strategy on the diagnostic with the following method.

1. Voltage based welded contactor test during shutdown and if pass, complete shutdown based on vehicle controller command and do not set DTC.
2. If fail, wait for enough time for passive discharge on the bus to occur then repeat welded contactor test and if pass or fail, continue to shut down and do not set DTC. Loss of 12V shall not erase the count of retry strategy.
3. On wake-up perform welded contactor test if test on power-down failed. If pass, continue power-up and do not set a DTC.
4. If fail then set weld DTC = TRUE.

Once welded contactor fault is set to TRUE, the state of the BPCM welded contactor diagnostics shall be latched until reset by a service tool.

Once welded contactor fault is set as active, loss of 12V shall not erase the fault status.

I-15 Contactor Control Circuit Diagnostics

The BPCM shall perform the following diagnostics on the coils in the appropriate contactor state for each of the contactors:

- Contactor control high side drive circuit shorted high
- Contactor control high side drive circuit shorted low
- Contactor control low side drive circuit shorted high
- Contactor control low side drive circuit shorted low
- Contactor control circuit open

The BPCM shall internally store the following state of coils for each of the contactors

- Contactor coil high side state – Normal, Shorted low, Shorted high, Open
- Contactor coil low side state – Normal, Shorted low, Shorted high, Open

The state of each of the contactor control high side and low side drive circuits shall be stored and accessible via DID.

The diagnostics for each of the failure mode shall have a unique DTC and the fault reactions shall be defined in the DTC matrix.

I-16 Contactor Stuck Open Diagnostics

The BPCM shall perform contactor stuck open detection when the contactors have been commanded to close.

If the BPCM detects a contactor stuck open, then HVBatCntrWeld_ImpdOpn = STUCK_OPEN.

The BPCM shall store the status of the contactor stuck open for each of the contactors and shall be accessible via DID

The contactor closing sequence shall be inhibited or aborted if ANY of the contactors have been diagnosed with contactor stuck open conditions due to coil fault and an appropriate DTC shall be set.

The contactor closing sequence shall desource HVIL if ANY of the contactors have been diagnosed with contactor stuck open conditions during a closing sequence.

The BPCM shall set DTCs in accordance to the DTC Matrix.

J LOSS OF ISOLATION DETECTION

Loss of Isolation Detection (LOI) is an on-vehicle diagnostic function that detects the loss of galvanic separation between the HV circuits and chassis ground including LV circuits. The degree of LOI is controlled by regulatory requirements and industry standards. There are two isolation values that must be determined:

1. Isolation within the battery pack when the contactors are open
2. Isolation on the vehicle high voltage bus when the contactors are closed.

J-1 General Requirements for Loss of Isolation (LOI)

All Isolation requirements and Isolation Monitoring/Testing requirements in FMVSS 305 shall supersede the requirements in this document.

The BPCM shall monitor the HV bus to determine that the chassis and HV bus are isolated from one another.

If the BPCM determines the HV bus and chassis are not isolated, then the BPCM shall set the appropriate diagnostic and perform appropriate activities.

At the beginning of an Operation Cycle, the value of Isolation Status shall be initialized to the last recorded value in memory.

The BPCM shall perform Isolation after weld check sequence is completed or aborted.

On the event that HVBatIsolStat has remained failed through power down, on the next key on (and subsequent key cycles) thecontactors shall be inhibited from closing until cleared by a service routine.

Once HVBatIsolstat has failed and fault is set as active, loss of 12V shall not erase the fault status.

J-2 Isolation Abort and Inhibit Requirement

The BPCM shall abort Isolation Detection when ANY of the following is TRUE:

- Transition of HVIL Status to Failed
- Internal Isolation Circuitry has failed
- Contactors are undergoing closing or opening sequence
- When the BPCM receives the UDS $0308 Hybrid Battery HV - Isolation test, (in order to start the UDS routine) it shall first terminate the Isolation test that is underway and reset associated diagnostic variables to restart the test as commanded.

The BPCM shall inhibit Isolation Detection when ANY of the following is TRUE:

- Weld Check Contactor Faults are True
- HVIL Status is Failed

J-3 Isolation Status

The signals, HVBatIsolStat and PwrtrnHV_IsolStat, shall be used to indicate the status of isolation tests.

HVBatIsolStat shall indicate the status of the open contactor isolation detection status.

PwrtrnHV_IsolStat shall indicate the status of the closed contactor isolation detection status

The BPCM shall set the Isolation Status CAN signals (HVBatIsolStat and PwrtrnHV_IsolStat) to Not Sourced (N_S) when it has not performed the isolation detection. This includes initialization, when contactors are Open, or during any BPCM hardware failures.

The value of Isolation Status shall only be changed/updated once a complete isolation test has been performed on the Battery Pack.

After performing the isolation test, the BPCM shall report the Isolation Status as either “Pass” or “Fail.”

J-4 Isolation Diagnostics

On the event that the powertrain isolation has failed, a service light shall persist through key cycles until cleared by a service tool.

Diagnostic capability shall be able to determine the integrity of the Loss of Isolation circuitry.

This diagnostic test shall not occur if the contactors are welded.

All values of isolation and the statuses shall be available through diagnostic services via DIDs.

J-5 Isolation Routine at EOY Competition

In addition to Loss of Isolation monitoring, the Loss of Isolation routine will also be used in the End Of Year Competition validation process.

At least the following three cases shall be supported by the BPCM for the End Of Year Competition validation process (more cases shall be added, if necessary).

Case 1: Pack Test

- Battery Pack with Manual Service Disconnect installed and contactors open
- Routine Ctrl → Perform Isolation Test
- Monitor Pass/Fail

Case 2: Negative Rail Test

- Battery Pack with Manual Service Disconnect installed
- Routine Ctrl → Close Negative Precharge Relay
- Routine Ctrl → Perform Isolation Test
- Monitor Pass/Fail
- Routine Ctrl → Open Negative Relay

Case 3: Positive Rail Test

- Battery Pack with Manual Service Disconnect installed

- Routine Ctrl → Close Positive Precharge Relay
- Routine Ctrl → Perform Isolation Test
- Monitor Pass/Fail
- Routine Ctrl → Open Positive Relay

After completion of each of the test cases, the battery pack shall report the isolation impedance value via a DID

J-6 Calibrations Associated with Isolation Detection

Ke_R_IsolationFailResistanceLevel – This calibration shall represent the minimum level of measured resistance on the DC bus, determined by using an AC isolation method, which must be observed to consider that the bus is in a PASS state of isolation (default = 350 kOhms).

J-7 CAN Signals Associated with Isolation Detection

HVIsolStat – High Voltage Battery pack Isolation state

PwrtrnHV_IsolStat – Powertrain High Voltage Isolation state

K IMPACT RESPONSE BY THE BPCM

K-1 General Impact Response Requirements for BPCM

Three impact threads shall be employed to ensure HV shut down during an impact event:

1) Impact Message – BMS Optimal Thread. HCP transmits the ORC crash signal received through the Main High Voltage Contactor Command CAN message to the BMS

2) Impact Message - Direct Delayed Thread (Secondary Thread). BMS receives gated CAN ORC message through HCP.

3) Impact Message - Loss of Messages Thread. BMS assumes there was an impact due to no valid main contactor command message received on either primary or secondary CAN bus

The Occupant Restraint Component (ORC), HCP, and BMS strategy shall use the dual (redundant) CAN Bus to provide redundant communications.

Impact Response shall not be evaluated when ignition is off or accessory (HCP_GW_20.CmdIgnStat = IGN_LOCK or HCP_GW_20.CmdIgnStat = IGN_OFF_ACC). The ORC module is not communicating in Ignition Status equal to Lock and Accessory, so there is no need to run diagnostics on the ORC under these conditions.

The BMS shall receive HCP gated ORC signals on e-PT CAN busses.

In conditions with a vehicle impact, BMS shall specify ImpactHardwire = Actuate and ImpactHardwireV = Fail_Not_Present.

In conditions without a vehicle impact, BMS shall specify ImpactHardwire = Do_Not_Actuate and ImpactHardwireV = Fail_Not_Present.

The HCP gates impact crash signals from the vehicle CAN to ePT CAN via IMPACT_INFO.IMPACTCommand and IMPACT_INFO.IMPACTConfirm.

In conditions without a vehicle impact, the IMPACT_INFO.IMPACTCommand = Do_Not_Actuate and IMPACT_INFO.IMPACTConfirm = Do_Not_Actuate signals shall specify the communication path is operational.

In conditions with a vehicle impact, the IMPACT_INFO.IMPACTCommand = Actuate and IMPACT_INFO.IMPACTConfirm = Actuate signals shall specify an impact has occurred. The BMS must receive both actuate signals for a confirmed impact.

K-2 Impact Response Development

The BPCM shall provide the type of impact thread that occurred: Optimal, Direct Delayed, Loss of Message or No Impact.

The BPCM shall retain the type of impact thread that occurred in nonvolatile memory.

18.2.3. Reset type of impact thread occurrence to No Impact.

K-3 Optimal Thread

In conditions with a vehicle impact, the HCP shall initiate an impact open request via the Hybrid_Command_BPCM.MainHighVltCntctrCmd = Impact Open signal to specify an impact has occurred.

Upon receiving one valid sample of the Hybrid_Command_BPCM.MainHighVltCntctrCmd = Impact Open signal, the BMS shall set BPCM_MSG_01.HVBatCntctrReq = True and BPCM_MSG_01.HVBatCntctrOpn = True, set the corresponding Impact DTC (P167B) to be Active, and Open_HV_Contactors immediately without waiting any delay.

"Open_HV_Contactors" shall be defined as commanding all HV Contactors to mechanically open and the HV Bus external of the HVBS shall be galvanically separated from the HVBS cells and any internal power sources.

When detecting Impact via the Optimal Impact Response Thread, the BMS shall set "Lockout_BMS_Contactor_Close_Operation", which shall be defined as the BMS not allowing HV contactors to close unless a reset is provided by an external service tool.

K-4 Direct Delayed Thread

In conditions with a vehicle impact, the HCP shall initiate an impact open request by gating messages from the ORC via the IMPACT_INFO.ImpactCommand = Actuate and IMPACT_INFO.ImpactConfirm = Actuate signals to specify an impact has occurred.

Upon receiving four valid samples of IMPACT_INFO.ImpactCommand = Actuate and IMPACT_INFO.ImpactConfirm = Actuate signals, the BMS shall set BPCM_MSG_01.HVBatCntctrReq = True and BPCM_MSG_01.HVBatCntctrOpn = True, set the corresponding Impact DTC (P167B) to be Active, and Open_HV_Contactors within the short delay reaction timer (default = 1500ms).

When detecting Impact via the Direct Delayed Impact Response Thread, the BMS shall set "Lockout_BMS_Contactor_Close_Operation", which shall be defined as the BMS not allowing HV contactors to close unless a reset is provided by an external service tool.

K-5 Loss of Message Thread

The BMS upon not receiving a valid HCP main contactor command on ePT CAN (Hybrid_Command_BMS) for duration of time as specified by "BMS_Loss_of_Message_Timer" calibration (Ee_Impact_Loss_Of_Comm_Detection), default value of which shall be 1000ms, the BMS shall assume that an impact event has occurred.

An invalid HCP main contactor command on ePT CAN shall be defined as, on both Primary AND Secondary CAN, receiving message with incorrect CRC or MC, not receiving a message (Loss Of Communication), or detecting a Bus Off condition (CAN line shorted or open).

Upon reaching the "BMS_Loss_of_Message_Timer" time, the BMS shall set BPCM_MSG_01.HVBatCntctrReq = True and BPCM_MSG_01.HVBatCntctrOpn = True, set the corresponding Impact DTC (P167B) to be Active, and Open_HV_Contactors within the short delay reaction timer (default = 1500ms).

When detecting Impact via the Loss of Message Impact Response Thread, the BMS shall set "Lockout_BMS_Contactor_Close_Operation", which shall be defined as the BMS not allowing HV contactors to close unless a reset is provided by an external service tool.

The Loss of Message Thread shall be evaluated 7.0 s after ignition key is in either run or start (HCP_GW_20.CmdIgnStat = IGN_RUN or IGN_START).

K-6 Impact Diagnostics

The BMS shall have a routine to clear impact faults.

The timer value from when BPCM_MSG_01.HVBatCntctrReq = True to when contactors open under an impact condition shall be 1500ms (with the exception of the Optimal Thread which shall be an immediate open reaction)

ASW shall make all DTCs (both BSW and ASW) fault reactions to be calibratable via dedicated interfaces, with a default value to match the DTC matrix that shall be set by the OBD calibration team.

The BMS shall diagnose an Impact with P167B – Controlled System Shutdown and lock out the HV contactors.

See referenced documents for additional diagnostic requirements. Diagnostic Trouble Codes (DTC).

