BMS Software Requirements

Rose-Hulman Institute of Technology

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Power Up Requirements

1. The BPCM shall wake up when the hardware wakeup signal (ePT ECU Wakeup) is received from the EVCU.
2. The BPCM shall source the HVIL circuit within 60ms of receiving the wakeup signal, provided the startup inhibit flag is not set.
3. The BPCM shall complete all initialization processes within 160ms after sourcing the HVIL.
4. The BPCM shall determine and transmit all required CAN signals within 40ms after completing initialization processes.
5. The BPCM shall transmit Contactor Status within 20ms after determining all CAN signals.
6. The BPCM shall check the Qualified Contactor Command and HVIL status within 20ms after transmitting the Contactor Status.
7. The BPCM shall close the precharge sequence and negative contactor/precharge relay within 40ms of verifying that the Qualified Contactor Command is CLOSE and HVIL status is PASS.
8. The BPCM shall transmit Battery Contactor Status as "Precharging" within 20ms after initiating the precharge sequence.
9. The BPCM shall monitor the precharge process until it reaches 95% of pack voltage, which shall complete within 100ms.
10. The BPCM shall command the Positive Contactor closed and terminate the precharge sequence within 40ms after precharge reaches 95% of pack voltage.
11. The BPCM shall transmit Contactor Status as "Closed" within 30ms after closing the positive contactor.
12. The BPCM shall enable Loss of Communication diagnostics with EVCU independent of receiving the LOC Diagnostics Enable command, setting the diagnostic after 5000ms of wake-up.

Power Down Requirements

1. The BPCM shall open HV Contactors upon receiving an "Open Contactors" command from HCP if the HV Contactors are closed.
2. The BPCM shall initiate its controller power-down sequence within 1200ms + 120 seconds (maximum) of receiving the HCPShutDwnCmd = Initiate Powerdown command from the EVCU.
3. The BPCM shall cancel its controller power-down sequence and resume operation if the EVCU sends a Cancel Power-down command.

4. The BPCM shall disable its LOC diagnostics upon receiving the Disable LOC Diagnostics command from EVCU.
5. The BPCM shall shutdown EPT-CAN communication within 250ms of receiving the HCPShutDwnCmd = Shutdown Comm command and de-source HVIL.
6. The BPCM shall initiate its Pre power-down actions after shutting down EPT-CAN communication.
7. The BPCM shall continuously monitor the HW Wakeup line from EVCU for transitions during power-down.
8. The BPCM shall re-start the power-up process if the HW Wakeup line transitions from High to Low to High.
9. The BPCM shall complete its Pre power-down actions after determining there are no HW Wakeup line transitions.
10. The BPCM shall execute a controlled power-down if the HW Wakeup line from EVCU is Low.
11. The BPCM shall set a DTC and execute a controlled power-down if the HW Wakeup line does not transition and is not Low.

Initialization Requirements

1. The BPCM shall perform essential voltage, current, and temperature measurements specific to computing and reporting the available discharge power during initialization.
2. The BPCM shall source HVIL during initialization if no startup inhibit flag is set.
3. The BPCM shall read EEPROM data specific to the last isolation state and SOC from the previous ignition cycle during initialization.
4. The BPCM shall set the startup inhibit flag if any of the following conditions are true during initialization:

    a. BPCM observed Impact Faults are TRUE

    b. BPCM observed Loss of Internal Isolation Faults are TRUE

    c. BPCM observed Welded Contactor Faults are TRUE

5. The BPCM shall determine the HVBatRdy status during initialization and before contactors close.

Battery Conditioning (HVBatRdy)

1. The BPCM shall transmit the HVBatRdy signal to indicate whether the HV battery is ready to deliver or receive power.
2. The BPCM shall set HVBatRdy to 0 if any of the following conditions exist during initialization:

    a. HVBatCellVltMax is above HVBatCell_Voltage_High_Thrsh
    b. HVBatCellVltMin is below HVBatCell_Voltage_Low_Thrsh
    c. HVBatModuleTemp_Max is above HVBatHighTempThrsh
    d. HVBatModTempMin is below HVBatLowTempThrsh
3. The BPCM shall allow contactors to close without setting a DTC when HVBatRdy is set to 0.
4. The BPCM shall set HVBatRdy to 1 otherwise.
5. The BPCM shall open contactors to protect the battery pack if HVBatRdy is equal to 0 and DriveReady is equal to 1.
6. The BPCM shall transition HVBatRdy from 0 to 1 when all of the following conditions are met:
    a. HVBatCellVltMin is at least 0.1V above HVBatCell_Voltage_Low_Thrsh and HVBatSOC is greater than the minimum charge sustaining value (default: 15%)
    b. HVBatCellVltMax is at least 0.1V below HVBatCell_Voltage_High_Thrsh
    c. HVBatModTempMax is at least 0.5°C below HVBatHighTempThrsh
    d. HVBatModTempMin is at least 0.5°C above HVBatLowTempThrsh
7. The BPCM shall not change the HVBatRdy status from 1 to 0 in the same key cycle once HVBatRdy status sets as 1.

High Voltage Interlock Loop

HVIL Sourcing Requirements

1. The BPCM shall energize the HVIL circuit within a calibratable time (default: 60ms) when:
    a. BPCM wake-up from Sleep is TRUE (i.e., when hardware wakeup line is received) OR BPCM EPT modes transition from OFF to ACCESSORY, RUN, or CRANK, AND
    b. Startup inhibit flag is not set
2. The startup inhibit flag shall be set when ANY of the following conditions are true:
    a. BPCM detected impact faults are TRUE on initialization
    b. Loss of internal isolation faults are TRUE on initialization

   c. Welded contactor faults are TRUE on initialization

HVIL De-Sourcing Requirements

1. The BPCM shall de-energize the HVIL circuit when ANY of the following are TRUE:
   a. Shutdown command is received (HCPShutDwnCmd = Shutdown)
   b. Hardwired wakeup signal transitions from high to low AND loss of communication with HCP is TRUE
   c. Contactors are OPEN AND EPT wakeup transitions from high to low
   d. Impact faults are detected by the BPCM
2. For internal HVIL, the BPCM shall de-energize the circuit when ALL of the following are TRUE:
   a. Contactors are opened (after weld check)
   b. Internal isolation is complete
   c. BPCM is transitioning to sleep mode

