



BMS Technical Manual

SeaPower™ 57-Ah Battery Documentation

Document Version History

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1	INTRODUCTION	5
1.1	Introduction	5
1.2	BMS Role in SeaPower Battery Systems	5
2	BMS HARDWARE ARCHITECTURE	6
2.1	Summary	6
2.2	BMS Master Block Overview	6
3	BMS FIRMWARE LOGIC	10
3.1	BMS Operational States	10
3.2	BMS Firmware vs. System-Level Control: Coordinated Autonomy	11
3.3	Host-to-Battery Communication Protocol	11
4	BMS STARTUP, OPERATION, AND MAINTENANCE PROCEDURES	12
4.1	Starting the Battery	12
4.2	BMS Cell Balancing Logic	12
4.3	State of Charge (SoC)	12
4.4	Upgrading BMS Firmware	13
5	DIAGNOSTICS & FAULT HANDLING SUMMARY	14
5.1	Diagnostics & Fault Handling	14
5.2	Real-Time Monitoring and Fault Detection	14
5.3	Host System Role in Diagnostic	15
5.4	Error Reporting Protocol	16
6	BMS PROTECTIONS & SAFETY FEATURES	17
6.1	Over-Charge Protection	17
6.2	Over-Voltage Protection	17
6.3	Under-Voltage Protection	18

6.4	Deep Discharge Protection (DDP)	18
6.5	Over-Current Protection	18
6.6	Over-Temperature and Under-Temperature Protection	20
6.7	Short Circuit Protection	20
6.8	Protection & Safety Feature Table	21
7	LEGAL NOTICES & CONTACT INFORMATION	22
7.1	Copyright and Trademarks	22
7.2	Disclaimer	22
7.3	Feedback / Support	22

1 Introduction

1.1 Introduction

This manual provides a concise, up-to-date guide for understanding, operating, and maintaining the **SeaPower™ Battery Management System (BMS)**. It delivers comprehensive insights into the system's architecture, firmware logic, diagnostic and fault-handling features, communication protocols, and integration requirements-ensuring safe and effective use in demanding environments.

Designed for engineers, technicians, system integrators, and other qualified personnel, this guide supports informed decision-making and operational readiness in all interactions with the BMS.

1.2 BMS Role in SeaPower Battery Systems

The SeaPower BMS safeguards and optimizes battery operation by continuously maintaining a safe operating envelope for cell voltages and temperatures across the entire battery system. It functions as an intelligent monitoring and control platform, enabling reliable performance in mission-critical subsea applications.

The BMS provides the following core capabilities:

- **Autonomous Battery Management State Machine:** SeaPower BMS operates under a deterministic state machine architecture that governs transitions between **Standby**, **Charge**, **Discharge**, and **Fault** states. These transitions can be triggered either by the host system or autonomously by embedded logic. Real-time monitoring ensures safe, responsive transitions across operational modes.
- **Fault Response and Safety:** The SeaPower BMS implements a multi-layered protection framework combining hardware and firmware-based mechanisms. These systems monitor voltage, current, state of charge (SoC) and temperature in real time and respond automatically to abnormal conditions.
- **Cell Balancing:** The BMS supports passive cell balancing that can be triggered by host computer or charger. Using resistive dissipation, it equalizes voltages across all cells, maximizing capacity, prolonging life, and enhancing operational safety.
- **Robust Communication:** The system communicates to the host system over RS485—a robust, noise-resistant serial protocol ideal for harsh environments and long cable lengths. RS485 connectivity enables integration with topside controllers, mission planning systems, and vehicle health monitors.

2 BMS Hardware Architecture

2.1 Summary

The SeaPower Battery Management System (BMS) is built on a modular and distributed architecture, enabling intelligent, scalable, and safe control of complex battery systems. Each battery module contains a **Master BMS** and one or more **Cell Monitoring Units (CMU)**, assigned per cell block or shared across the module depending on the electrical configuration.

The CMU units continuously measure individual cell voltages and cell block temperatures. This data is transmitted to the Master BMS, which oversees system-wide behavior-including state transitions (Standby, Charge, Discharge, Error), fault detection, and protection logic.