L Battery Conditioning (HVBatRdy)

The signal, HVBatRdy, will be sent from the BPCM indicating to the vehicle whether or not the HV battery is ready to deliver or receive power.

If the signal is set to 0, this will indicate that the HV battery is not ready due to extremely hot or cold battery temperatures and/or high or low cell voltages. The contactors will still close to allow a small amount of power to heat or cool the battery, or raise or lower the voltage.

During initialization and before contactors close the determination of the value for the HVBatRdy signal shall be made.

The HVBatRdy determination for zero shall only be made during the initialization time.

HVBatRdy shall be set to zero in the following conditions. In these conditions, the BPCM shall allow contactors to close and not set a DTC. Otherwise, HVBatRdy = 1.

- HVBatCellVltMax is above HVBatCell_Voltage_High_Thrsh
- HVBatCellVltMin is below HVBatCell_Voltage_Low_Thrsh
- HVBatModuleTemp_Max is above HVBatHighTempThrsh
- HVBatModTempMin is below HVBatLowTempThrsh

Any other faults present which are not related to the HVBatRdy function and would either open the contactors or not allow the contactors to close shall still be allowed to perform their required action independent of the value of HVBatRdy.

If HVBatRdy is equal to 0 and DriveReady is equal to 1, the BPCM shall open contactors to protect the battery pack

When the conditions which made HVBatRdy = 0 are no longer true, with an appropriate amount of hysteresis, then HVBatRdy shall transition to 1 and continue to be 1 until the next wake-up/initialization.

Once HVBatRdy status sets as 1, the BPCM shall not change the HVBatRdy status to 0 in the same key cycle.

The hysteresis for each condition to transition from HVBatRdy = 0 to HVBatRdy = 1 shall be defined as follows:

- Low cell voltage: HVBatCellVltMin is x volts above HVBatCell_Voltage_Low_Thrsh (calibratable, default = 0.1 V) and HVBatSOC is greater than the minimum charge sustaining value (calibratable, default: 15%)
- High cell voltage: HVBatCellVltMax is below HVBatCell_Voltage_High_Thrsh by at least x volts (calibratable, default: 0.1 V)
- High module temperature: HVBatModTempMax is below HVBatHighTempThrsh by at least x deg C (calibratable, default: 0.5 deg C)
- Low module temperature: HVBatModTempMin is above HVBatLowTempThrsh by at least x deg C (calibratable, default = 0.5 deg C)

L-1 Battery Pack Conditioning CAN Signals

HVBatRdy --- High Voltage Battery Ready

M Sensor Measurements

M-1 Current Measurement

The BPCM shall measure and communicate over CAN the current in and out of the battery pack assembly (according to DBC file, default: 20 ms).

The sensors shall have an accuracy consistent with supporting the Team's algorithms and SOC accuracy requirements.

The Team shall provide data sheets for the current sensors and an assessment of why the accuracy is sufficient for their algorithms and diagnostics.

The battery pack current shall report 0A on vehicle CAN when the contactor is open and no faults present.

Redundancy in current measurements shall be required for rationality checks.

The BMS shall have redundant current sensors inside the battery pack.

The raw/unfiltered values of all current sensors shall be available over a private CAN bus from the BPCM (to be used during vehicle development).

M-1.1 Current Measurement Diagnostics

The current sensor diagnostics shall include the conditions of out of range, high, low, and rationality checks.

The raw/unfiltered value of the battery pack current DIDs shall be the same value read by the battery current sensors.

The validity of the current measurement shall be communicated over CAN.

BPCM pack current validity shall be set to INVALID (BPCM internal validity) when ANY of the following is TRUE:

- BPCM pack current is abnormal (e.g., current sensor failure) BPCM abnormal (e.g., RAM/Stack or EEPROM Microcontroller failure)
- Otherwise, BPCM pack current validity shall be set to VALID

M-2 Voltage Measurement

M-2.1 Battery Pack Voltage Measurement

The battery pack voltage shall be measured before the main contactor on the battery side (per DBC file, default: 20 ms).

The accuracy of the battery pack voltage shall be sufficient to support the Team's diagnostics and algorithms.

The Team shall provide data sheets for the battery pack voltage sensors and an assessment of why the accuracy is sufficient for their algorithms and diagnostics.

The BPCM shall have the sum of the cell voltages available as an internal variable for rationality and substitution for the battery pack voltage.

The value of the sum of the cell voltages shall be accessible via a DID.

The battery pack voltage diagnostics shall include the conditions of out of range high and low and rationality checks.

The value of the battery pack voltage shall be determined from the following priority:

- Valid Sum of Cell/Module Voltages
- Valid Pack Voltage Measurements
- Invalid if no of the measurement is available.

The value of the battery pack voltage source shall be determined from the following priority:

- CELL_SUM if through Valid Sum of Cell/Module Voltages
- SENSOR if through Valid Pack Voltage Measurements
- NONE if Invalid

M-2.2 Battery Pack Link Voltage

The battery pack link voltage shall be measured after the main contactor on the vehicle side of the high voltage bus.

The accuracy of the battery pack link voltage shall be sufficient to support the Team's diagnostics and algorithms.

The Team shall provide data sheets for the battery pack link voltage sensor and an assessment of why the accuracy is sufficient for their algorithms and diagnostics.

The value of the battery pack link voltage shall be determined from the following priority:

- Valid link voltage sensor measurement
- Combination of other rationalized high voltage measurements (e.g. other HV component sensing element A, B, C and D)
- Invalid if none of the measurement is available.

The value of the battery pack voltage source shall be determined from the following priority:

- LINK_SENSE if through Valid link voltage sensor measurement
- ELEMENT (A, B, C or D) if through Combination of other rationalized high voltage measurements
- NONE if Invalid

The value of the battery pack link voltage and its source shall be accessible via a DID.

The value of the link voltage shall be available over a private CAN bus from the BPCM (to be used during vehicle development).

M-2.3 Additional High Voltage Measurements

Additional High Voltage Measurements shall be available to properly support diagnostics (e.g. DC Fast Charging voltage sensors, contactor weld check voltage sensors, …).

The accuracy of the additional high voltage measurements shall be sufficient to support the Team's diagnostics and algorithms.

The Team shall provide data sheets for the additional high voltage sensors and an assessment of why the accuracy is sufficient for their algorithms and diagnostics.

The values of the additional high voltage measurements shall be accessible via a DID.

The values of the additional high voltage measurements shall be available over a private CAN bus from the BPCM (to be used during vehicle development).

M-2.4 Module Voltages

Module voltages, defined as a group of cells measured on the same ASIC, shall be measured and accessible via a DID.

A modules voltage shall be considered VALID when all the DTC's (e.g., diagnostics for element voltage sensors shorted to ground, shorted to battery, and rationality) are set to either NOT TESTED or PASS. Otherwise, the modules voltages shall be considered INVALID.

The accuracy of the module voltage measurements shall be sufficient to support the Team's diagnostics and algorithms.

The Team shall provide data sheets for the module voltage sensors and an assessment of why the accuracy is sufficient for their algorithms and diagnostics.

The BPCM shall have the sum of the module voltages available as an internal variable for rationality and substitution for the battery pack voltage.

The value of the sum of the modules shall be accessible via a DID.

The sum of modules shall be INVALID if one of the module voltages is INVALID.

The values of the module voltages shall be available over a private CAN bus from the BPCM (to be used during vehicle development).

M-2.5 Cell Voltages

The BPCM shall measure the voltage of every cell/cell block and report battery pack voltage and the cell minimum, maximum, and average voltages over CAN on the vehicle network. Cell block is a group of parallel cells.

The accuracy of the cell voltage measurements shall be sufficient to support the Team's diagnostics and algorithms.

The Team shall provide data sheets for the cell voltage sensors and an assessment of why the accuracy is sufficient for their algorithms and diagnostics.

The voltages of every cell shall be available over a private CAN bus from the BPCM (to be used during vehicle development).

The measurement of the cell voltages shall be synchronized with the current within the specification of microprocessor ability.

Bus bars and any other wiring that significantly effects the voltage measurements shall be compensated for.

The cell locations (cell number) for the minimum and maximum cell voltages shall be communicated over CAN.

The BPCM shall keep a lifetime history, accessible via a DID, of at least the top 3 cells voltages that were high and the top 3 cells that were low, including the position identification of the cells. Can update NVM during shutdown.

All the cell voltages shall be accessible via a DID.

The cell voltage sensor diagnostics shall include the conditions of out of range high and low and rationality checks.

The rationality checks shall include cell summation and comparison with other available voltage measurements.

M-3 Temperature Measurement

The term, cell temperature, is used to denote the temperature that is used for temperature compensation of the Team's algorithms and the associated diagnostics.

The BPCM shall measure the temperature of every cell that is determined to be needed as a result of DFMEA, SOC/SOH algorithm support, or other engineering analyses (locations to be described and specified by the Team).

The cell temperature sensor locations shall be reviewed at Y2 workshop design reviews.

The accuracy of the cell temperature measurements shall be sufficient to support the Team's diagnostics and algorithms.

The Team shall provide data sheets for the cell temperature sensors and an assessment of why the accuracy is sufficient for their algorithms and diagnostics.

The minimum, maximum, and average cell temperatures and the corresponding cell locations shall be reported over CAN on the vehicle network.

On initialization, the validity bits for the minimum, maximum and average cell temperatures shall indicate VALID (validity bit = 0) within 100 ms of communication. Once accurate temperatures are communicated, the validity bits shall stay VALID (validity bit = 0) and the signal validity should be INVALID (Validity bit = 1) only when both the inputs are unavailable and the sensor faults are confirmed.

All temperatures and pertinent thermal management parameters shall be available through service diagnostics via DIDs.

The BPCM shall keep a lifetime history of at least the 3 top highest cell temperatures and the 3 lowest cell temperatures, including their positions within the battery pack. Can update NVM during shutdown.

These values shall be accessible via a DID.

The BPCM shall also measure and report the temperatures of the cooling inlet and outlet (either liquid or air, whichever is applicable) and any other temperatures that need to be measured to implement the thermal management algorithms.

The BPCM shall measure and report the temperature of any other battery pack component that is essential for reliable operation (e.g., the CPU, balancing boards, precharge circuitry, etc.).

These values shall be accessible via a DID.

The cell temperature and inlet and outlet sensor diagnostics shall include the conditions of out of range high and low and rationality checks.

All temperature measurements shall be available over a private CAN bus from the BPCM (to be used during vehicle development).

M-4 Cell Voltage and Temperature Thresholds

The BPCM shall send the following cell voltage and temperature thresholds to indicate to the vehicle controller that the values are outside the normal region.

The strategy for how these thresholds may change with conditions (temperature, SOC, diagnostic status, plug-in charging, etc.) shall be documented by the Team and submitted to Competition Organizers for approval.

- HVBatLowTempThrsh – Signal from the BPCM indicating the value that the minimum module temperature needs to be above in order to become functional. Below this value, the BPCM will set HVBatCntctrReq to 1, and HVBatCntctrOpn to 1 after the appropriate maturation time. If below this value during power up, HVBatRdy will also be set to 0.
- HVBatHighTempThrsh – Signal from the BPCM indicating the value that the maximum module temperature needs to be below in order to become functional. Above this value, the BPCM will set HVBatCntctrReq to 1, and HVBatCntctrOpn to 1 after appropriate maturation time. If above this value during power up, HVBatRdy will also be set to 0.
- HVBatCell_Voltage_Low_Thrsh – Signal from the BPCM indicating the minimum cell voltage that the battery pack needs to be above in order to become functional. Below this value, the BPCM will set HVBatCntctrReq to 1, and HVBatCntctrOpn to 1 after appropriate maturation time. If below this value during power up, HVBatRdy will also be set to 0.
- HVBatCell_Voltage_High_Thrsh – Signal from the BPCM indicating the maximum cell voltage that the battery pack needs to be below in order to become functional. Above this value, the BPCM will set HVBatCntctrReq to 1, and HVBatCntctrOpn to 1 after appropriate maturation time. If below above this value during power up, HVBatRdy will also be set to 0.
- HVBatMinCellVltAlld – The minimum allowed cell voltage during operation. It is considered an extreme abnormality to exceed this value.

- HVBatMaxCellVltAlld – The maximum allowed cell voltage during operation. It is considered an extreme abnormality to exceed this value.

M-4.1 Dynamic Limits of Cell Voltage and Temperature Thresholds

The BPCM shall allow for cell voltage limits shifted by temperature to account for conditions such as limp home, plug in charging, discharge and regen during driving, and cold cranking conditions.