HVIL Status Monitoring

1. The HVIL diagnostic shall be executed with at least a 100ms refresh rate
2. The diagnostic shall initially execute within 100ms of the HVIL circuit becoming energized
3. The BPCM shall set HVIL status to "Pass" when PWM frequency and duty cycle are within range
4. The BPCM shall set HVIL status to "Fail" and communicate via CAN (HVBatIntrlkStat = Fail) within 100ms when PWM frequency and duty cycle are out of range
5. The BPCM shall set HVIL status to "Not Sourced" when:
   a. BPCM has not sourced HVIL
   b. BPCM cannot measure the HVIL circuit
   c. HVIL circuit has been de-asserted after receiving HCPShutDwnCmd = Shutdown

HVIL Status Determination Logic

1. Set HVIL status to "UNDETERMINED (NOT SOURCED)" at beginning of BPCM wake-up until initial evaluation is complete
2. Set HVIL status to "PASS" when:

    a. Test has run for a duration equal to KeHLVR_t_HVILOpenSamplesDurationTime BPCM has not detected electrical faults with the HVIL circuit

3. Set HVIL status to "FAIL" when:

    a. Test has run for a duration equal to KeHLVR_t_HVILOpenSamplesDurationTime

    b. BPCM has detected an open circuit or out-of-range fault in the HVIL circuit

4. Set HVIL status to "INVALID" when:

    a. Test has run for a duration equal to KeHLVR_t_HVILOpenSamplesDurationTime

    b. BPCM has detected a short to high or short to low fault in the HVIL circuit

HVIL Diagnostics

1. The BPCM shall perform short-to-high, short-to-low, and open circuit diagnostics on both external and internal HVIL lines when the circuit is energized
2. These diagnostics shall be capable of detecting:

    a. HVIL signal short to high voltage

    b. HVIL signal short to ground

    c. HVIL circuit open

    d. HVIL signal out of range high

    e. HVIL signal out of range low

CAN Communication Requirements

1. The BPCM shall transmit the following HVIL-related signals via CAN:

    a. HVBatIntrlk_InternalStat: Status of internal current loop (Not Sourced, Pass, Fail, or Invalid)

    b. HVBatIntrlkStat: Status of vehicle high voltage interlock state (Not Sourced, Pass, Fail, or Invalid)

Calibration Parameters

1. The BPCM shall include the following calibratable parameters:

    a. Ke_t_HVILShortSamplesDurationTime: Duration for diagnosing shorts

b. Ke_t_HVILOpenSamplesDurationTime: Duration for diagnosing opens

c. Ke_t_HVIL_Dly_Tim: HVIL diagnostic delay after wake-up

d. Ke_t_HVILOnTimeout: Timeout for HVIL energization on startup

Contactor Control

General Contactor Control Requirements

1. The BPCM shall control the actuation of contactors when appropriate conditions and timing exist.
2. The BPCM shall inhibit the closing of contactors and set applicable diagnostic codes when fault conditions are detected.
3. During Loss of Communication (LOC) with the 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.
4. The BPCM shall implement LOC diagnostics with the EVCU independent of receiving LOC Diagnostics Enable command, setting the diagnostic after 5000 ms of wake-up without communication.

Battery Contactor Status

1. The BPCM shall report Battery Contactor Status via CAN, representing the state of the battery pack contactors (negative main, precharge, and positive main).
2. The BPCM shall define and transmit the following contactor states:

    a. OPEN: Positive Main and precharge contactors are de-energized

    b. PRECHARGING: Negative Precharge Contactor(s) are energized

    c. CLOSED: Breaktor/Negative and Positive Main Contactors are energized

    d. PRECHARGE FAILED: All contactors are OPEN due to precharge time-out, HVIL open, excessive precharge current, or retry attempt failure

    e. PRECHARGE INHIBITED: All contactors are de-energized due to precharge circuit thermal protection

3. The BPCM shall update Battery Contactor Status within two CAN message cycles.
4. The BPCM shall set appropriate Diagnostic Trouble Codes (DTCs) when Battery Contactor Status is PRECHARGEINHIBIT.

Connecting to the Bus

1. The BPCM shall implement a two-step process for connecting to the high voltage bus:
    a. Precharge
2. Completion of the Circuit

Precharge Control

1. The BPCM shall precharge the HV bus when:
    a. HVIL continuity has been confirmed
    b. Qualified Contactor Command equals CLOSED
    c. No contactor close inhibit conditions are present
2. The BPCM shall determine precharge completion by comparing battery pack voltage to bus voltage, verifying the link voltage is within a calibrated percentage of pack voltage.
3. The BPCM shall connect the main HV bus (close Positive Main Contactor) when:
    a. Vehicle Controller commands contactors to "CLS" (close)
    b. Precharge is complete
4. The BPCM shall terminate precharge if complete criteria has not been achieved after the prescribed time (default: Ke_t_HighVoltageBusPrechargeTime).
5. The BPCM shall implement a precharge penalty timer to allow precharge circuitry cooling before reattempting precharge.
6. The BPCM shall provide a count down timer until the next allowed precharge attempt.
7. The precharge penalty timer shall continue counting down independent of key position or BPCM wake/sleep state.
8. The BPCM shall restart the precharge penalty timer after 12V power loss recovery.

Precharge Diagnostics

1. The BPCM shall detect and communicate through DIDs or DTCs the following conditions during precharge:
    a. Precharge into a short (shorted bus or excessive current)
    b. Precharge too long

    c. Precharge too short

2. The BPCM shall monitor current during precharge to detect potential shorts on the HV bus.
3. The BPCM shall communicate precharge status (precharging, inhibited, failed) through CAN.
4. The BPCM shall only set the "Precharge Time Too Short" diagnostic when starting link voltage is below a calibratable value.
5. The BPCM shall store precharge diagnostic results and associated Figures of Merit (FOMs) to EEPROM.

Contactor Opening Control

1. The BPCM shall report all reasons for not closing contactors when commanded, failing to complete precharge, or opening contactors while commanded closed.
2. The BPCM shall immediately open contactors upon receiving MainHighVltCntctrCmd = Fast Open from the Vehicle Controller, bypassing diagnostic checks.
3. The BPCM shall inhibit contactor closure until both internal and external HVIL are passing.
4. No conditions preventing contactors from closing shall exist without a corresponding DTC.
5. The BPCM shall clear contactor inhibit and related DTCs only through service control routine.