The master BMS is also responsible for system diagnostics, thermal and voltage regulation, and coordination of cell balancing operations. It interfaces with external systems via RS485, providing robust integration into host-level power management, mission planning, and telemetry platforms.

This architecture delivers high reliability, safety, and operational flexibility for demanding subsea, defense, and industrial applications, supporting configurations from kilowatt-hour to megawatt-hour scale.

2.2 BMS Master Block Overview

The **BMS Master Block** is the central control unit responsible for managing battery safety, operation, and communication. It integrates key subsystems listed below and shown graphically on figure 2:

2.2.1 Battery External Communications

This subsystem enables communication between the battery and external systems. It includes:

- **RS485 Interface:** The primary communication channel for telemetry, fault reporting, and host-issued commands.
- **USB Interface:** Used for local access during service for configuration, firmware updates, and diagnostics.
- **Control Signal Lines:**
 - **BMU_ON:** A safety signal that initiates BMS power-up.
 - **Load_ON:** Enables the output load connection.
 - **Return:** Provides the common return path for control signals.

2.2.2 DC/DC Converter

The DC/DC Converter powers the BMS electronics by converting energy from the battery cells:

- It activates upon receiving the BMU_ON signal.
- Requires a continuous **KeepAlive** signal from the master board to stay powered.
- Includes a Recovery input line for supplying external power during recovery or service scenarios when internal power is not available.

2.2.3 IVTS (Integrated Voltage, Temperature, and Current Sensor)

The IVTS monitors critical system-level parameters, including:

- System current
- Power path voltages
- Battery-level temperatures

2.2.4 Master Board

The master board contains the microcontroller that executes embedded firmware and oversees all battery operations. Key functions include:

- Communicates with the **Cell Monitoring Units (CMUs)** via an isolated ISO SPI bus to acquire individual cell voltage and temperature data.
- Processes system-level measurements from the **IVTS**, including voltage, current, and temperature.
- Monitors the status and temperature of solid-state relays (SSRs).
- Controls all high- and low-side SSRs in the power path.

2.2.5 Solid State Relays (SSRs)

The Solid-State Relays (SSRs) manage the high-current switching functions within the battery's power path. Each SSR is equipped with integrated temperature sensing to ensure thermal protection and enable fault detection. The SSRs are controlled by the BMS to safely connect or disconnect various power pathways based on operational states and safety conditions. The relay configuration includes:

- **High-Side Pre-Charge Relay** - Enables controlled charging of output capacitance to prevent inrush currents.
- **High-Side Discharge Relay** - Connects the battery to the load during discharge.
- **High-Side Charge Relay** - Connects the charger to the battery during charging.

- **Low-Side Relay** - Provides switching on the low-side return path, enhancing isolation and protection.
- **Heater Relay (Optional)** - Controls power to the battery heater circuit, if installed.

2.2.6 Power Path

The power path distributes electrical energy from the battery and includes:

- **Hard Fusing:** Present on the high-side, low-side, pre-charge, and heater circuits for protection.
- **Directional Diodes:** Prevent reverse current flow during charge and discharge.
- **Solid State Relays:** Actively control the connection and disconnection of each path based on BMS logic.