M-5 Cell Voltage and Temperature Sensor Diagnostics

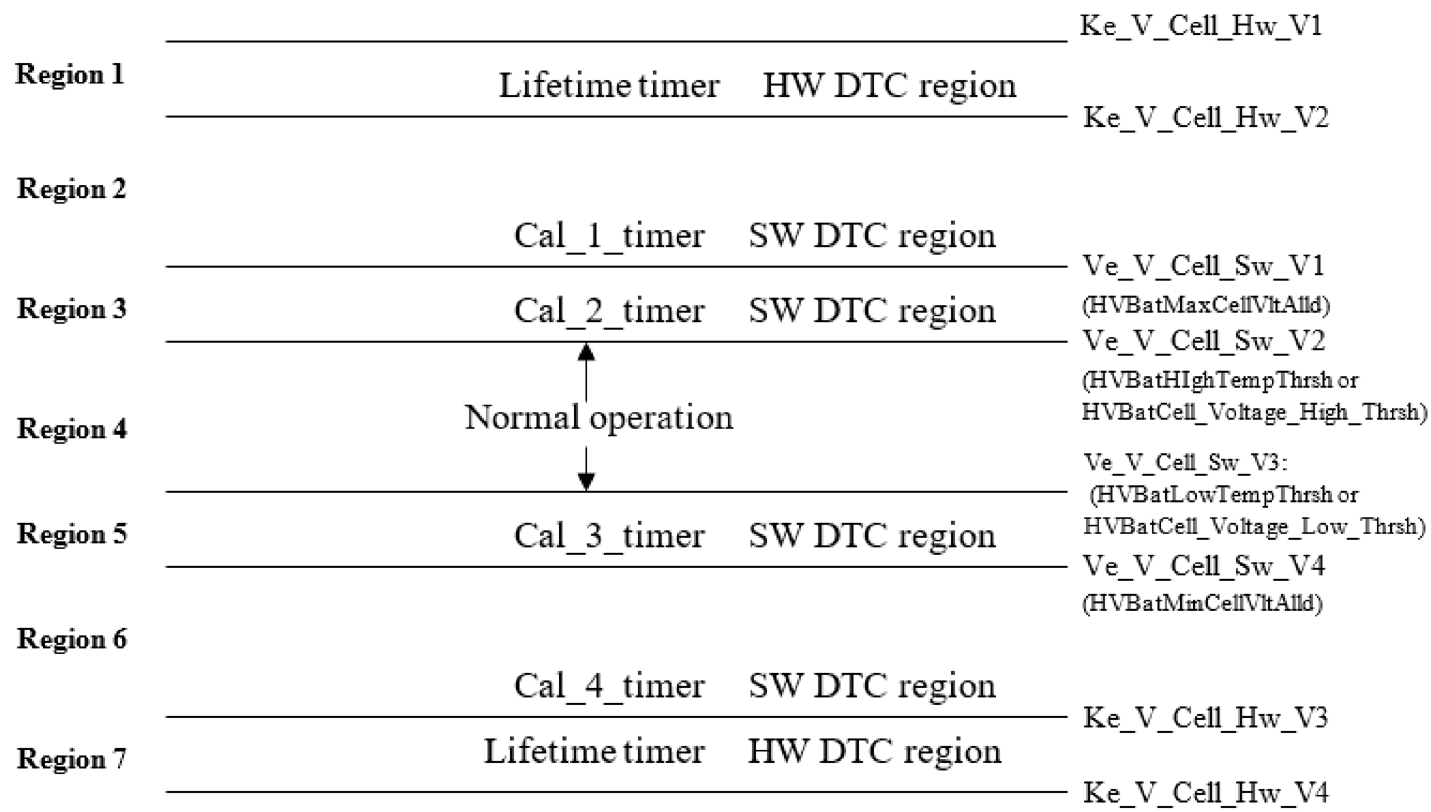
The limits for the voltage and temperature sensors shall be divided into 7 regions (see Figure below). Each of these regions has lifetime timers associated with them (a total of 7 lifetime timers for this implementation).

The temperature and voltage sensor values within region 4 shall be termed as a region of normal operation.

Voltage and temperature sensor operating limits within regions 1 and 7 shall be termed as a hardware fault which could be due to short to reference high or short to reference low

Each of these conditions shall have a DTC associated with it.

Voltage and temperature sensor output voltage limits within the regions 2, 3, 5, and 6 that exceed calibration timer values (0-10 seconds) shall take the appropriate action defined in the DTC Matrix.



M-6 CAN Signals Associated with Sensor Measurements

Any invalid sensor measurement shall report as SNA to indicate its measurement is not considered to be valid instead of the measured value.

HVBatteryCurrent_BEV– Battery pack current and its associated validity

HVBatteryVoltage_BEV– Battery pack voltage and its associated validity

HVBatCellVltAvg and HVBatCellVltAvgV – Average cell voltage and its associated validity

CellVoltage_NumMin_BEV– Minimum cell voltage and its associated validity

CellVoltage_NumMax_BEV– Maximum cell voltage and its associated validity

HVBatCell_NumMinVlt – Cell number in module that is minimum voltage

HVBatCell_NumMaxVlt – Cell number in module that is maximum voltage

HVBatModuleTemp_Max– Maximum cell temperature in the battery pack array of cell temperatures and its associated validity

HVBatModuleTemp_Min– Minimum cell temperature in the battery pack array of cell temperatures and its associated validity

HVBatModTempAvg and HVBatModTempAvgV – Average of all cell temperatures in the battery pack array of cell temperatures and its associated validity

HVBatClgInletTemp and HVBatClgInletTempV – The temperature of the inlet of the cooling medium and its associated validity

HVBatClgOutletTemp and HVBatClgOutletTempV – The temperature of the outlet of the cooling medium and its associated validity

HVBatModuleTemp_Nummax– Cell temperature sensor position which has maximum temperature

HVBatModuleTemp_Nummin– Cell temperature sensor position which has minimum temperature

N Plug-In Charging

N-1 Plug-In Charging Algorithms

The plug-in charging algorithm shall be explained and documented by the Team.

The algorithm shall include, but not be limited to, dependencies on temperature, voltage, current, battery age, and diagnostic status.

The plug-in charging algorithm shall comprehend charge power supplies at the 1.0 kW, 11.0 kW, and 0.5C rates.

N-2 Plug-In Charger Control

The proper voltage and current limits shall be communicated over CAN to allow the selected charger to properly charge the battery pack in an efficient and reliable manner.

N-3 CAN Messages and Signals Associated with Plug-In Charging

ChargeSystemSts: This signal comes from the Vehicle Controller and indicates the status of the charging function. It is enumerated as follows:

0: not charging
1: charging
2: charge interrupted
3: charge complete
7: SNA

HVBatMaxCellVltAlld: This signal is sent out by the BPCM to the Vehicle Controller to indicate the maximum allowable cell voltage during charge.

HVBatMaxPkVltAllwd: This signal is sent out by the BPCM to the Vehicle Controller to indicate the maximum allowable battery pack voltage during charge.

HVBatChargeStat: This signal is sent out by the BPCM as an indication of its present status. The signal is enumerated as follow:

- NOT_READY – When the contactors are open or when there are conditions with preclude charging
- READY
- Complete
- SNA

N-4 AC Plug-In Charging Procedure

Initially, the contactors are not closed, and the signal HVBatChargeStat shall be equal to Not Ready.

Once a plug in is determined by the Vehicle Controller, contactors will be commanded closed, and the BPCM shall close contactors and transition HVBatChargeStat = Ready. If the main contactors are closed, the battery shall continually acknowledge that it is ready for charge by setting HVBatChargeStat = Ready. If the battery should not or cannot be charged, the status of HVBatChargeStat = Not Ready.

If the Vehicle Controller determines that it is time to charge, ChargingSysSts will transition to “charging”. During this phase, the BPCM shall populate HVBatMaxChgCurrAlwd = with the max plugin charge current allowed to charge the HV battery (a calibratable value with default = 30A).

The battery shall enable any routines that pertain to charging only and prepare for charge and over-charge protection. When in charge mode, the charge power limits (for regen) will be based on HVBatCell_Voltage_High_Thrsh used during plug-in charge.

Since contactors are closed and charging hand shake has taken place (ChargingSysSts = Charging and HVBatChargeStat = Ready), the battery shall transition into one of the following states:

- HVBatMaxChgCurrAlwd = with the max plugin charge current allowed to charge the HV battery.
- If the battery needs to cool or heat HVBatMaxChgCurrAlwd = reduced value or 0 A
- If charging has completed (according to BPCM charge completion criteria and retry count) HVBatChargeStat = Complete

The BPCM shall continually calculate and update the signals HVBatMaxCellVltAlld, HVBatMaxChgCurrAllwd, and HVBatMaxPkVltAllwd based on battery cell chemistry and communicate these to the Vehicle Controller. The Vehicle Controller will continuously monitor the cell voltage, current, pack voltage, and temperature.

If the temperature goes above Ke_T_HighChrgTempThresholdIn (default: 50 deg C) or if the temperature goes below Ke_T_LowChrgTempThresholdIn (default: = - 25 deg C), HVBatMaxChgCurrAlwd shall equal 0.

Once the temperature falls below Ke_T_HighChrgTempThresholdOut (default: 48 deg C) or the temperature increases above Ke_T_LowChrgTempThresholdOut (default: -23 deg C) HVBatMaxChgCurrAlwd shall be > 0.

The teams shall provide a table of temperature range and HVBatMaxChgCurrAlwd for both AC charging and DC Fast Charging and not to exceed other vehicle side components.

An example of the table is show below:

SOC (%) / Temp (C)	-25	-20	-10	0	5	10	20	25	35	40	50
5	12	15	20	30	30	30	30	30	30	30	
10	12	14	20	30	30	30	30	30	30	30	
15	11	14	20	30	30	30	30	30	30	30	
20	11	14	20	30	30	30	30	30	30	30	30
25	10	13	20	30	30	30	30	30	30	30	30
30	8	12	20	30	30	30	30	30	30	30	30
35	7	12	20	30	30	30	30	30	30	30	30
40	7	12	20	30	30	30	30	30	30	30	30
45	7	11	20	30	30	30	30	30	30	30	30
50	7	11	20	30	30	30	30	30	30	30	30
55	6	11	20	30	30	30	30	30	30	30	30

60	5	10	19	30	30	30	30	30	30	30	30
65	5	9	19	30	30	30	30	30	30	30	30
70	4	8	15	25	28	30	30	30	30	30	30
75	4	6	12	19	21	23	30	30	30	30	30
80	3	5	8	14	15	20	25	30	30	30	30
85	3	4	7	10	12	12	20	25	25	26	27
90	2	3	5	6	8	8	15	20	22	25	26
95	2	2	3	3	4	4	10	15	20	22	24

The BPCM shall indicate to the Vehicle Controller when it is fully charged at a charge level set higher than the Vehicle Controller (calibratable: Ke_U_ChargeCompletionVlt, 4.14V (example), for at least 300 ms) by setting HVBatMaxChgCurrAlwd = 0.

N-5 DC Fast Charge Plug-In Charging Procedure BEV

Direct Current Fast Charging (DCFC) provides direct current (DC) to the EV battery by the inversion of a 3-phase 480 volt AC supply. DCFC (known as Level 3 charging) as part of public infrastructures, requires special BPCM software protections to ensure a robust charging event.

Upon making a connection with the DCFC Station:

Initially the main contactors are not closed, and the signal HVBatChargeStat shall be equal to Not Ready.

Main contactors will be commanded closed, and the BPCM shall close contactors and transition HVBatChargeStat = Ready.

Once a “DCFC plug in” is determined by the vehicle controller, the BPCM shall disable its continuous isolation detection monitoring immediately, when it receives DC_Isolation_Disable_Cmd = 1.

The BPCM shall set DC_Isolation_Disable_Sts = DISABLE, when it successfully disables the continuous isolation detection.

The BPCM shall run its continuous isolation detection whenever:

- DC_Isolation_Disable_Cmd = 0 and provide isolation detection status when DC_Isolation_Disable_Sts = ENABLE.

The DCFC contactors are commanded closed through DC_CntctrCmd = CLS by the vehicle controller, and once receiving DC_CntctrCmd = CLS, the BPCM shall provide the DCFC contactors status through HVBat_DC_CntctrStat = Closed.

The BPCM shall indicate if the DCFC contactors are open through HVBat_DC_CntctrStat = Open.

If the Vehicle Controller determines that it is time to charge, ChargingSysSts will transition to “charging”. During this phase, the BPCM shall populate HVBatMaxChgCurrAlwd_ High = calibratable value based on its DCFC current profile.

Since DCFC contactors are closed and charging hand shake has taken place (HVBatChargeStat = Ready, DC_Isolation_Disable_Sts = DISABLE , HVBat_DC_CntctrStat = Closed, and ChargingSysSts = Charging), the battery shall transition into one of the following states:

- HVBatMaxChgCurrAlwd_ High > 0
- If the battery needs to cool or heat HVBatMaxChgCurrAlwd_High = reduced value or 0 A
- If charging has completed (according to BPCM DCFC completion criteria) HVBatChargeStat = Complete

If the BPCM detects a critical failure during charging, a diagnostic code shall be set and HVBat_DC_CntctrOpn = 1 notifying the vehicle controller that the DCFC contactors will open in a calibrated amount of time (Ke_t_DCFC CntctrOpn default: 1500 ms).