Contactor Weld Diagnostics

1. The BPCM shall monitor bus voltage after contactors have been opened to ensure voltage drops appropriately.
2. The BPCM shall indicate HVBatCntrWeld_ImpdOpn = STUCK_CLOSED when a welded contactor is detected.
3. The BPCM shall de-source HVIL with an active contactor weld diagnostic.
4. The BPCM shall implement weld check bypass under specified conditions:
    a. When transitioning from IMPENDING OPEN to OPEN
    b. When Vehicle Speed exceeds Ke_v_WeldCheckEnableSpeed
    c. During impact event (indicated by Contactor Command = IMPACT OPEN)
5. The BPCM shall provide a means to enable/disable weld check diagnostics through the parameter Ke_b_WeldCheckEnabler.

Contactor Stuck Open Diagnostics

1. The BPCM shall perform contactor stuck open detection when contactors have been commanded to close.
2. The BPCM shall report HVBatCntrWeld_ImpdOpn = STUCK_OPEN upon detecting a stuck open contactor.
3. The BPCM shall inhibit or abort contactor closing sequence if any contactors have been diagnosed with stuck open conditions due to coil fault.
4. The BPCM shall de-source HVIL if any contactors are diagnosed with stuck open conditions during closing sequence.
5. The BPCM shall set appropriate DTCs according to the DTC Matrix when contactor stuck open conditions are detected.

Contactor Control Circuit Diagnostics

1. The BPCM shall diagnose the following conditions for each contactor's coil:
    a. Contactor control high side drive circuit shorted high
    b. Contactor control high side drive circuit shorted low
    c. Contactor control low side drive circuit shorted high
    d. Contactor control low side drive circuit shorted low
    e. Contactor control circuit open
2. The BPCM shall store coil states for each contactor and make them accessible via DID.
3. Each failure mode shall have a unique DTC with fault reactions defined in the DTC matrix.

Loss of Isolation Detection

General Requirements

1. The BPCM shall monitor the high voltage (HV) bus to determine that the chassis and HV bus are properly isolated from one another.
2. The BPCM shall perform isolation detection after the weld check sequence is completed or aborted.
3. The BPCM shall set appropriate diagnostics and perform required activities if it determines the HV bus and chassis are not sufficiently isolated.
4. At the beginning of an Operation Cycle, the value of Isolation Status shall be initialized to the last recorded value in non-volatile memory.

5. The BPCM shall inhibit contactor closure when HVBatIsolStat has remained failed through power down, until cleared by a service routine.
6. The fault status shall persist through loss of 12V power once an isolation fault is set as active.

Isolation Abort and Inhibit Requirements

1. The BPCM shall abort Isolation Detection when any of the following conditions are TRUE:
    a. Transition of HVIL Status to Failed
    b. Internal Isolation Circuitry has failed
    c. Contactors are undergoing closing or opening sequence
    d. Receipt of UDS $0308 Hybrid Battery HV - Isolation test command
2. The BPCM shall inhibit Isolation Detection when any of the following conditions are TRUE:
    a. Weld Check Contactor Faults are True
    b. HVIL Status is Failed

Isolation Status Requirements

1. The BPCM shall use HVBatIsolStat to indicate the status of open contactor isolation detection.
2. The BPCM shall use PwrtrnHV_IsolStat to indicate the status of closed contactor isolation detection.
3. The BPCM shall set Isolation Status signals to "Not Sourced" (N_S) when it has not performed isolation detection, including during:
    a. Initialization
    b. When contactors are Open
    c. During any BPCM hardware failures
4. The BPCM shall only update the value of Isolation Status once a complete isolation test has been performed on the Battery Pack.
5. The BPCM shall report Isolation Status as either "Pass" or "Fail" after performing a complete isolation test.

Isolation Diagnostics Requirements

1. The BPCM shall ensure a service light persists through key cycles until cleared by a service tool when powertrain isolation has failed.
2. The BPCM shall provide diagnostic capability to determine the integrity of the Loss of Isolation circuitry.
3. The BPCM shall not perform the diagnostic test if the contactors are welded.
4. The BPCM shall make all values of isolation and statuses available through diagnostic services via DIDs.

EOY Competition Validation

1. The BPCM shall support at least the following three test cases for the End Of Year Competition validation process:

    a. Pack Test (with Manual Service Disconnect installed and contactors open)

    b. Negative Rail Test (with Manual Service Disconnect installed)

    c. Positive Rail Test (with Manual Service Disconnect installed)

2. The BPCM shall report the isolation impedance value via a DID after completion of each test case.

Calibrations Associated with Isolation Detection

1. The BPCM shall include the calibration Ke_R_IsolationFailResistanceLevel, which represents the minimum level of measured resistance on the DC bus that must be observed to consider the bus in a PASS state of isolation (default = 350 kOhms).

CAN Signals Associated with Isolation Detection

1. The BPCM shall transmit the following CAN signals related to isolation detection:

    a. HVIsolStat (High Voltage Battery pack Isolation state)

    b. PwrtrnHV_IsolStat (Powertrain High Voltage Isolation state)

    c. IsolationResistance (measured isolation resistance in kOhms)

Impact Response by the BPCM

General Impact Response Requirements

1. The BPCM shall implement three distinct impact response threads to ensure high voltage shutdown during an impact event:

    a. Impact Message - BMS Optimal Thread: Process impact commands through the MainHighVltCntctrCmd CAN message

b. Impact Message - Direct Delayed Thread: Process impact commands through the IMPACT_INFO.IMPACTCommand and IMPACT_INFO.IMPACTConfirm CAN messages

c. Impact Message - Loss of Messages Thread: Assume an impact event if no valid main contactor command is received on the primary and secondary CAN buses

2. The BPCM shall utilize dual (redundant) CAN bus communications to provide redundant impact detection paths.
3. The BPCM shall not evaluate impact response when the ignition is off or in accessory mode (HCP_GW_20.CmdIgnStat = IGN_LOCK or HCP_GW_20.CmdIgnStat = IGN_OFF_ACC).
4. The BPCM shall set ImpactHardwire = Actuate and ImpactHardwireV = Fail_Not_Present when a vehicle impact is detected.
5. The BPCM shall set ImpactHardwire = Do_Not_Actuate and ImpactHardwireV = Fail_Not_Present when no vehicle impact is detected.