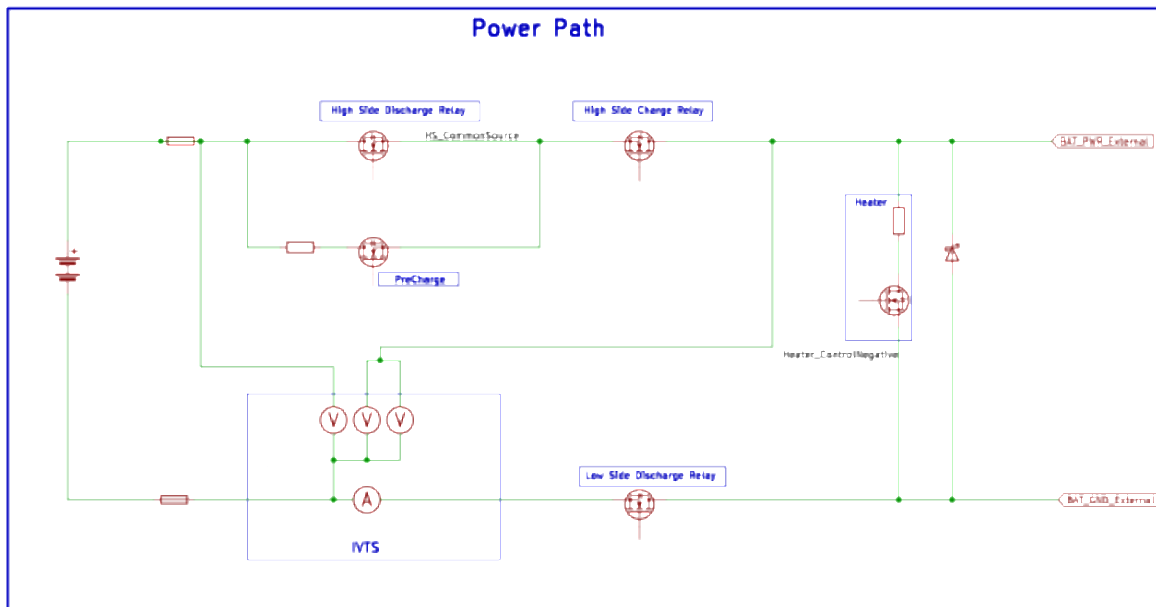


Figure 1 - Battery Power Path

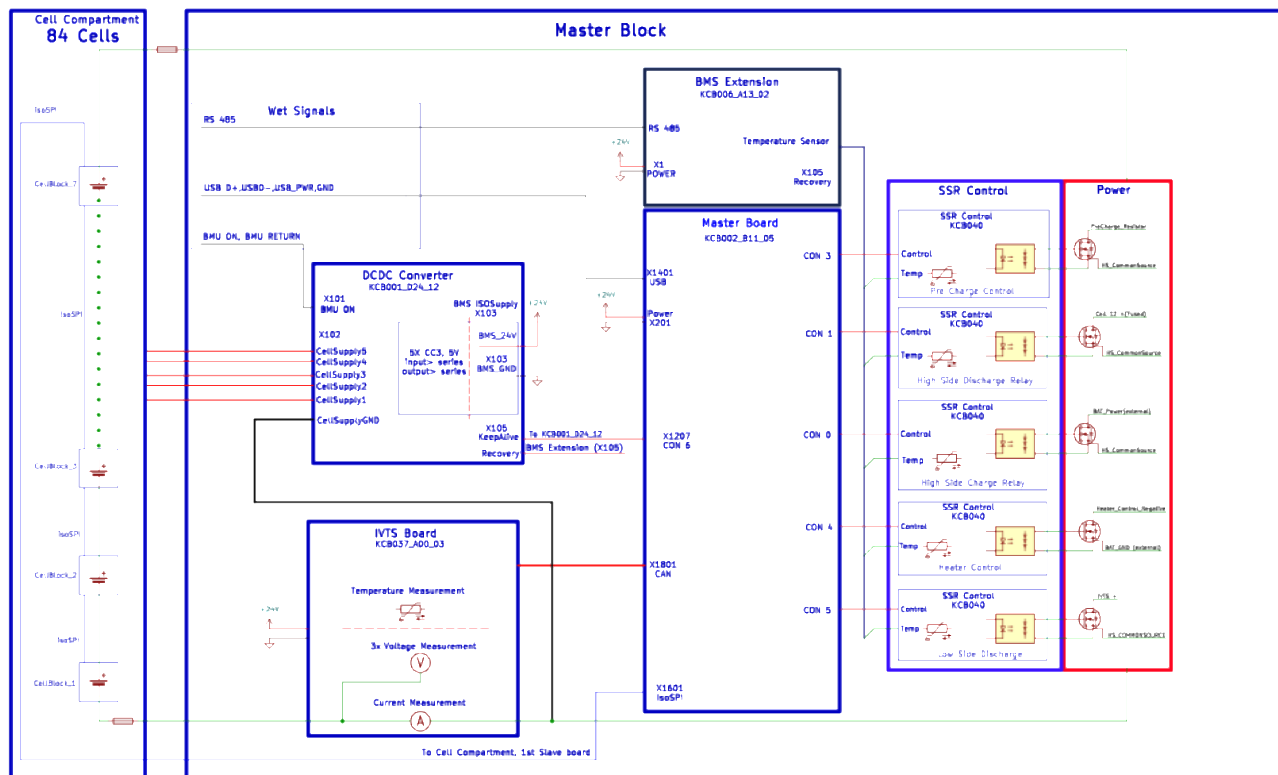


Figure 2 - BMS electric layout, cell compartment set-up changes with battery model

3 BMS Firmware Logic

The BMS firmware governs all safety and control logic for SeaPower battery systems. Running on a dedicated microcontroller, it continuously monitors voltage, current, and temperature data against predefined thresholds to determine the battery's operational state. The firmware autonomously initiates actions such as relay switching, fault isolation, or safety shutdowns - ensuring predictable and safe battery behavior.

At the heart of the system is a deterministic state machine that processes real-time sensor data to evaluate conditions and transition between operational states (Standby, Charge, Discharge, Error). Hardware elements such as relays, contactors, balancing circuits, and heaters are controlled via digital outputs based on this logic.

3.1 BMS Operational States

State	Description
STANDBY	All solid-state relays (SSRs) are open; charge and discharge paths are disconnected. The system is powered and monitoring is active.