Once the vehicle controller has determined charge complete, DC_CntctrCmd = OPN and BPCM shall open DCFC contactors and publish HVBat_DC_CntctrStat = Open.

If the BPCM detects a DCFC contactor failure, such as a weld or driver circuit fault, then the BPCM shall set HVBat_DC_CntctrStat = Faulted and publish a corresponding diagnostic code.

If the BPCM detects a DCFC contactor weld then the BPCM shall set HVBatCntctrReq = 1 and HVBatCntctrOpn = 1, then proceed to open the contactors in 1.5 seconds, inhibit main contactor closure and not source HVIL throughout all key cycles.

O CELL BALANCING

O-1 General Cell Balancing Requirements

Cell balancing is the process of equalizing the voltages and state of charge among the cells when they are at a full charge.

- Passive Cell balancing removes the additional charge available in the higher SOC cells, by dissipating heat through the bleed resistors
- This allows charging all the cells to the same 100% SOC, thereby maximizing the available energy at top of charge

The BPCM shall allow balancing of individual cells only when any one of the following is TRUE:

- The BPCM is in autonomous balancing state AND autonomous balancing is enabled
- When in Key in Ignition or plug-in charging mode

Autonomous balancing shall only be enabled if approved.

The Team shall meet the following conditions if Autonomous balancing has been enabled.

- The BPCM shall not wake up other vehicle controllers in the system (via CAN or hardwired)
- The BPCM shall not draw 12V power throughout the duration of the autonomous balancing (i.e. no parasitic 12V draw).

O-2 Cell Balancing Diagnostics and Protection

The BPCM shall be able to distinguish between cells that are out of balance and cells that are failing for any operational conditions.

The BPCM shall diagnose the following for each of the balancing circuit and take appropriate actions:

- Cell Balance Circuit Stuck Open
- Cell Balance Circuit Stuck Closed
- Cell Balance Circuit Normal

The BPCM shall have protection to ensure that the balancing does not turn on when it is not intended to balance.

O-3 Cell Balance Mode

The BPCM shall communicate the balancing state on the internal battery CAN bus with a signal HVBatBalMd.

- NO BALANCING – When Balancing Enable Conditions are not True.
- BALANCING/Balance in Progress – When Balancing Enable Conditions are True and at least one cell is being balanced.
- BALANCING COMPLETE

P Thermal Management System Controls

The BPCM shall control the Battery Coolant Pump (BCP) and Battery Coolant Heater (BCH) to maintain the High Voltage Battery Pack temperature at normal ranges. HCP is the controller for BCP and BCH. This is accomplished by the BPCM acting as CAN to LIN gateway for information from the BCP and BCH to HCP and vice versa.

The BPCM shall start LIN communication with the BCP within a calibrate-able time after power up.

When the BPCM starts LIN communication, the BCP shall start responding via LIN communication within a calibrate-able time.

HCP → BPCM (CAN)	**BPCM → BCP** (LIN)	**BPCM → HCP** (CAN)	**BCP → BPCM** (LIN)
Thermal_Command (0x3EE)	BCP_REQ	BPCM_LTRActPump1 (0x3EA)	BCP_STAT
LTAP_Cmd	BCP_RPM_REQ	LTAP_Crnt	BCP_RPM_TGT
LTAP_Failsafe_ACT	BCP_POST_RUN_REQ	LTAP-PmpRPMTgt	BCP_RPM_ACTL
LTAP_PostRunCom	BCP_FL_SAFE_ACTVT	LTAP_RPMAct	BCP_VLTG
		LTAP_Temp	BCP_TEMP
		LTAP_Vlt	BCP_CURR
		BPCM_LTRActPump2 (0x3EB)	BCP_FL_SAFE_ACTVTD
		LTAP_AirPreErr	BCP_LMP_HM_AN_ON
		LTAP_Deblock	BCP_AIR_PRE_ERR
		LTAP_DryRun	BCP_OVR_TMP_ERR
		LTAP_Failsafe	BCP_OVR_CUR_ERR
		LTAP_LimpHmAnON	BCP_DR_RN_ERR
		LTAP_MontrngRPM	BCP_VLTG_ERR
		LTAP_NodeErr	BCP_DBLK_ACTV
		LTAP_OvrCrnt	BCP_MONTRNG_RPM
		LTAP_OvrTemp	BCP_NODE_ERR
		LTAP_PostRunSts	BCP_POST_RUN_STAT
		LTAP_RespErr	RsErr_BCP_PUMP
		LTAP_Supplier	BCP_VER
		LTAP_SuppVltErr	BCP_VER
			BCP_SUPPLIER

If communication is lost between the BPCM and the BCP, then the BPCM shall report all related CAN Low Temperature Active Pump signals as “SNA”.

If the BCP reports that it has a communication error, then the BPCM shall report all related CAN Low Temperature Active Pump signals as “SNA”.

P-1 Heater Command

The BPCM shall start LIN communication with the BCH within a calibrate-able time after power up.

When the BPCM starts LIN communication, the BCH shall start responding via LIN communication within a calibrate-able time.

When BPCM controller communication network is established, the BPCM shall communicate all the following related variables to the respective controllers:

HCP → BPCM (CAN)	**BPCM → BCH** (LIN)	**BPCM → HCP** (CAN)	**BCH → BPCM** (LIN)
Thermal_Command (0x3EE)	CCMLIN18Fr02	BPCM_BattHtr1 (0x3EC)	HVCHLIN18Fr02
BATHTR_Enbl	HvWtrHeatrPwrCnsAllwd	BATHTR_HVCurrCns	RsErr_BCH
BATHTR_PwrCnsAllwd	HvWtrHeatrWtrTDes	BATHTR_MeasuredHV	HvCooltHeatrWarnFlt InCom
BATHTR_WtrTempDes	HvCooltHeatrEnad	BATHTR_PwrCnsAct	HvCooltHeatrWarnHv OutOfRng
		BATHTR_PwrCnsDes	HvCooltHeatrWarnUL oOutOfRng
		BPCM_BattHtr2 (0x3ED)	HvCooltHeatrWarnCo oltTOutOfRng
		BATHTR_CoolantInletSnsrFlt	HvCooltHeatrProtnOf SelfTmpHwProtn
		BATHTR_CoolantOutletSnsrFlt	HvCooltHeatrProtnOf SelfTmpOvrheatg
		BATHTR_CoolantTempInlet	HvCooltHeatrSnsrFlt CooltTInSnsrFlt
		BATHTR_CoolantTempOutlet	HVCHLIN18Fr02
		BATHTR_HCSensorFlt	HvCooltHeatrSnsrFlt CooltTOutSnsrFlt
		BATHTR_RespErr	HvCooltHeatrSnsrFlt TInMtrlSnsrFlt
		BATHTR_SelfProtectHW	HvCooltHeatrSrvRqrd CircForDrvrShoOrOp en
		BATHTR_SelfProtectOvrHeat	HvCooltHeatrSrvRqrd ICnsOutOfRng
		BATHTR_ServiceCurrOutofRng	HvCooltHeatrSrvRqrd MemErr
		BATHTR_ServiceDrvrCirc	HvCooltHeatrSrvRqrd SrvRqrd
		BATHTR_ServiceMemErr	HVCHLIN18Fr01
		BATHTR_ServiceRqrd	HvCooltHeatrSts
		BATHTR_Status	HvCooltWtrHeatrWtrT InIntk

		BATHTR_WarnCommFlt	HvWtrHeatrWtrT
		BATHTR_WARNCoolantTempOOR	HvCooltHeatrICns
		BATHTR_WarnHV_OOR	HvCooltHVmeas
		BATHTR_WarnLV_OOR	HvHeatrPwrCns
			HvHeatrPwrCnsDes

P-2 Thermal Propagation Protection Strategy

The purpose of the Thermal Propagation Protection Strategy should be to provide the vehicle occupants with controlled conditions to exit the vehicle, while providing an alarm to the driver in the event of thermal propagation detection. The alarm constitutes an evacuation warning 30-minutes prior to impending hazardous conditions which may result from thermal propagation.

P-3 Thermal Runaway Requirements

As per the GB/T regulation, the driver should be notified/alerted to evacuate the vehicle 5mins prior to a hazardous situation which is caused by thermal propagation.

The BPCM should detect a thermal runaway at least 30 mins prior to a hazardous situation and vehicle shutdown.

With the teams having 12V battery disconnect switches, it is not possible for this competition to implement this requirement: The BPCM should be able to detect a thermal event during BPCM sleep mode.

The BPCM shall send ThermalRunaway = ‘No Thermal Runaway Detected’ when BPCM detects the battery is in normal operating mode with no thermal hazardous detected.

The BPCM shall send ThermalRunaway = ‘Thermal Runaway Detected’ to Hybrid Controller informing thermal propagation is detected.

When thermal runaway is detected (ThermalRunaway_Status = ‘Thermal Runaway Detected’), the BPCM shall latch ThermalRunaway_Status and lock the contactor to ‘OPEN’ for next key cycle, until the Battery is replaced or an override is performed by a service tool.

The BPCM Shall report DTC P29FF00 “Hybrid/EV Battery Thermal Runaway Detected”.

Q State of Charge (SOC) Requirements

Q-1 SOC Algorithm

The BPCM shall determine Battery State of Charge (SOC) based on inputs of battery cell temperatures, battery pack current, and cell voltages.

An appropriate algorithm as determined by the Team shall be used to achieve desired accuracy and robustness.

The SOC algorithm shall internally estimate the SOC of every cell/cell block in the battery pack. Cell block is a group of parallel cells. Internal BPCM CAN signals shall be available to report the SOC of every cell/cell block. The recommended naming convention of these signals is HVBat_SOCcellXXX, with the incrementing cell number 001, 002, 003, and continue per the required number of cells. The inputs into the SOC algorithm that are stored in memory shall be accessible by a DID.

The inputs into the SOC algorithm that are stored in memory shall be accessible by a DID.

Each cell/cell block capacity and cell resistance value shall be a DID.

Any additional inputs shall be identified and updated in the Diagnostic Definition Table (DDT) as necessary.

The SOC algorithm used by the Team shall be fully explained and documented by the Team for review.

Q-2 Changing SOC Value

Teams are required to provide a means of changing the SOC for the development of over and under voltage control and observation of SOC corrections.

The SOC change shall happen immediately and not require a key cycle.

Q-3 SOC Definitions

State-of-Charge (SOC) – The SOC (CAN signal, HVBatSOC) is defined as the remaining – percentage pack level SOC as defined by the blending equation. SOC shall be expressed as 100% denoting full charge and 0% defining a depleted battery.

Cell Characterization in this specification typically refers to the method of cell pulse testing (e.g. HPPC) to determine equivalent models parameters (ohmic/dynamic resistance, time constraints).

The definition of SOC=100% and SOC=0% shall be based on a SOC-OCV relationship as determined from cell characterization.

It is expected that the SOC-OCV relationship look-up-table shall be able to accurately map cell voltage to SOC when the battery is in a sufficiently rested state, i.e. zero current for sufficient time and at thermal equilibrium.

The SOC-OCV curve calibration shall be provided.

The signal HVBatSOC is a pack level SOC signal that blends the minimum and maximum estimate SOC cells/cell blocks into a single percentage signal. The following blending equation shall be used:

MidPoint = (MaxCellSOC + MinCellSOC) / 2;

UpperMid = SOCMaxLimit - ((MaxCellSOC - MinCellSOC)/2);

LowerMid = SOCMinLimit + ((MaxCellSOC - MinCellSOC)/2);

// base the weight factor for max and min cell soc on location of midpoint

// within the possible midpoint range

LowWeightNum = (UpperMid - MidPoint);

LowWeightDen = max((UpperMid - LowerMid),1e-6);

// update the weight used to determine how important the min cell soc will be

LowWeight = LowWeightNum / LowWeightDen;

If LowWeight<0 then LowWeight=0;

If LowWeight>1 then LowWeight=1;

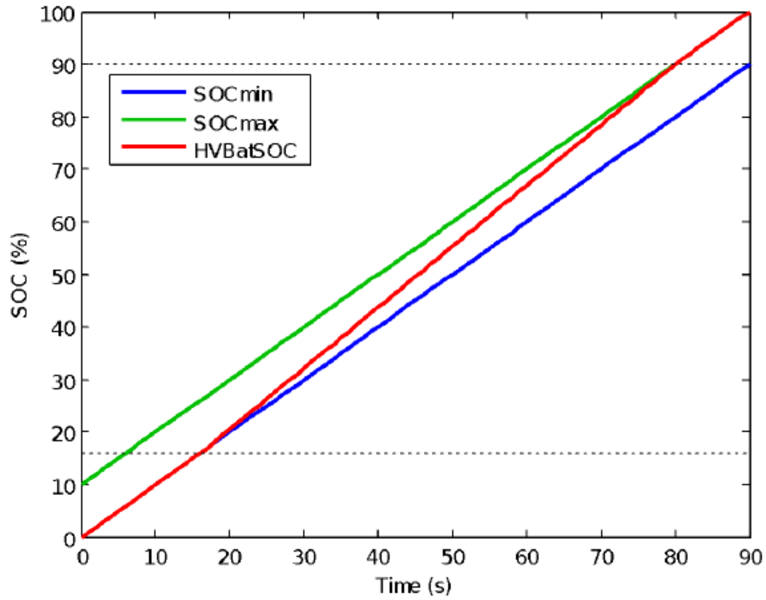
// update the weight used to determine how important the max cell soc will be

HighWeight = 1 - LowWeight;

BlendedValue = HighWeight*MaxCellSOC + LowWeight*MinCellSOC

The calibrations SOCMaxLimit and SOCMinLimit indicate extreme values such that when the maximum cell SOC >= SOCMaxLimit then HVBatSOC=MaxCellSOX; moreover when the minimum cell/cell block SOC <= SOCMinLimit then HVBatSOC=MinCellSOC.