Optimal Thread Response

1. Upon receiving one valid sample of MainHighVltCntctrCmd = Impact Open, the BPCM shall:

   a. Set BPCM_MSG_01.HVBatCntctrReq = True

   b. Set BPCM_MSG_01.HVBatCntctrOpn = True

   c. Set the corresponding Impact DTC (P167B) to Active state

   d. Command all HV contactors to open immediately

2. When detecting an impact via the Optimal Impact Response Thread, the BPCM shall set "Lockout_BMS_Contactor_Close_Operation", preventing HV contactors from closing without a reset from an external service tool.

Direct Delayed Thread Response

1. Upon receiving four valid samples of both IMPACT_INFO.ImpactCommand = Actuate and IMPACT_INFO.ImpactConfirm = Actuate, the BPCM shall:

   a. Set BPCM_MSG_01.HVBatCntctrReq = True

   b. Set BPCM_MSG_01.HVBatCntctrOpn = True

   c. Set the corresponding Impact DTC (P167B) to Active state

    d. Open HV contactors within a maximum of 1500ms

2. When detecting an impact via the Direct Delayed Impact Response Thread, the BPCM shall set "Lockout_BMS_Contactor_Close_Operation", preventing HV contactors from closing without a reset from an external service tool.

Loss of Message Thread Response

1. The BPCM shall initiate the Loss of Message Thread 7.0 seconds after the ignition key is in run or start position (HCP_GW_20.CmdIgnStat = IGN_RUN or IGN_START).
2. If the BPCM does not receive a valid HCP main contactor command on the ePT CAN (Hybrid_Command_BMS) for a duration of time as specified by the "BMS_Loss_of_Message_Timer" calibration (default: 1000ms), the BPCM shall:

    a. Set BPCM_MSG_01.HVBatCntctrReq = True

    b. Set BPCM_MSG_01.HVBatCntctrOpn = True

    c. Set the corresponding Impact DTC (P167B) to Active state

    d. Open HV contactors within a maximum of 1500ms

3. An invalid HCP main contactor command shall be defined as one of the following occurring on both Primary AND Secondary CAN:

    a. Message received with incorrect CRC or MC

    b. No message received (Loss of Communication)

    c. Bus Off condition detected (CAN line shorted or open)

4. When detecting an impact via the Loss of Message Impact Response Thread, the BPCM shall set "Lockout_BMS_Contactor_Close_Operation", preventing HV contactors from closing without a reset from an external service tool.

Impact Diagnostics Requirements

1. The BPCM shall provide a service routine to clear impact faults.
2. The BPCM shall store the type of impact thread that occurred (Optimal, Direct Delayed, Loss of Message, or No Impact) in non-volatile memory.
3. The BPCM shall provide a mechanism to reset the type of impact thread occurrence to "No Impact".
4. The BPCM shall implement Diagnostic Trouble Code P167B (Controlled System Shutdown) to indicate an impact event.
5. The BPCM shall implement appropriate fault reaction calibrations that can be set by the OBD calibration team.

Battery Conditioning (HVBatRdy)

Signal Management

1. The BPCM shall generate and transmit the HVBatRdy signal over CAN to indicate battery readiness for power delivery or reception
2. The HVBatRdy signal shall be binary (0 = not ready, 1 = ready)
3. The HVBatRdy signal shall be updated at least every 100ms
4. The HVBatRdy signal's validity shall be communicated over the diagnostic CAN bus

Initialization

1. The BPCM shall determine the value of HVBatRdy during initialization and before contactors close
2. The BPCM shall set HVBatRdy to 0 when any of the following conditions are true:
    a. HVBatCellVltMax is above HVBatCell_Voltage_High_Thrsh
    b. HVBatCellVltMin is below HVBatCell_Voltage_Low_Thrsh
    c. HVBatModuleTemp_Max is above HVBatHighTempThrsh
    d. HVBatModTempMin is below HVBatLowTempThrsh
3. The BPCM shall set HVBatRdy to 1 when none of the above conditions are true

Operational Behavior

1. The BPCM shall allow contactors to close even when HVBatRdy = 0 to enable battery conditioning
2. The BPCM shall not set a DTC when contactors close with HVBatRdy = 0
3. When HVBatRdy = 0, the BPCM shall limit power delivery and acceptance to allow for conditioning
4. If HVBatRdy = 0 and DriveReady = 1, the BPCM shall open contactors to protect the battery pack

Hysteresis Management

1. Once HVBatRdy transitions to 1, it shall not change back to 0 during the same key cycle
2. The BPCM shall implement hysteresis for transitions from HVBatRdy = 0 to HVBatRdy = 1 as follows:
    a. Low cell voltage: HVBatCellVltMin must be at least 0.1V (calibratable) above HVBatCell_Voltage_Low_Thrsh and HVBatSOC must be greater than 15% (calibratable)

b. High cell voltage: HVBatCellVltMax must be at least 0.1V (calibratable) below HVBatCell_Voltage_High_Thrsh

c. High module temperature: HVBatModTempMax must be at least 0.5°C (calibratable) below HVBatHighTempThrsh

d. Low module temperature: HVBatModTempMin must be at least 0.5°C (calibratable) above HVBatLowTempThrsh

Calibration Parameters

1. The BPCM shall support the following calibratable parameters:

    a. HVBatCell_Voltage_High_Thrsh: Maximum allowed cell voltage

    b. HVBatCell_Voltage_Low_Thrsh: Minimum allowed cell voltage

    c. HVBatHighTempThrsh: Maximum allowed module temperature

    d. HVBatLowTempThrsh: Minimum allowed module temperature

    e. HVBatCellVltHysteresis: Voltage hysteresis for transition to ready state (default = 0.1V)

    f. HVBatTempHysteresis: Temperature hysteresis for transition to ready state (default = 0.5°C)

    g. HVBatSOCMinThreshold: Minimum SOC threshold for ready state (default = 15%)

Fault Handling

1. The BPCM shall prioritize other faults that prevent contactors from closing or that open contactors over the HVBatRdy determination
2. The BPCM shall log instances of battery operation outside normal range in non-volatile memory
3. The BPCM shall provide status of battery conditioning parameters to diagnostic tools via DIDs