PRE-CHARGE	Automatic safety routines briefly engage to equalize potential across contacts before relays close. If voltage mismatch persists, the system remains in Standby.
CHARGE	Enabled only from Standby. Charging begins only if battery voltage is lower than charger voltage to prevent reverse current flow.
DISCHARGE	Enabled only from Standby. Discharge begins only if battery voltage is higher than load voltage to prevent back-feed.
ERROR	Triggered by safety violations or hardware failures. All relays are opened, and the system remains in a locked-out state until a reset command is received.

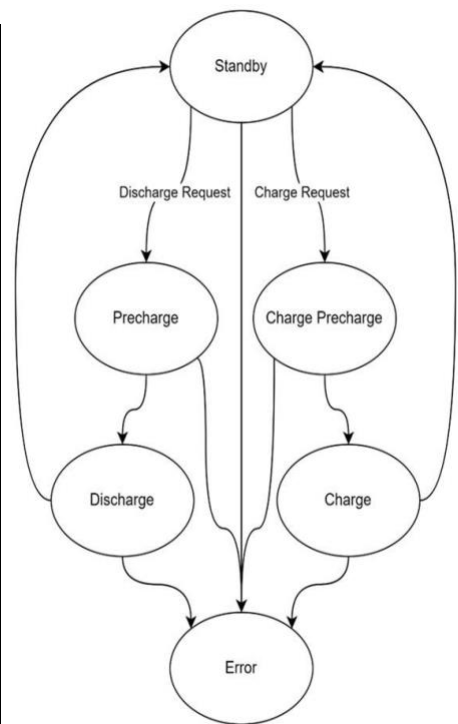


Figure 3 – BMS state machine

3.2 BMS Firmware vs. System-Level Control: Coordinated Autonomy

The BMS operates independently based on internal logic, while the host system provides supervisory control. The BMS autonomously handles protection enforcement, fault response, and mode transitions. External systems (e.g., AUVs, subsea platforms) send high-level commands (Charge, Discharge, Standby) via RS485 but do not override internal safety logic.

While the BMS ensures safe, real-time operation of each battery module, the host system provides broader coordination across multi-battery architectures.