An example depiction of HVBatSOC blending is shown below for a typical application.



Q-4 CAN Signals Associated with SOC

HVBatSOC – This is the battery SOC described above

HVBatSOCV – This indicates the validity of the HVBatSOC signal (1 = invalid)

HVBatSOCMax – This signal represents the SOC of the cell/cell block with the highest SOC

HVBatSOCMin – This signal represents the SOC of the cell/cell block with the lowest SOC

HVBatFull_Amp_Hr_Capacity – This signal represents the amp hour capacity of the battery pack (as tested by the prescribed capacity test mentioned above).

R State of Power (SOP) Requirements

The State of Power (SOP) algorithm in the BPCM software will need to report power limits based on parameters, including the SOC, temperature and battery aging factors. These power limits affect vehicle drivability and determine the vehicle usage of the battery under all conditions and states. The HCP (vehicle controller) is responsible for abiding by these power limits.

R-1 Power Limit Estimation Algorithm

Battery power limits with three time durations shall be required: instantaneous, short term, and long term. Unless otherwise stated, instantaneous power limit, short-term power limit, and long-term power limit refers to refers to 2 sec power limit, 10 sec power limit, and 30 sec power limit, respectfully, for charge and discharge.

The charge power limits shall be based upon the maximum cell voltage in the battery pack, while the discharge power limits shall be based upon the minimum cell voltage in the battery pack.

The power limits shall be based on the minimum battery pack temperature for low temperature and the maximum battery pack temperature for high temperature.

The BPCM software shall not impose additional power deratings for ensuring that the power limits are not exceeded. This is the responsibility of the HCP (vehicle controller).

Power limits and charging current limits broadcast by the BPCM shall be affected by changing the SOC.

R-2 Static Power Limiting Tables

The Team shall provide the following static power limit input tables to Competition Organizers for discharge and regenerative braking charging, for the instantaneous, short-term, and long-term power durations.

The tables shall include entries for the SOC at full vehicle charge and entries for the temperatures and SOCs when the power limits become zero. The information must be provided in proper formats as defined and requested by Competition Organizers.

One example of the Detailed Requirements is defined below:

Static Power Limits

- 2s/10s/30s Discharge Power Limit Tables
- 2s/10s/30s Discharge Current Limit Tables
- Constant Discharge Current Limit Table
- 2s/10s/30s Regen Charge Power Limit Tables
- 2s/10s/30s Regen Charge Current Limit Tables
- Constant Charge Current Limit Table

The maximum charge/discharge tables shall include entries for SOC and temperatures.

Maximum currents shall be respected in the power-limiting algorithm to prevent over-current scenarios.

The Table below is provided as an example of the Static Power Limit tables required:

x-sec Power Limit	Discharge/Regen Power (kW)	Battery Temperature (deg C)											
	SOC	55	45	35	25	20	10	5	0	-10	-20	-30	-40
	100												
	95												
	90												
	85												
	80												
	75												
	70												
	65												
	60												
	55												
	50												
	45												
	40												
	35												
	30												
	25												
	20												
	15												
	10												
	5												
	0												

Separate maximum charge/discharge current tables shall also be provided for short term and continuous duration. These tables shall include entries for SOC and temperatures. These maximum currents shall be respected in the power-limiting algorithm to prevent over-current scenarios.

The normal operational range for SOC shall include SOC accuracy such that there are no power limits less than 9 kW under normal conditions.

R-3 Power Limits for Charge and Discharge

Initial software for test vehicles shall have mutually agreed upon conservative values.

The BPCM shall broadcast over CAN for the 2, 10, 30, and 180-second discharge and regenerative braking charge power limits. These values always have a positive sign and are in the units of kW.

If the inputs going into determining the power limits become unreliable (due to things like bad sensors, corrupt readings, etc.), the power limit validity should be set to INVALID.

On initialization, the validity bits for the power limits shall indicate VALID (validity bit = 0) within 100 ms of communication. Once accurate power limits are communicated, the power limits validity bits shall stay VALID (validity bit = 0).

The 2-second and 180-second charge and discharge power shall not fall below 9 kW within the operational range of the battery pack. The 10 and 30 second power limits may go to zero power under severe temperature conditions.

The BPCM shall not change the power limits faster than a calibratable value (default = 10kW per second, no step functions from 100kW to 60kW in less than 4 seconds), unless a cell voltage limit is being violated or BEV_HVBatPwrLim_On_BPCM= 1 (Limp Mode). The 10kW per second “De-rating” power limit factor is governed by the 180-second De-rating Continuous Power Limit for charge and discharge.

In limp conditions, the power limits shall step change to calibratable value (Ke_v_LimpRegenPwr and Ke_v_LimpDischargePwr).

Exceeding the power limits in normal operation shall be acceptable for a duration of one second with an increase of 20% of the communicated power limit (e.g., if the communicated power limit is 30kW, the power used could be 36kW for one second in a 10 second timeframe). The decision to exceed power limits is determined by the HCP (vehicle controller).

In limp conditions, the allowable power excursions shall be an additional to 6kW for less than 1 second. This is to allow for high voltage devices such as compressors and heaters to change power modes.

Additional power limiting shall be allowed to occur due to loss of sensor inputs.

The values and conditions of the additional power limiting shall be described in the Component Protection Strategy (described elsewhere in this document).

When the power limits are reduced due to loss of sensor inputs, a CAN signal, BEV_HVBatPwrLim_On_BPCM, shall indicate to the HCP (vehicle controller) that additional power limiting is occurring.

When in charge mode, the charge power limits (for regen) shall be based on the max cell voltage threshold used during plug-in charge.

R-4 Continuous Power Limit

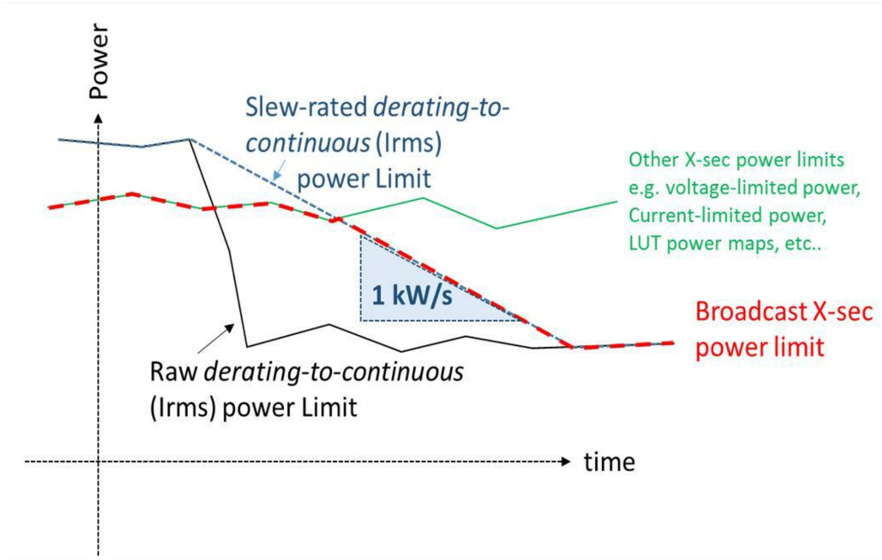
The Continuous Power Limit is a software algorithm that protects the battery from quasi-continuous (prolonged) charge discharge events (e.g. downhill regen and highway/uphill discharge). The Continuous Power Limit strategy has been successfully used in other Stellantis EV programs to protect from a potential voltage collapse prospective.

Continuous Power Limits are in addition to 2/10/30-second power limits.

The 2/10/30-second power limits shall de-rate to the continuous power limit based on a 180-second rolling window concept.

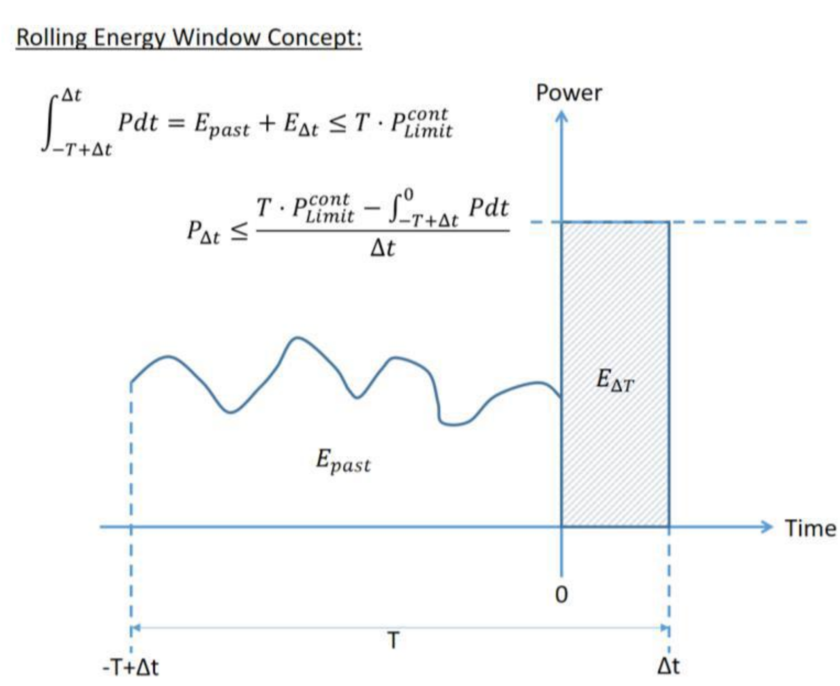
The de-rating shall be subject to a separate slow slew rate of 1 kW/s.

Example of Slew Rate:



The final outputted power will still be subject to a 10 kW/s slew rate.

Example of Rolling Window:



Example of Algorithm:

$$P_{\Delta t}^{charge} \leq \frac{\left(T \cdot P_{Dchrg_{Limit}}^{continuous} + \int_{-T+\Delta t}^{0} P^{-}\, dt\right)}{\Delta t} \qquad P^{-}(t) = \, min(0, P(t)) < 0$$

$$P_{\Delta t}^{discharge} \leq \frac{\left(T \cdot P_{Dchrg_{Limit}}^{continuous} + \int_{-T+\Delta t}^{0} P^{+}\, dt\right)}{\Delta t} \qquad P^{+}(t) = max\big(0, P(t)\big) > 0$$

$$\Delta t = 2\ s, 10\ s, or\ 30\ s$$

$$T = 180\ s$$

Voltage collapse can occur in continuous depletion at all temperatures, worst condition is near 10 degrees C. Continuous Power Limits should prohibit voltage collapse in all conditions.

An internal CAN signal shall report the continuous power. Competition Organizers requires exact calculations and logic to reproduce continuous power limits for prediction purposes.

R-5 Accuracy of Power Limit Estimation

The accuracy of the power limit signals and calculations shall be at least 90%of the actual battery power capability, unless otherwise stated.

This accuracy requirement shall be met in a conservative manner, such that operating limits shall always be respected. For example an error that would result in over/under voltage is unacceptable even if it is within the +/- 5% target accuracy.

This accuracy requirement shall include variables such as temperature, battery age, duty profile (power v. time, aggressive v. non-aggressive), sensor measurement errors, and cell imbalances.

A separate SOP validation document shall be provided to Stellantis to describe MIL, HIL, pack, and vehicle testing procedures used to validate the SOP algorithms. The methodology shall include Stellantis provided drive cycles with periodically inserted power pulses of magnitude determined online by the SOP algorithm.

Error metrics to assess accuracy based on the limiting conditions (voltage-limited, current-limited, power-table limited, battery safety limited, etc.) shall be described in detail in the separate SOP validation document. Percentage error in the case of voltage-limited conditions is calculated based on how close the tested power pulses reached the limit. For table based limits (current/power), percentage error is calculated by using the reported power.