CAN Communications

1. The BPCM shall broadcast the HVBatRdy signal according to the DBC file specification
2. The BPCM shall broadcast all threshold values used for HVBatRdy determination over CAN
3. The BPCM shall provide detailed status during conditioning mode over diagnostic CAN

Sensor Measurements

Current Measurement

1. The BPCM shall measure and communicate the battery pack current over CAN every 20ms
2. Current measurements shall follow the sign convention where charging (current into the pack) is negative and discharging (current out of the pack) is positive
3. The BPCM shall read at least two redundant current sensors for rationality checks and fault detection
4. The BPCM shall implement out-of-range detection for current sensor readings (high/low thresholds)
5. The BPCM shall implement cross-check diagnostics that compare readings between redundant current sensors
6. The BPCM shall report current as 0A when contactors are open and no faults are present
7. The BPCM shall indicate validity status of current measurement over CAN
8. The BPCM shall set current validity to INVALID when either:
    a. Current sensors read outside acceptable range
    b. Difference between redundant sensors exceeds threshold
    c. BPCM detects internal software or hardware faults
9. Raw/unfiltered current sensor readings shall be available over diagnostic CAN for debugging
10. Current sensors shall have accuracy sufficient to support SOC, SOH, and power limit calculations

Temperature Measurement

1. The BPCM shall measure temperatures from all critical locations including:
    a. Individual cell/module temperatures (quantity and positioning to be determined by thermal analysis)
    b. Coolant inlet temperature
    c. Coolant outlet temperature
    d. Power electronics temperatures (BDU, contactors, pre-charge resistor)
    e. Ambient temperature inside battery enclosure

2. The BPCM shall report temperature measurements over CAN at a minimum rate of once per second
3. The BPCM shall record minimum, maximum, and average cell temperatures along with their respective locations
4. The BPCM shall maintain a lifetime history of the 3 highest and 3 lowest cell temperature excursions with timestamps and locations
5. The BPCM shall implement diagnostics for temperature sensor malfunctions including:
    a. Open circuit detection
    b. Short circuit detection
    c. Out-of-range detection
    d. Rationality checks comparing adjacent sensors
6. The BPCM shall indicate validity status of each temperature measurement over CAN
7. Temperature sensor accuracy shall be within ±2°C across the operating range of -40°C to 85°C
8. The BPCM shall select temperature sensor positions to detect the hottest and coldest cells in the pack based on thermal modeling
9. The BPCM shall use temperature measurements for thermal management control, cell balancing decisions, and power limit calculations

Voltage Measurement

1. The BPCM shall measure and report the following voltage readings:
    a. Individual cell voltages for all cells in the pack
    b. Module voltages (groups of cells measured on the same ASIC)
    c. Total pack voltage measured on battery side of contactors
    d. Link voltage measured on vehicle side of contactors (when contactors are closed)
2. The BPCM shall record minimum, maximum, and average cell voltages along with their respective locations
3. The BPCM shall report voltage measurements over CAN at minimum rate of once per 100ms

4. The BPCM shall maintain a lifetime history of the 3 highest and 3 lowest cell voltage excursions with timestamps and locations
5. The BPCM shall implement diagnostics for voltage measurement malfunctions including:
    a. Open circuit detection
    b. Short circuit detection
    c. Out-of-range detection
    d. Rationality checks comparing sum of cell voltages to pack voltage
6. The BPCM shall indicate validity status of each voltage measurement over CAN
7. Cell voltage measurement accuracy shall be within ±5mV across the operating range of 2.5V to 4.2V
8. Pack voltage measurement accuracy shall be within ±0.5% of reading
9. The BPCM shall synchronize voltage measurements with current measurements to enable accurate impedance calculations
10. The BPCM shall detect and report cell voltage imbalance exceeding pre-defined thresholds
11. The BPCM shall use voltage measurements for SOC calculations, cell balancing decisions, and power limit calculations

Plug-in Charging

General Requirements

1. The BPCM shall implement a plug-in charging algorithm that considers dependencies on temperature, voltage, current, battery age, and diagnostic status.
2. The plug-in charging algorithm shall comprehend charge power supplies at the 1.0 kW, 11.0 kW, and 0.5C rates.
3. The BPCM shall communicate proper voltage and current limits over CAN to allow the selected charger to properly charge the battery pack in an efficient and reliable manner.

Charging Status and Communication

1. The BPCM shall transmit the HVBatChargeStat signal to indicate its present charging status. The signal shall be enumerated as:
    a. NOT_READY – When contactors are open or when conditions preclude charging

b. READY – When the system is prepared for charging

c. COMPLETE – When charging has completed

d. SNA – Signal Not Available

2. The BPCM shall use ChargeSystemSts signals from the Vehicle Controller to determine charging status, including:

    a. 0: not charging

    b. 1: charging

    c. 2: charge interrupted

    d. 3: charge complete

    e. 7: SNA

3. The BPCM shall transmit HVBatMaxCellVltAlld to indicate the maximum allowable cell voltage during charge.
4. The BPCM shall transmit HVBatMaxPkVltAllwd to indicate the maximum allowable battery pack voltage during charge.

AC Plug-In Charging Procedure

1. Initially, with contactors not closed, the BPCM shall set HVBatChargeStat to Not Ready.
2. Once a plug-in is determined by the Vehicle Controller and contactors are commanded closed, the BPCM shall:

    a. Close contactors

    b. Transition HVBatChargeStat to Ready

3. If contactors are closed, the BPCM shall continue to acknowledge readiness for charge by maintaining HVBatChargeStat = Ready.
4. If the battery should not or cannot be charged, the BPCM shall set HVBatChargeStat = Not Ready.
5. When the Vehicle Controller determines it is time to charge and sets ChargingSysSts to "charging," the BPCM shall:

    a. Set HVBatMaxChgCurrAlwd to the maximum allowable plugin charge current (default calibration value = 30A)

    b. Enable charge-specific routines

   c. Prepare for charge and over-charge protection

   d. Base charge power limits on HVBatCell_Voltage_High_Thrsh used during plug-in charge

6. During charging, the BPCM shall transition to one of the following states:

   a. Set HVBatMaxChgCurrAlwd to the maximum plugin charge current allowed

   b. Set HVBatMaxChgCurrAlwd to a reduced value or 0A if the battery needs cooling or heating

   c. Set HVBatChargeStat = Complete when charging has completed according to BPCM completion criteria

7. The BPCM shall continually calculate and update HVBatMaxCellVltAlld, HVBatMaxChgCurrAllwd, and HVBatMaxPkVltAllwd based on battery cell chemistry.