3.3 Host-to-Battery Communication Protocol

The host system communicates over RS485 using a master-slave architecture. All requests are host-initiated and include telemetry polling, command transmission, and fault interrogation. Each message consists of a header, payload, and checksum. Only one active request is allowed at a time. The following request types are supported by the battery communication interface:

Request Type	Description	Response Type
Handshake	Used to identify available batteries on the communication bus. The host must wait at least 500 ms after sending this request.	Handshake Response
Charge Request	Transitions the battery to charging mode, if conditions allow.	Charge Acknowledgement
Standby Request	Places the battery into Standby mode.	Standby Acknowledgement
Discharge Request	Transitions the battery to discharge mode.	Discharge Acknowledgement
Switch Heater	Enables or disables internal heaters based on external power availability.	(Implicit Acknowledgement)
Switch Auto Balancing	Enables or disables automatic cell balancing.	(Implicit Acknowledgement)
System Reset	Performs a soft reset of the battery's internal systems.	(Implicit Acknowledgement)
System Monitoring Data	Requests real-time telemetry such as voltage, current, and temperature.	System Monitoring Data
System Parameters	Requests configuration and static system-level parameters.	System Parameters Data

4 BMS Startup, Operation, and Maintenance Procedures

4.1 Starting the Battery

The BMS is activated when a valid **BMU_ON** signal is applied to the designated input pin. Upon power-on, it enters the Standby state and awaits further commands.

As long as BMU_ON remains active, the BMS remains powered. If the battery drops below critical voltage, **Deep Discharge Protection (DDP)** will trigger a hard shutdown to prevent irreversible damage.

An optional configuration allows entry into Discharge mode if a **Load_ON** signal is provided. In this case, the system will enter Discharge mode, providing a short window for the host system to assume control.

4.2 BMS Cell Balancing Logic

SeaPower employs passive cell balancing, which is user-initiated via command. Each cell module contains a balancing board that dissipates energy from higher-voltage cells through resistors to equalize voltage across the pack.

Periodic balancing:

- Improves usable capacity
- Reduces cell drift over time
- Enhances safety and longevity

Balancing is not continuous and must be enabled or disabled either manually or via host command.

4.3 State of Charge (SoC)

The State of Charge (SoC) represents the battery's remaining capacity, expressed as a percentage. It is calculated based on the lowest individual cell voltage within the pack. In cases where the battery is unbalanced, the SoC may appear lower than what would be estimated from the overall system voltage alone.

4.4 Upgrading BMS Firmware

Firmware updates are performed via USB using a serial converter on the Master BMS board. During upgrades:

- The battery must be in Standby.
- All relays are opened to isolate current paths.
- The new firmware is flashed.
- Post-flash bus address assigned via USB command line.
- Automatic reboot and self-check, system re-enters Standby.
- Upon success, the system re-enters Standby.

Upgrades are conducted by Kraken technicians or qualified personnel to ensure compatibility and safety.

5 Diagnostics & Fault Handling Summary

5.1 Diagnostics & Fault Handling

SeaPower batteries feature an integrated diagnostics and fault management system that ensures safe and reliable performance in subsea and mission-critical environments. The BMS firmware continuously monitors system conditions, identifies abnormal states, and enforces protective actions that isolate faults, communicate system status, and transition the battery to a safe operating mode.

The diagnostics framework combines real-time telemetry, fault flags, and system response logic to support safe operation, error transparency, and field recovery.

5.2 Real-Time Monitoring and Fault Detection

The BMS continuously monitors critical parameters at both the module and pack levels using distributed sensors. Each parameter is compared to predefined safety thresholds. If a value deviates beyond allowable limits, the BMS triggers fault logic within **10 ms**.

5.2.1 Fault Response Workflow

Upon detecting a fault, the BMS:

1. **Flags the fault** via a dedicated error bitfield.
2. **Transitions the system** to a defined safe state (typically Standby or Error).
3. **Opens all relays**, halting charge and discharge paths.
4. **Communicates** the error to the host via RS485, including the active fault flags in telemetry responses.

Some faults are recoverable, while others require a system reset or manual technician intervention.