R-6 CAN Signals Associated with Power Limiting

BPCM_HVBatDischrgPowLong – The value of the battery system's ability to deliver 30-second discharge power.

BPCM_HVBatDischrgPowShort – The value of the battery system's ability to deliver 10-second discharge power.

BPCM_HVBatDischrgPowInstant – The value of the battery system's ability to deliver 2-second discharge power.

BPCM_HVBatChrgPowLong– The value of the battery system's ability to deliver 30-second regenerative braking charging power.

BPCM_HVBatChrgPowShort – The value of the battery system's ability to deliver 10-second regenerative braking charging power.

BPCM_HVBatChrgPowInstant– The value of the battery system's ability to deliver 2-second regenerative braking charging power.

TotalAmpHrCapacity– Indicates additional power limiting is occurring due to Component.

S STATE OF HEALTH (SOH) REQUIREMENTS

SOH capacity and resistance estimation shall be performed on each cell internally through algorithms. The signals HVBatSOH and HVBatSOHLow will report worst case conditions among all cells.

S-1 SOH – Capacity

The BPCM shall send a CAN signal that communicates the relative capacity of the battery pack SOH, HVBatFull_Amp_Hr_Capacity [units: Ah, range: 0 to 200, resolution: 0.1].

This value shall change with age and is defined at room temperature and 100% SOC. It is the value one would get if the Capacity Test Procedure was executed on the battery pack (this procedure specifies the temperature and discharge rate).

The reported value of HVBatFull_Amp_Hr_Capacity shall have an error from actual capacity by no more than 5%.

If the value of HVBatFull_Amp_Hr_Capacity becomes unreliable, there shall be a validity signal which signifies this.

The service end-of-life for capacity shall be defined as when the HVBatFull_Amp_Hr_Capacity has reached a level below 70% of the initial value on a new battery pack.

The BPCM shall request the MIL light to illuminate when the HVBatFull_Amp_Hr_Capacity has fallen below a calibratable value (default: 70% of the initial value for a new pack). This will be further defined in the DTC Matrix.

The value of HVBatFull_Amp_Hr_Capacity shall be stored in a DID (to be defined in the program DDT).

The reported value of HVBatFull_Amp_Hr_Capacity shall be equal to the applied capacity, while the estimation algorithm is running.

The value of HVBatFullAmp_Hr_Capacity shall be updated at power up.

The BPCM shall store the value of HVBatFull_Amp_Hr_Capacity in EEPROM, minimally upon shutdown, and use the value on the next wake-up.

The maximum change in HVBatFullAmp_Hr_Capacity shall be no more than 4% for a single update.

A provision for a service routine which can set the value of HVBatFull_Amp_Hr_Capacity to any desired value shall be provided.

The SOH capacity estimation algorithm shall include an empirical model to be used in cases when online capacity estimates are unavailable or known to be poor. For example; during situations involving mainly long-term charge sustaining operation the on-line SOH capacity estimation may not be accurate enough. To protect against such scenarios an empirical capacity fade model needs to be implemented. This empirical model shall take inputs of measured temperature, sleep/drive times, and battery charge/discharge usage to update capacity and its fading.

The reported SOH capacity estimation shall be a blended value between online estimated capacity and empirical model estimated capacity.

A separate SOH validation document will be provided to Stellantis to describe MIL, HIL, pack, and vehicle testing procedures used to validation capacity estimation accuracy. In particular, multi-day and/or multi-key on/off cycles shall be used to demonstrate robustness of the capacity estimation algorithm in the presence of sensor errors, battery aging effects, cell imbalances, and initialization errors.

S-2 SOH – Resistance (2 Signals)

The signal HVBatSOHLow (CAN Signal 1) will be used as an indicator value to assess the resistance of the battery as a percentage of health. The maximum cell charge and discharge resistance of the battery will be estimated as internal values. There will be an internal HVBatSOHrC and HVBatSOHrd signal that will compute SOHr charge and discharge respectively to derive HVBatSOHLow.

A value of HVBatSOHrC=100% indicates the maximum cell charge resistance at Beginning of Life (BOL). The corresponding resistance value is obtained from BOL cell characterization.

End-of-Life charge resistance shall be determined from the cell characterization of aged end of life cells. For example; cells that have been aged for four-seasons aging and/or cells that have been aged to an end-of-life capacity value.

HVBatSOHrC=70% shall be mapped to the Charge Resistance value of EOL charge resistance as defined above. Values between 50% and 70% will indicate excessive resistance growth.

HVBatSOHrD indicates the Discharge Resistance Health. A value of HVBatSOHrD=100% shall indicate the discharge resistance value is at the BOL, using the same BOL cell characterization as described above.

HVBatSOHrD=70% shall indicate that the discharge resistance is at the EOL value. The corresponding value of the EOL discharge resistance shall be determined using the same cell characterization of EOL cells as described above.

The final reported value HVBatSOHLow shall report the minimum of HVBatSOHrC and HVBatSOHrD. The fundamental concept is that HVBatSOHLow shall provide the resistance based health assessment of the cell.

HVBatSOH (CAN Signal 2), this signal shall be calculated and filtered at a calibratable high SOC window (70 to 100% SOC) and scaled to a calibratable point (default: 85% SOC). It shall be defined by the equation:

$$HVBatSOH = kCAP * (HVBatFull\_Amp\_Hr\_Capacity/CAPBOL) - kRd * (SOHRL * / SOHRL\ 0) + koffset$$

where kCAP, kRd, koffset are calibratable parameters to define HVBatSOH.

It is desired that HVBatSOH=70% corresponds to EOL charge resistance.

The end of life resistance shall be defined as when either of the resistance based SOH signals leads to a greater than 30% degradation in the BOL (beginning of life) power as calculated in the BPCM static power limits at 25 deg C.

The BPCM shall request the MIL light to illuminate when either of these resistances based SOH signals falls below a calibrated value (default: that value of resistance which causes the power as calculated in the BPCM static power limits at 25 deg C to fall below 30% of the BOL value). For example, values of HVBatSOH and HVBatSOHLow in the range of 50-70% are anticipated to result in power fades of 30% or more with respect to BOL power.

Both resistance based SOH CAN signal values shall be stored in a DID (to be defined in the program DDT).

A separate SOH validation document will be provided to Stellantis to describe MIL, HIL, pack, and vehicle testing procedures used to validation SOH impedance estimation accuracy. In particular, multi-day and/or multi-key on/off cycles shall be used to demonstrate robustness of the algorithm in the presence of sensor errors, battery aging effects, cell imbalances, and initialization errors.

S-3 Amp-Hour Throughput

The cumulative amp-hour throughput for the battery shall be calculated for both negative values of current (charge) and positive values of current (discharge).

Both charge and discharge amp-hour throughput cumulative values shall be stored in a DID (to be defined in the program DDT).

S-4 Battery Data Recorder / Battery Usage History (BUH)

Any values being recorded by the BPCM to track the usage of the battery pack (battery data recorder) shall be fully explained by the Team.

All battery data recorder values shall be stored in a DID (to be defined in the program DDT).

S-5 CAN Signals Associated with SOH

HVBatFullAmp_Hr_Capacity – Full capacity of the battery (per Capacity Test Procedure)

HVBatSOH – Resistance based SOH value measured at high SOC.

HVBatSOHLow – Resistance based SOH value measure at low SOC.

T Diagnostics Requirements

See referenced documents for additional diagnostic requirements. Diagnostic Trouble Codes (DTC).

The DTCs shall be defined in the DTC Matrix by the Team and all columns shall be filled in thoroughly unless given approval by Competition Organizers. The format for the DTC Matrix is described in the document DTC_sample.xlsx.

The DTC Matrix shall be submitted by the Team and require approval by Competition Organizers.

The DTC Matrix shall include all diagnostics identified in the DFMEA and be referenced to the DFMEA.

The Team shall review with Competition Organizers the DFMEA and the corresponding associated DTCs.

Diagnostics shall be capable of 2-Trip fault detection.

Unless otherwise specified, faults shall not be latched between key off/on cycles.

Exceptions to not latching faults between key off/on cycles shall be approved by Competition Organizers and currently only include, impact response, isolation (within battery pack only), and welded contactors.

Any device that communicates faults to the BPCM through fault flags shall have a separate DTC and DIDs for counting events.

No DTCs shall be present after a flash event except for those that were present before the flash event.

All DTCs shall have two records: the first event and the last event.

The setting of a DTC on a fail event shall not cause the setting of other DTCs. For example, the setting of the fuse circuit fault should not result in the setting of a blown fuse fault.

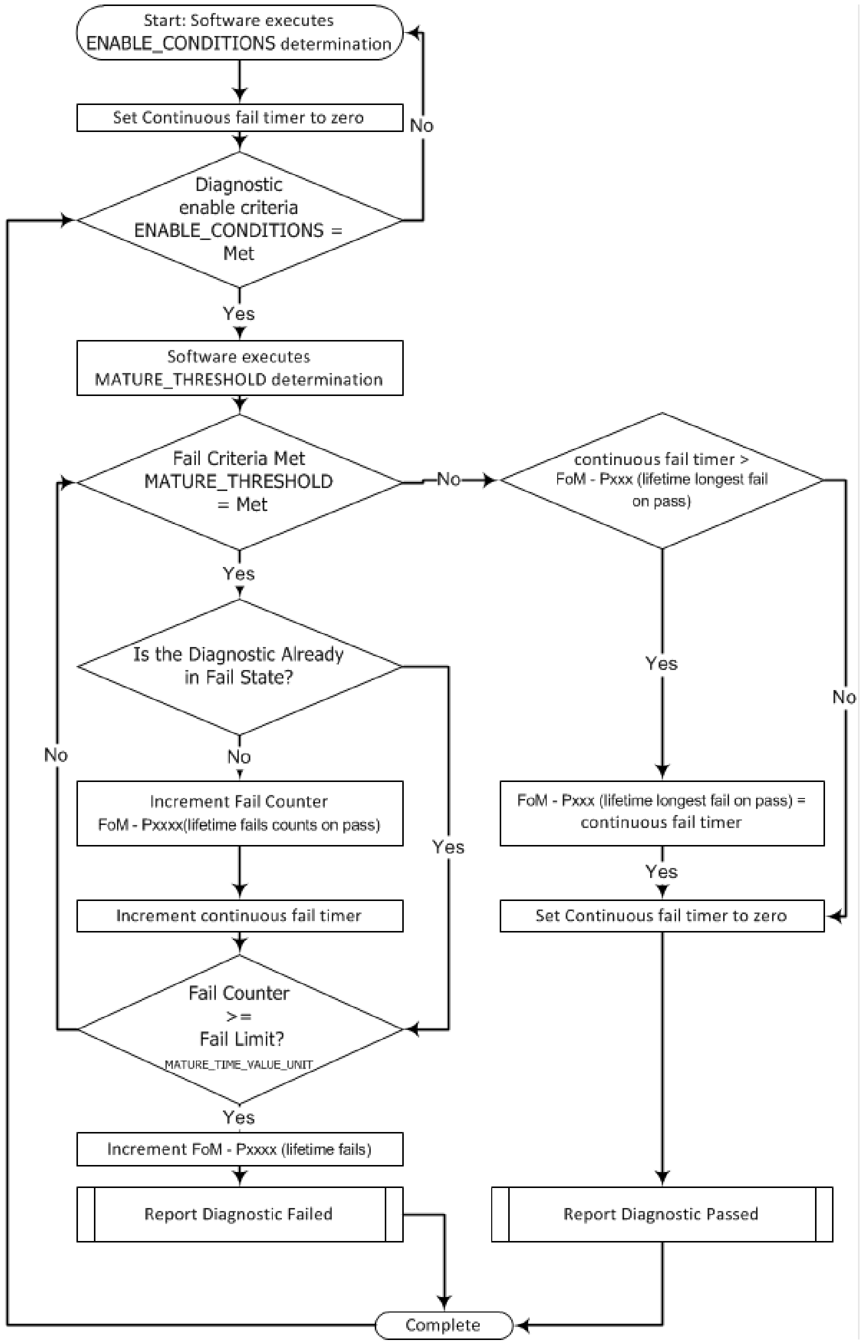
DTCs that are difficult to determine root cause in the field should have the additional data shown in the environmental data.

Any fault that opens contactors or prevents contactors from closing shall have a unique DTC assigned to it.

All voltage, current, temperature, and other sensors shall be diagnosed on a continuous basis and monitored using the X/Y method of determination for a pass or fail condition.

T-1 Figures of Merit (FOM)

The purpose of the figures of merit is to have a full comprehension of how faults are matured while enabled and tripped. The intent is to keep permanent record of the detections of fault. FOMs provide proof of the existence of the fault detection even after it has been cleared by a service tool. A flowchart which depicts how FOMs are updated is shown below (the flowchart is for how FOMs work, not DTCs). The flowchart is based on the fault status register.