Temperature Management During Charging

1. If the temperature goes above Ke_T_HighChrgTempThresholdIn (default: 50°C), the BPCM shall set HVBatMaxChgCurrAlwd to 0.
2. If the temperature goes below Ke_T_LowChrgTempThresholdIn (default: -25°C), the BPCM shall set HVBatMaxChgCurrAlwd to 0.
3. Once the temperature falls below Ke_T_HighChrgTempThresholdOut (default: 48°C) or increases above Ke_T_LowChrgTempThresholdOut (default: -23°C), the BPCM shall set HVBatMaxChgCurrAlwd to be greater than 0.
4. The BPCM shall implement a temperature-dependent current limit table for both AC charging and DC Fast Charging.

Charge Completion

1. 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) by setting HVBatMaxChgCurrAlwd = 0.

DC Fast Chare Plug-In Charging Procedure

1. Initially, with main contactors not closed, the BPCM shall set HVBatChargeStat to Not Ready.
2. When main contactors are commanded closed, the BPCM shall:

   a. Close contactors

   b. Transition HVBatChargeStat to Ready

3. Once a "DCFC plug in" is determined by the vehicle controller, the BPCM shall:

    a. Disable its continuous isolation detection monitoring when it receives DC_Isolation_Disable_Cmd = 1

    b. Set DC_Isolation_Disable_Sts = DISABLE when isolation detection is successfully disabled

4. 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.
5. When DCFC contactors are commanded closed through DC_CntctrCmd = CLS, the BPCM shall:

    a. Provide DCFC contactors status through HVBat_DC_CntctrStat = Closed

    b. Indicate if DCFC contactors are open through HVBat_DC_CntctrStat = Open

6. During DCFC operation, the BPCM shall manage the charging process as follows:

    a. Set HVBatMaxChgCurrAlwd_High based on its DCFC current profile when charging begins

    b. Reduce HVBatMaxChgCurrAlwd_High if battery cooling or heating is needed

    c. Set HVBatChargeStat = Complete when charging is complete according to DCFC completion criteria

7. If the BPCM detects a critical failure during charging, it shall:

    a. Set a diagnostic code

    b. Set HVBat_DC_CntctrOpn = 1

    c. Notify the vehicle controller that DCFC contactors will open in a calibrated amount of time (Ke_t_DCFC CntctrOpn default: 1500 ms)

8. When the vehicle controller determines charge is complete and sets DC_CntctrCmd = OPN, the BPCM shall:

    a. Open DCFC contactors

    b. Set HVBat_DC_CntctrStat = Open

9. If the BPCM detects a DCFC contactor failure such as a weld or driver circuit fault, it shall:

a. Set HVBat_DC_CntctrStat = Faulted

b. Publish a corresponding diagnostic code

10. If the BPCM detects a DCFC contactor weld, it shall:

    a. Set HVBatCntctrReq = 1

    b. Set HVBatCntctrOpn = 1

    c. Open contactors within 1.5 seconds

    d. Inhibit main contactor closure

    e. Not source HVIL throughout all key cycle

Cell Balancing

General Requirements

1. The BPCM shall implement passive cell balancing to equalize cell voltages by dissipating excess energy from higher-charged cells through balancing resistors.
2. The BPCM shall allow balancing of individual cells only when any one of the following is TRUE:

    a. HVBatBalReq signal = Balance Allowed or No Request

    b. The BPCM is in autonomous balancing state AND autonomous balancing is enabled

    c. The system is in Key in Ignition mode or plug-in charging mode

3. Cell balancing shall only be enabled when cell imbalance exceeds a calibratable threshold (default: 30mV).
4. The BPCM shall monitor cell voltage differences continuously and initiate balancing when the difference between maximum and minimum cell voltage exceeds the calibratable threshold.
5. The BPCM shall prioritize balancing of cells with the highest voltage when multiple cells exceed the balancing threshold.
6. Autonomous balancing shall be disabled by default and shall require explicit enabling through a calibration parameter.
7. When autonomous balancing is enabled, the BPCM shall:

    a. Not wake up other vehicle controllers in the system (via CAN or hardwired)

b. Not draw 12V power throughout the duration of autonomous balancing (i.e., no parasitic 12V draw)

c. Operate within temperature and voltage safety limits

Cell Balancing Diagnostics and Protection

1. The BPCM shall be able to distinguish between cells that are out of balance and cells that are failing for any operational conditions.
2. The BPCM shall diagnose the following for each balancing circuit and take appropriate actions:

    a. Cell Balance Circuit Stuck Open

    b. Cell Balance Circuit Stuck Closed

    c. Cell Balance Circuit Normal

3. The BPCM shall perform diagnostics on cell balancing circuits at system startup and periodically during operation.
4. The BPCM shall have protection mechanisms to ensure that balancing does not turn on when it is not intended to balance.
5. Cell balancing shall be disabled if any cell temperature exceeds a calibratable threshold (default: 50°C).
6. Cell balancing shall be disabled if any cell voltage falls below a calibratable threshold (default: 3.0V).
7. The BPCM shall set appropriate diagnostic trouble codes (DTCs) when cell balancing faults are detected.

Cell Balance Mode and Communication

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

    a. NO BALANCING – When Balancing Enable Conditions are not True

    b. BALANCING/Balance in Progress – When Balancing Enable Conditions are True and at least one cell is being balanced

    c. BALANCING COMPLETE – When balancing has completed and no cell is being balanced

2. The BPCM shall communicate to the vehicle system when balancing is complete through the CAN signal HVBatBalComplete.
3. The BPCM shall maintain a log of cell balancing history, including:

a. Timestamp of balancing events

b. Duration of balancing for each cell

c. Maximum voltage difference before and after balancing

4. The BPCM shall update the HVBatBalMd signal within 100ms of a balancing state change.
5. The BPCM shall provide access to balancing status and configuration parameters through diagnostic interfaces.