A diagnostic's figure of merit shall be updated when the specified enable criteria for a diagnostic have been met and no inhibiting criteria are present.

Figures of merit shall be stored over key cycles.

Variables that track the diagnostic FOM shall be retained in non-volatile memory as part of the X/Y diagnostic strategy. They shall include:

- FOM - PCodeXXX (lifetime fails) – This is incremented when the DTC for the fault gets set
- FOM – PCodeXXX (lifetime fails counts on pass) – This is incremented while the DTC is maturing.
- FOM – PCodeXXX (lifetime longest fail on pass) – This is updated with the longest duration where fails are detected but the DTC has not yet matured while the enabling criteria is true.
- FOM – PCodeXXX Path n (where is n <3) (lifetime fails) – This is a count of the path by which the DTC was set.

A routine shall be available to reset the FOMs to zero.

The software should have ability to erase the FOM parameters from the NVRAM based on the memory map change or individual diagnostic change.

Individual FOMs shall have ability to reset to zero when the BPCM is flashed and this is directed by Competition Organizers otherwise FOM's should retain from memory after BPCM is flashed.

Enough processing speed shall be available to run FOMs for 200 DTCs.

FOMs shall run on an interrupt basis.

DTCs and environmental snapshot data shall be written to EEPROM at point of maturity so that the events are ensured to be captured.

The BPCM shall be able to clear the FOM data separately in EEPROM.

T-2 Diagnostic Robustness

It is required that all diagnostics be robust to reduce the probability of false failures and ensure that real failures are detected. The robustness will be analyzed and achieved by the following tasks.

There shall be a calculation of the probability of failure for each DTC.

For all diagnostic circuits, a tolerance stack-up analysis for all the components in the circuit shall be conducted. This is to ensure that the DTC will be calibrated in a manner which includes all the variable inputs to the elements of the circuit over the life of the vehicle (e.g., temperature, age, voltage references, etc.).

All inputs used to determine the diagnostic shall be available in the internal CAN bus so that they can be monitored during vehicle development.

The internal CAN bus shall remain awake during shutdown for as long as possible so that the diagnostics occurring during shutdown can be analyzed. The ePT CAN line will remain silent during shutdown.

The maturation times shall be calibrated to be as long as possible.

Once matured, the reaction for those DTCs which influence drivability (e.g., contactors opening, power limiting to zero kW) shall be delayed by a minimum calibratable value (variable Ke_t_DTCdelay, default: 30 seconds).

The BPCM shall, where specified on the DTC matrix, support Two-Trip DTC determination in accordance with ISO 15765 – 4.

The priority for the work flow is shown below.

- Those diagnostics which open contactors during vehicle driving
- Those diagnostics which prevent contactors from closing at power up
- Those diagnostics which light the MIL light – one trip
- Those diagnostics which light the MIL light – two trip
- Those diagnostics which inhibit plug-in charge
- All other diagnostics

Team shall supply a list of DTCs which fall within each category and when each design and robustness task will be completed and ready for review by Competition Organizers. The key elements are:

- Early design tasks, requirement compliance, resulting P-diagram from DFMEA and any virtual analysis
- Diagram of sensing circuit
- Worst Case Analysis Stackup and relationship to calibrations
- Description of algorithm
- Justification for reaction and calibrations
- Testing and analysis which support reaction and calibrations
- Validation
- Service

The BPCM should monitor and diagnose its critical systems. When a fault is detected, appropriate reactions should be taken to ensure safety and to minimize damage to the hardware whenever possible. It is also important to not have false failures that interfere with the ability to make use of the battery.

Therefore, the diagnostics should be robustly designed with the following:

Enable Conditions – The diagnostic only runs while under the correct conditions
Mature Threshold – The failure condition is well defined to accommodate all 'normal' conditions
Mature Time – The failure condition must persist for some reasonable amount of time to confirm the failure

The following critical systems failures should be diagnosed. This list may not be comprehensive:

Cell over/under voltage
Cell voltage measurement failure
Cell voltage imbalance
Cell over/under temperature
Cell temperature measurement failure
Cell temperature imbalance
Thermal runaway
Isolation
HV Voltage measurement failure
HV Current measurement failure
Over current (charging and discharging)
Contactors (or equivalent) stuck closed/open
Contactor control circuit failure

Precharge failure
HVIL circuit failure
LV power supply high/low
Loss of communication (if the BPCM for this project is meant to be receiving regular external communication)
Blown fuse detection
Impact detection

Teams will need to send out all diagnostic status that BMS would send out

Teams can implement their own diagnostics on their Team's private CAN

T-3 BPCM Warning and [Shutdown SW] Contactor Open Requirements

The BPCM shall protect itself from improper usage of the vehicle by using warning stages to the vehicle, as to reduce the probability of damage to the battery and/or cause a failed start condition or a vehicle to be disabled during operation.

The warning stages shall be communicated over CAN as follows:

- HVBatCntctrOpn – A notification that contactors will open in no more than a calibrated amount of time (default: 1500 ms). This gives the vehicle controller time to react and lower current before contactors open.
- HVBatCntctrReq – A request to return to normal operating range or request to open contactors. This will transition to HVBatCntctrOpn if the conditions persist for a calibratable amount of time (default = 30 s).

The Team shall provide to Competition Organizers a plan for minimizing shutdowns and vehicle performance issues which lists all reasons why contactor open, contactor won't close, if power limits are reduced, and how DTC's will be set through cascading failures.

The plan shall include what happens when sensor values are lost or invalid, including any mitigating actions taken.

Sensor values shall be substituted with other available data to the maximum extent possible. Substitution of values read by sensors shall be conducted in a manner most appropriate for accuracy and continued vehicle functionality.

T-4 Service Routine for Battery Pack Outside Normal Voltage Range

There shall be a service routine available for the purpose of restoring battery packs back to the normal voltage range. This would be for battery packs that for some reason have gotten voltages too high or too low but are still at a point where they are salvageable. The routine will require the contactors to close to allow the vehicle to either charge the battery pack (using the motor) or discharge the battery pack.

T-5 Validation of DTCs

The Team shall develop a method to test all DTCs with a breakout box for the signal lines leaving the battery pack.

A pack can be instrumented with the ability to cause all faults manually or through software in the vehicle. If it is done using software other than CANalzyer, then a computer with that software and all supported hardware and harnesses should be provided.

The purpose of DTC testing at the vehicle level is to verify the integration functionality (fault reactions and vehicle response). Testing fault maturation, enablement, FOMs, status byte, etc. shall be conducted at the pack level by the Team.

DTC tests at the vehicle level will fall into a few categories:

- Bridge layer – Some tests will require bridge layer to induce false failures. Teams shall provide any out of the ordinary harness for connection, software, and instruction to perform these tests.
- Breakout box – Some tests will require a breakout box to simplify the ability to manipulate the wiring harness to the BPCM. (As some wiring to the BPCM may be internal to the battery for this program this will need to be considered for the instrumented pack section).

For any DTC that has multiple failure conditions, a DID shall be defined with a root cause and the failure associated with it. And the path which set the DTC shall be identified in the environmental data.

All DTCs shall be thoroughly validated by the Team and shall include the following test cases:

- DTC sets when attribute is exceeded (e.g., cell voltage threshold)
- DTC sets only when enable conditions allow
- Proper light was requested for DTC (MIL, Service)
- DTC maturation time correct
- DTC didn't set when inhibited by other DTCs
- DTC dematuration correct
- DTC has proper link to contactor signals (HVBatCntctrReq, HVBatCntctrOpn)
- DTC has proper link to HVBatRdy
- DTC stores correctly
- DTC clears correctly
- Persistent DTCs stay persistent
- Persistent DTCs clear with service mode
- Supporting DIDs are proper for DTCs
- Snap shot and environmental data information is correct
- All testable cells in the DTC Matrix
- Removal of 12V Supply through all the operational modes (Wake up, Shutdown, Run, Charging etc.)

T-6 Supplemental Vehicle Validation Testing for DTC's

To supplement vehicle validation testing for DTCs, Competition Organizers asks that the Team provide the minimum information from their HIL testing for each DTC described below. As shown in appendix xx Note: That this does not describe a comprehensive test of the DTC matrix. That comprehensive test shall be submitted separately by the Team, and it shall include all testable cells in the dtc matrix (for example: enable conditions, contactor reaction, etc.

T-7 Diagnostic Retry Strategy

A Diagnostic Retry Strategy is required to reduce false failures and ensure conditions are true, that result in a “No Start” condition, warning conditions to the customer, or a contactor lock out on the following key cycle. A diagnostic retry attempt strategy will authenticate or disprove failures using singular or multiple test.

Some retry attempts may cause issues for power moding, which will need to be reviewed and approved by the OSC.

Team shall provide a list of “all” the DTC’s that cause; a “No Start” condition, warning conditions to the customer, or a contactor lock out where contactors will not close on the following key cycle.

Based on the provided list (DTC Matrix); DTC’s will be selected to go through a process of availability engineering that will focus on increasing testability. DTC’s will be reviewed to determine what test and retry attempts can take place through a power down or power up event.

T-7.1 DTC Prioritization

1. No Start – DTC’s that cause a contactor lockout
2. DTC’s that cause warning indications

Diagnotic Code	Diagnostic Description
P0AA1-00	Hybrid/EV Battery Positive Contactor Circuit Stuck Closed
P0AA4-00	Hybrid/EV Battery Negative Contactor Circuit Stuck Closed

T-7.2 Diagnostic Retry Strategy for On-Demand monitor type DTC items.

On-demand monitor type DTC’s cause a contactor lock out, where contactors will not close on the following key cycle.

Process of identifying Diagnostic Retry DTC’s:

1. Which DTC’s (in the DTC Matrix), can be retried on “power up” and which ones can be retried during “power down”.

N/A

								GENERAL WARNING MARK										
SAE J2012	(Chrysler) UDS DTC Description			DTC Classification				Temperature difference warning; 0: Normal	1: Battery high-temperature warning; 0: Normal	1: Vehicle energy-storage device type over-voltage warning; 0: Normal	1: Vehicle energy-storage device type under-voltage warning; 0: Normal	1: Cell over-voltage warning; 0: Normal	1: Cell under-voltage warning; 0: Normal	1: Chargeable energy-storage system unmatched warning; 0: Normal	1: Cell poor-consistency warning; 0: Normal	1: Insulation warning; 0: Normal	1: High-voltage interlocking state warning ; 0:Normal	1: Vehicle energy-storage device type over-charging; 0: Normal
		MIL ON	SERV ON	3	2	1	Other											
P1A9F-00	Hybrid/EV Battery Temperature Sensor 2 Out of Range High-	1		1														
P1AA2-00	Hybrid/EV Battery Temperature Sensor 3 Out of Range Low-	1		1					1									
P1AA3-00	Hybrid/EV Battery Temperature Sensor 3 Out of Range High-	1		1														
P1AA6-00	Hybrid/EV Battery Temperature Sensor 4 Out of Range Low-	1		1					1									
P1AA7-00	Hybrid/EV Battery Temperature Sensor 4 Out of Range High-	1		1														
P1AAA-00	Hybrid/EV Battery Temperature Sensor 5 Out of Range Low-	1		1					1									
P1AAB-00	Hybrid/EV Battery Temperature Sensor 5 Out of Range High-	1		1														
P1AAE-00	Hybrid/EV Battery Temperature Sensor 6	1		1					1									
P1AAF-00	Hybrid/EV Battery Temperature Sensor 6	1		1														
P1AE	Battery Energy Control Module High Voltage System Interlock Circuit-	1		1													1	
P1AE3-00	Battery Energy Control Module High Voltage System Interlock Circuit Low-	1		1													1	
P1AE4-00	Battery Energy Control Module High Voltage System Interlock Circuit High-	1		1													1	
P1B70-00	Hybrid/EV Electronics Coolant Temperature Sensor "A" Out of Range Low-	1				1												
P1B71-00	Hybrid/EV Electronics Coolant Temperature Sensor "A" Out of Range	1				1												
P1C00-00	Hybrid/EV Battery Voltage Sense 1 Out of Range Low-	1		1									1					
P1C01-00	Hybrid/EV Battery Voltage Sense 1 Out of Range High-	1		1								1						
P1C02-00	Hybrid/EV Battery Voltage Sense 2 Out of Range Low-	1		1									1					
P1C03-00	Hybrid/EV Battery Voltage Sense 2 Out of Range High-	1		1								1						
P1C04-00	Hybrid/EV Battery Voltage Sense 3 Out of Range Low-	1		1									1					
P1C05-00	Hybrid/EV Battery Voltage Sense 3 Out of Range High-	1		1								1						
P1C06-00	Hybrid/EV Battery Voltage Sense 4 Out of Range Low-	1		1									1					
P1C07-00	Hybrid/EV Battery Voltage Sense 4 Out of Range High-	1		1								1						
P1C08-00	Hybrid/EV Battery Voltage Sense 5 Out of Range Low-	1		1									1					
P1C09-00	Hybrid/EV Battery Voltage Sense 5 Out of Range High-	1		1								1						
P1C0A-00	Hybrid/EV Battery Voltage Sense 6 Out of Range Low-	1		1									1					

U Software Requirements Compliance

U-1 Documented Sourcing Compliance

A DVP&R shall be provided by the Team which describes all test cases used to validate all requirements in this document and all referenced documents.

The test cases shall include appropriate sweeps of input parameters in the defined operating and storage ranges as well as outside the ranges for the case of DTC validation.

The Team shall verify that diagnostic responses show up correctly.

U-1.1 Traceability Document (One to one Correspondence):

Competition Organizers requires the HV battery Team to provide a summary document to confirm compliance to all requirements. The summary should be in the form of a spreadsheet with the first column to list all Requirements, and additional columns to provide corresponding information; requirement reference (if applicable), Team's Test Case (test report/data reference), dates tested, Test Method (HIL, HV Bench, in vehicle, etc.), software version tested, result (pass/fail), Team's Issue Report # (if fail, e.g. Redmine), Corrective Action (if fail), Planned Retest (if fail) and Comments.

Example of Spreadsheet:

Test Requirement	Team Requirement Reference	Team Test Case	Date Tested	Test Method	Software Version Tested	Result (Pass/Fail)	If Test Fails			Comments (Notes
							Corrective Action	Team Report Number	Planned Reset date	

V VALIDATION

V-1 DVP&R

A validation summary shall be supplied by the Team which list the requirement, when it was tested, in which software version it was tested, whether it passed or failed, and, if failed, a recovery action plan for rectifying the failure. The requirements in this BMS core software requirements document as well as all other referenced documents shall be included.

A completed DVP&R shall be provided by the Team which describes all test cases used to validate all requirements in this document and all referenced documents. Simple example DVP&R template are available on the internet, here is one example at the bottom of this web page:

https://www.specterengineering.com/blog/2018/12/15/dvpampr-for-dummies

The test cases shall include appropriate sweeps of input parameters in the defined operating and storage ranges as well as outside the ranges for the case of DTC validation.

The Team shall verify that diagnostic responses show up correctly.

The Team DVP&R which validates all requirements in the BMS core software requirements document shall be reviewed with Competition Organizers. This includes both the test procedures and results.

The DVP&R shall be part of the validation test for each software release.

W Functional Requirements

The Team shall prepare a document of functional requirements which properly addresses the requirements decomposition from the requirements in this BMS core software requirements document, its referenced documents, and any additional requirements that the Team has.

This functional requirements document shall be reviewed by Competition Organizers.

X Appendix A

X-1 CAN Signals

A signal list will be provided by Stellantis in a CAN DBC file, showing signals that shall be sent from or received by the BPCM. These signals are subject to change given the vehicle program DBC File.

For all CAN signals for which there are associated validity bits, the strategy for what makes these signals INVALID shall be documented and submitted to Competition Organizers for approval.

The value of the validity bit shall be 1 when INVALID and 0 when VALID.

All validity bits that the BPCM transmits shall not be set to INVALID until the corresponding DTC has fully matured. This is to avoid the vehicle controller setting an "Invalid Data Received from Battery Pack Control Module" DTC based on a transient event.

X-1.1 Sensors

Problem Illumination Lights

MIL_OnRq_BPCM – BPCM request MIL light to illuminate due to an OBDII fault

HEV_OnRq_BPCM – BPCM requesting service light to illuminate due to a DTC

Y Appendix B

BPCM Software Calibrations

A calibration table shall be created by Teams.

Z Appendix C

BPCM Core Software Requirement Updates per Project Memorandums

Project memos to be listed during product development.

AA APPENDIX D

AA-1 Descriptions of Part Number and ECU Identification DIDs

The following DIDs are an attachment of the Part Number and ECU Identification section of this document. The DIDs described in detail below shall be Mandatory. A limited number of these DIDs may be optional based on applications. Additional DIDs may apply.

RDI $F100 – Active Diagnostic Information – This Data Record shall provide active diagnostic information which uniquely identifies the diagnostic status of the ECU.

RDI $F10B – ECU Qualification – This Data Identifier shall provide vehicle specific parameters which allow the vehicle's ECU software to enable vehicle specific features and or functions to optimize the use of diagnostic tools.

RDI $F10D – Diagnostic Specification Information – This Data Identifier shall provide detailed specification version records which identify the standards the ECU diagnostic software was developed under.

RDI $F112 – FCA Group Hardware Part Number – This Data Identifier shall be used to report the Stellantis Group ECU Hardware Part Number as reported on the EBOM. The ECU may be Stellantis developed hardware or team developed hardware.

RDI SF112 shall be entered in EEprom in a permanent manner in the Stellantis or Team's End of Line and the content must be rewritable in every manner including the reprogramming operation (even if not updated as part of flash).

As a plan of record for use in this vehicle program, the DID shall not be updated after the EOL process at the battery assembly facility.

The DID shall retain the hardware part number of the pack as originally manufactured upon arrival at the vehicle assembly plant.

RDI $F122 – FCA Group Software Part Number – This DID shall be identical to $F132 in every way, except the parameter describes the Software Part Number requirements.

RDI $F132 – ECU Part Number – The ECU Part Number identifier $F132 shall identify the latest CN number updated upon reprogramming the operation flash. It is used for flash supercedance identification. This is the pack assembly number read by EOL. The part number is unique for each specific combination of hardware and software.

RDI $F150 – ECU Hardware Version Information – In the event that the hardware part number $F112 is changed, the hardware version $F150 shall also be written during Team's EOL process. $F150 is to be written to match the Year, Week, and Patch level that corresponds to the approximate hardware version release date as part of the Change Management Process.

If no patch level is applicable [00 Hex] shall be reported as default. See the Change Management Process below for detailed instructions.

RDI $F151 – ECU Application Software Version Information – In the event that the software has been updated, $F151 shall be updated to a unique Year, Week, and Patch level that corresponds to the software release date.

RDI $F153 – ECU Boot Software Version Information – The boot software version information identifier $F153, shall identify the software version of the ECU's bootloader, which defines the development state of the software.

RDI $F154 – ECU Hardware Supplier Identification – The hardware Supplier identifier $F154, shall identify the manufacturer of the ECU's hardware.

RDI $F155 – ECU Software Supplier Identification – The software Supplier identifier $F155, shall identify the software developer who designed and developed the ECU's software. The software Supplier identifier is required for flash and non-flash programmable ECU's.

RDI $F158 – Vehicle Information – The vehicle information identifier $F158, shall identify the diagnostic service read data by Model Year, Vehicle Line, Body Style, and Country Code.

RDI $F15A – Write Software Fingerprint – The write software fingerprint identifier $F15A, shall be used to select the respective logical memory block intended to be reprogrammed. Tool Supplier information, programming date, and the diagnostic tool serial number is also written as identification data.

RDI $F15B – Read Software Fingerprint – The data identifier shall uniquely identify the last external tool (Team or FCA-US tool) which reprogramed a specific logical block.

The information shall also include; if a logical block has not been programmed, has never been programmed, and software fingerprint information.

RDI $F160 – F16F – SW Module Information – The Software Module Information data record shall report the version information of standard software modules implemented in the respective ECU.

RDI $F170 – F17F – Physical Layer Channel Configuration – The Physical Layer Channel Configuration data record shall provide information about bit-timing and hardware in respect to the physical layer channel configuration.

RDI $F18C – ECU Serial Number – This data identifier shall be used to uniquely identify specific ECU hardware. The identifier is expressly purposed to identify ECU's of a specific batch to provide traceability.

RDI $F190 – VIN Original – The VIN Original data identifier shall record the Vehicle Identification Number (VIN) and the vehicle configuration of the ECU as originally installed.

RDI $F1A0 – VIN Current – The VIN Current data identifier shall record the Vehicle Identification Number (VIN) and the vehicle and the vehicle configuration of the ECU as currently installed.

BB Abbreviations

ADRESS: AUTOMATED DOCUMENT RETRIEVAL & ENGINEERING STANDARDS SYSTEM
BCH: BATTERY COOLANT HEATER
BCP: BATTERY COOLANT PUMP
BEV: BATTERY ELECTRIC VEHICLE
BMS: BATTERY MANAGEMENT SYSTEM
BPCM: BATTERY PACK CONTROL MODULE
CAN: CONTROLLER AREA NETWORK
CAN FD: CONTROLLER AREA NETWORK FLEXIBLE DATA
CC: CONTINUOUS CONFORMANCE
CDA: FCA DIAGNOSTIC APPLICATION
CPTS: COMPONENT PARTS TRACEABILITY SYSTEM
CRC: CYCLIC REDUNDANCY CHECK
CSC: CELL SUPERVISING CIRCUIT
CVR: COMPONENT VERIFICATION REPORT
DDT: DIAGNOSTIC DEFINITION TABLE
DFMEA: DESIGN FAILURE MODES AND EFFECTS ANALYSIS
DID: DATA IDENTIFIER
DPRS: DIAGNOSTIC PERFORMANCE REQUIREMENTS SPECIFICATION
DTC: DIAGNOSTIC TROUBLE CODE
DV: DESIGN VERIFICATION
DVP&R: DESIGN VERIFICATION PLAN & REPORT
E2E: END TO END (COMMUNICATION PROTECTION)
ECU: ELECTRONIC CONTROL UNIT
ED&D: ENGINEERING DESIGN & DEVELOPMENT
EEPROM: ELECTRICALLY ERASABLE PROGRAM READ ONLY MEMORY
EMC: ELECTROMAGNETIC COMPATIBILITY
EPT: ELECTRIFIED POWER TRAIN
EOL: END OF LINE / END OF LIFE EV: ELECTRIC VEHICLE
EVCU: ELECTRIC VEHICLE CONTROL MODULE (CONTAINS HCP)
EVSE: ELECTRIC VEHICLE SUPPLY EQUIPMENT
FCA: FIAT CHRYSLER AUTOMOBILES
FMVSS: FEDERAL MOTOR VEHICLE SAFETY STANDARD
FOM: FIGURE OF MERIT
HCP: HYBRID CHARGE CONTROLLER
HEV: HYBRID ELECTRIC VEHICLE
HIL: HARDWARE IN THE LOOP
HV: HIGH VOLTAGE
HVBS: HIGH VOLTAGE BATTERY SYSTEM
HVIL: HIGH VOLTAGE INTERLOCK
IOD: IDLE OFF DRAW (CURRENT DRAWN WHILE CONTROLLER IS OFF/ASLEEP)
LED: LIGHT EMITTING DIODE
LIN: LOCAL INTERCONNECT NETWORK
LOC: LOSS OF COMMUNICATION
LOI: LOSS OF ISOLATION
LV: LOW VOLTAGE
MC: MESSAGE COUNTER
MIL: MODEL IN THE LOOP / MALFUNCTION INDICATOR LIGHT
MRD: MATERIAL RECEIVED DATE
NM: NETWORK MANAGEMENT
NMIF: NETWORK MANAGEMENT INTERFACE
NVRAM: NON-VOLATILE RANDOM ACCESS MEMORY
OBC/OBCM: ON BOARD CHARGER/ON BOARD CHARGE MODULE
OBD: ON-BOARD DIAGNOSTIC
ORC: OCCUPANT RESTRAINT CONTROLLER
PID: PARAMETER IDENTIFIER
PIM: POWER INVERTER MODULE (CONTAINS HCP), EVCU REPALCES PIM IN BEV VEHICLES
PV: PRODUCTION VALIDATION
RAM: RANDOM ACCESS MEMORY
ROM: READ ONLY MEMORY
RTC: REAL TIME CONTROL
SNA: SIGNAL NOT AVAILABLE
SOB: STATE OF BATTERY
SOC: STATE OF CHARGE
SOH: STATE OF HEALTH
SOF: START OF FRAME
SOP: STATE OF POWER
SRD: SOFTWARE REQUIREMENTS DOCUMENT
TTF: TEST TO FAILURE
UDS: UNIFIED DIAGNOSTIC SERVICES

CC - Change Log

Date	Revision	Section	Change Description	Initials
1/15/2024	0	ALL	Initial Document Release	OSC
8/01/2024	1	Multiple	Adjusted documentation to reflect breaktor requirements, remove PWM requirements that are not applicable and other highlighted updates	OSC
10/24/2024	2	I-6	Clarified language on precharge sequence for breaktor	OSC
1/22/2025	3	K	Added impact response requirements	BC
1/22/2025	3	H-1.3	Removed HVIL repeated requirement	OSC
2/10/2025	4	Multiple	Adjusted CAN dbc signal names to match current database and remove unused signals	OSC
3/4/2025	5	I-2	Added Qualified Contactor Command internal variable and description	OSC

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