Thermal Management System Controls

General Requirements

1. The BPCM shall control the Battery Coolant Pump (BCP) and Battery Coolant Heater (BCH) to maintain the High Voltage Battery Pack temperature within normal operating ranges.
2. The BPCM shall act as a CAN to LIN gateway for information exchange between the BCP/BCH and the HCP (Hybrid Charge Controller).
3. The BPCM shall start LIN communication with the BCP within a calibratable time after power up (default: 100ms).
4. The BCP shall respond via LIN communication within a calibratable time after the BPCM initiates communication (default: 100ms).

Communication Requirements

1. The BPCM shall forward thermal control commands from HCP to BCP via the LIN bus.
2. The BPCM shall forward status information from BCP to HCP via the CAN bus.
3. If communication is lost between the BPCM and the BCP, the BPCM shall report all related CAN Low Temperature Active Pump signals as "SNA" (Signal Not Available).
4. If the BCP reports a communication error, the BPCM shall report all related CAN Low Temperature Active Pump signals as "SNA".

Heater Control Requirements

1. The BPCM shall start LIN communication with the BCH within a calibratable time after power up (default: 100ms).
2. When the BPCM starts LIN communication, the BCH shall respond via LIN communication within a calibratable time (default: 100ms).
3. The BPCM shall forward HCP heater commands to the BCH via the LIN bus.
4. The BPCM shall forward BCH status information to the HCP via the CAN bus.

Temperature Monitoring and Control

1. The BPCM shall monitor battery cell temperatures and coolant temperatures to determine cooling or heating needs.
2. The BPCM shall request cooling when the maximum cell temperature exceeds a calibratable threshold (default: 35°C).
3. The BPCM shall request heating when the minimum cell temperature is below a calibratable threshold (default: 0°C).
4. The BPCM shall monitor coolant inlet and outlet temperatures to ensure the thermal management system is functioning properly.
5. The BPCM shall adjust coolant flow rates based on temperature differentials between cells to achieve uniform temperature distribution.

Thermal Protection Strategies

1. The BPCM shall implement a thermal propagation protection strategy to provide vehicle occupants with controlled conditions to exit the vehicle in the event of thermal issues.
2. The BPCM shall detect a thermal runaway at least 30 minutes prior to a hazardous situation and vehicle shutdown.
3. The BPCM shall send ThermalRunaway = 'No Thermal Runaway Detected' when the battery is in normal operating mode with no thermal hazards detected.
4. The BPCM shall send ThermalRunaway = 'Thermal Runaway Detected' to the Hybrid Controller when thermal propagation is detected.
5. When thermal runaway is detected (ThermalRunaway_Status = 'Thermal Runaway Detected'), the BPCM shall latch ThermalRunaway_Status and lock the contactor to 'OPEN' for the next key cycle, until the Battery is replaced or an override is performed by a service tool.
6. The BPCM shall report DTC P29FF00 "Hybrid/EV Battery Thermal Runaway Detected" when thermal runaway is detected.

Temperature Based Operational Mode Control

1. The BPCM shall adjust power limits based on temperature conditions to protect the battery.
2. The BPCM shall disable regenerative braking when the battery temperature exceeds a calibratable threshold.
3. The BPCM shall limit discharge power when battery temperature exceeds a calibratable threshold.
4. The BPCM shall communicate temperature-based operational mode changes to the vehicle controller.

Diagnostics Requirements

1. The BPCM shall monitor the thermal management system for faults and report appropriate diagnostic codes.
2. The BPCM shall detect and report coolant pump failures.
3. The BPCM shall detect and report coolant heater failures.
4. The BPCM shall detect and report coolant temperature sensor failures.
5. The BPCM shall detect and report coolant flow restrictions or blockages.
6. The BPCM shall detect and report coolant leaks.

SOC

SOC Algorithm

1. The BPCM shall determine Battery State of Charge based on inputs of battery cell temperatures, battery pack current, and cell voltages
2. The SOC algorithm shall internally estimate the SOC of every cell/cell block in the battery pack
3. The BPCM shall provide cell-level SOC values over the diagnostics CAN bus using the naming convention HVBat_SOCcellXXX
4. The inputs to the SOC algorithm shall be stored in memory and be accessible via diagnostic data identifiers (DIDs)
5. Each cell/cell block capacity and cell resistance value shall be accessible via DIDs

SOC Definitions

1. SOC shall be expressed as a percentage with 100% denoting full charge and 0% defining a depleted battery
2. The definition of SOC 100% and SOC 0% shall be based on an SOC-OCV relationship determined from cell characterization
3. The SOC-OCV relationship shall accurately map cell voltage to SOC when the battery is in a sufficiently rested state
4. The BPCM shall implement a blended SOC calculation that considers both the minimum and maximum cell SOC values

SOC Reporting

1. The BPCM shall report pack-level SOC (HVBatSOC) over CAN according to the provided DBC file specifications
2. The BPCM shall report minimum cell SOC (HVBatSOCMin) and maximum cell SOC (HVBatSOCMax) over CAN
3. The BPCM shall maintain SOC accuracy within ±5% under normal operating conditions

4. The BPCM shall implement SOC correction mechanisms based on voltage measurements during periods of low current
5. The BPCM shall maintain SOC estimation during sleep modes and report the last calculated value upon wake-up

SOP

SOP Algorithm

1. The BPCM shall calculate and report power limits for three time durations: 2 seconds (instantaneous), 10 seconds (short term), and 30 seconds (long term)
2. The charge power limits shall be based upon the maximum cell voltage in the battery pack
3. The discharge power limits shall be based upon the minimum cell voltage in the battery pack
4. Power limits shall factor in both the minimum battery pack temperature for low temperature and the maximum battery pack temperature for high temperature
5. The BPCM shall not impose additional power deratings beyond what is defined in the power limit tables

SOP Requirements

1. The 2-second and 180-second charge and discharge power shall not fall below 9 kW within the operational range of the battery pack
2. The BPCM shall not change power limits faster than 10kW per second under normal conditions
3. In limp mode conditions, power limits shall immediately step change to the calibrated values (Ke_v_LimpRegenPwr and Ke_v_LimpDischargePwr)
4. The BPCM shall broadcast over CAN the 2, 10, 30, and 180-second discharge and regenerative braking charge power limits
5. The BPCM shall set power limit validity to INVALID if any inputs used to determine power limits become unreliable

Continuous Power Limit

1. The BPCM shall implement a continuous power limit algorithm to protect the battery from prolonged charge/discharge events
2. The 2/10/30-second power limits shall de-rate to the continuous power limit based on a 180-second rolling window concept
3. The de-rating shall be subject to a separate slow slew rate of 1 kW/s
4. The BPCM shall prevent voltage collapse under all conditions using the continuous power limit algorithm

SOH

Capacity

1. The BPCM shall calculate and report the relative capacity of the battery pack (HVBatFull_Amp_Hr_Capacity) over CAN
2. The reported value of HVBatFull_Amp_Hr_Capacity shall have an error from actual capacity by no more than 5%
3. The BPCM shall define service end-of-life for capacity when HVBatFull_Amp_Hr_Capacity reaches a level below 70% of the initial value
4. The BPCM shall request MIL light illumination when HVBatFull_Amp_Hr_Capacity falls below a calibratable value
5. The BPCM shall store the value of HVBatFull_Amp_Hr_Capacity in EEPROM upon shutdown and use it on the next wake-up
6. The maximum change in HVBatFull_Amp_Hr_Capacity shall be no more than 4% for a single update

Resistance

1. The BPCM shall calculate and report HVBatSOHLow as an indicator value to assess battery resistance as a percentage of health
2. The BPCM shall internally estimate maximum cell charge resistance (HVBatSOHrC) and discharge resistance (HVBatSOHrD)
3. A value of HVBatSOHrC=100% shall indicate the maximum cell charge resistance at Beginning of Life (BOL)
4. HVBatSOHrC=70% shall correspond to the End-of-Life charge resistance value
5. HVBatSOH shall be calculated based on a weighted formula considering capacity and resistance factors
6. The BPCM shall define end-of-life resistance when either SOH signal leads to greater than 30% degradation in BOL power

Amp-Hour Throughput

1. The BPCM shall calculate and store cumulative amp-hour throughput for both charge (negative values) and discharge (positive values)
2. The charge and discharge amp-hour throughput values shall be accessible via DIDs
3. The BPCM shall maintain these values across sleep cycles and power-downs
4. The BPCM shall use amp-hour throughput as one input to the empirical capacity fade model

Diagnostics Requirements

General Diagnostics

1. The BPCM shall implement a comprehensive diagnostic strategy to detect, report, and respond to faults in the battery system.
2. The BPCM shall use an X/Y methodology for fault determination, where a fault must be present for X time out of Y time to be considered valid.
3. The BPCM shall maintain Figures of Merit (FOM) for all diagnostics to track the occurrence and frequency of fault conditions.
4. The BPCM shall store all FOMs in non-volatile memory to persist across key cycles.

DTCs

1. The BPCM shall implement all DTCs as defined in the DTC Matrix.
2. Each DTC shall have two records maintained: the first event and the last event.
3. The BPCM shall store all DTCs in non-volatile memory to persist between power cycles.
4. The BPCM shall record environmental data when DTCs are set to aid in root cause analysis.
5. The BPCM shall ensure the setting of one DTC does not cause the setting of unrelated DTCs.

Fault Response & Prioritization

1. The BPCM shall implement appropriate responses to detected faults as defined in the DTC Matrix.
2. For faults that affect drivability (e.g., opening contactors, limiting power), the BPCM shall delay the response by a calibratable value (default: 30 seconds).
3. The BPCM shall communicate fault status over CAN through the following signals:

    a. HVBatCntctrOpn: Notification that contactors will open within a calibrated time (default: 1500 ms)

    b. HVBatCntctrReq: Request to return to normal operating range or request to open contactors

4. The BPCM shall prioritize diagnostic execution as follows:

    a. Diagnostics which open contactors during vehicle driving

    b. Diagnostics which prevent contactors from closing at power up

    c. Diagnostics which light the MIL light – one trip

    d. Diagnostics which light the MIL light – two trip

    e. Diagnostics which inhibit plug-in charge

    f. All other diagnostics

Robustness

1. The BPCM shall ensure all diagnostics have appropriate enable conditions to prevent false failures.
2. The BPCM shall perform a tolerance stack-up analysis for all diagnostic circuits to ensure robust calibration.
3. The BPCM shall make all diagnostic inputs available on the internal CAN bus for development monitoring.
4. The BPCM shall maintain the internal CAN bus awake during shutdown to allow monitoring of shutdown diagnostics.
5. The BPCM shall support Two-Trip DTC determination for applicable faults as defined in the DTC Matrix.

Sensor Diagnostics

1. The BPCM shall diagnose all voltage, current, and temperature sensors on a continuous basis.
2. The BPCM shall implement appropriate sensor substitution strategies when sensor values are lost or invalid.
3. The BPCM shall define sensor diagnostic regions with appropriate time-based thresholds for each region.
4. The BPCM shall detect the following sensor fault conditions:

    a. Short to high reference

    b. Short to low reference

    c. Open circuit

    d. Rationality checks against expected values

Critical Systems Diagnostics

1. The BPCM shall diagnose the following critical systems:

    a. Cell over/under voltage

    b. Cell voltage measurement failure

    c. Cell voltage imbalance

d. Cell over/under temperature
e. Cell temperature measurement failure
f. Cell temperature imbalance
g. Thermal runaway detection
h. Isolation faults
i. HV voltage measurement failure
j. HV current measurement failure
k. Over current (charging and discharging)
l. Contactors (or equivalent) stuck closed/open
m. Contactor control circuit failure
n. Precharge failure
o. HVIL circuit failure
p. LV power supply high/low
q. Loss of communication
r. Blown fuse detection
s. Impact detection

Diagnostic Retry Strategy

1. The BPCM shall implement retry attempts for diagnostics that can cause a "No Start" condition, a warning to the customer, or a contactor lock out on the following key cycle.
2. The BPCM shall establish a diagnostic retry strategy to reduce false failures for critical diagnostics.
3. The BPCM shall maintain a log of retry attempts in non-volatile memory.

Service Functionality

1. The BPCM shall implement a service routine to restore battery packs to normal voltage range when they are outside normal parameters.
2. The BPCM shall provide diagnostic capabilities through Data Identifiers (DIDs) to support service and development.

3. The BPCM shall provide a method to clear DTCs and reset FOMs through service tool commands.