Fault Category	Typical Action	Recovery Type
Recoverable Faults	BMS resets state when conditions normalize	Automatic or Host Command
Non-Recoverable Faults	Persist until explicitly cleared	Host Command or Technician Reset
Hardware Lockouts (e.g. fuse, DDP)	Battery isolated, requires service	Manual Recovery (Hardware-Dependent)

5.2.2 Manual and Software Recovery Options

Recovery Type	Description
Host Command Reset	Software-based reset of firmware; clears transient faults and reinitializes state
Manual Technician Reset	Requires intervention via recovery cable or reset jumper; used for persistent or hardware faults
Power Cycle (DDP)	Deep Discharge Protection must be cleared by re-powering or battery service

5.2.3 System Self-Checks and Startup Validation

When the BMS is first powered on via the BMU_ON signal, it performs a series of self-checks within 1 second to verify:

- Relay function
- Sensor availability
- Communication with slave boards
- Internal voltage rail stability

If any self-check fails, the BMS halts transitions and enters Error or Standby state with the relevant fault bit set.

5.3 Host System Role in Diagnostic

The host system plays a critical role in BMS fault handling by:

- Polling system telemetry via RS485 requests
- Interpreting the error bitfield
- Issuing resets or state change commands
- Coordinating multi-battery behavior and system-level recovery

5.4 Error Reporting Protocol

Faults are communicated to the host system via RS485 in response to requests such as **System Monitoring Data**. Each response includes a 16-bit error field, where each bit represents a specific fault. A value of 1 indicates the presence of that fault.

Bit	Fault Description	Trigger Condition
0	Current Sensor Not Responding	IVT-S communication loss
1	Charge Relay Defect	Relay self-check failure or no actuation detected
2	Discharge Relay Defect	Relay self-check failure or no actuation detected
3	<i>Reserved</i>	-
4	Slave Module SPI Error	Communication fault between Master and Slave boards
5	Pre-charge Error	Pre-charge circuit failed or timed out
6	Dead Short Error	High current spike indicative of short circuit
7	<i>Reserved</i>	-
8	Over Charge Current	Input current exceeded limit
9	Over Discharge Current	Output current exceeded limit
10	Over Cell Voltage	One or more cells exceed max voltage
11	Under Cell Voltage	One or more cells below min voltage
12	Over Discharge Temperature	Too hot during discharge
13	Under Discharge Temperature	Too cold during discharge
14	Over Charge Temperature	Too hot during charging
15	Under Charge Temperature	Too cold during charging

6 BMS Protections & Safety Features

Subsea energy systems depend on uninterrupted, autonomous battery performance. The SeaPower™ Battery Management System (BMS) incorporates intelligent, real-time safety logic - combining firmware control with hardware fail-safes - to detect and respond instantly to unsafe conditions. This integrated protection ensures system integrity even in harsh and mission-critical environments.

SeaPower batteries are designed to govern their own safety using embedded sensors, firmware logic, and predefined responses. These protections operate autonomously, synchronizing local fault handling with system-level awareness.

6.1 Over-Charge Protection

Over-charge protection is implemented as a pack-level control function designed to safely terminate charging before any individual cell exceeds its voltage limit. During the charging process, each BMS slave board continuously reports cell-level voltage measurements to the BMS master board. The firmware evaluates these values in real time, using the highest cell voltage as the key indicator to estimate the overall state of charge (SOC) of the battery pack.

When the highest cell voltage approaches the defined full-charge threshold (typically corresponding to 100% SOC), the BMS transitions to the Standby state and opens the charge relay, effectively terminating the charging process. This transition is condition-based, triggered solely by the firmware's internal evaluation of battery status- no external command is required.

This mechanism prevents further current flow into the pack, thereby protecting all cells from entering an over-voltage condition. In situations where cell imbalance is present, the overall system SOC may remain below 100%, even though one or more cells have reached their maximum allowable voltage.

6.2 Over-Voltage Protection

Over-voltage protection is a cell-level safety mechanism triggered when any individual cell exceeds a predefined maximum voltage threshold. Each BMS slave board continuously monitors cell voltages and transmits this data to the BMS master board, which runs real-time firmware logic to detect over-voltage conditions. If any cell surpasses the configured over-voltage limit, the master board immediately flags a fault, transitions the system into Error state, and opens all relays to isolate the battery and prevent potential damage.

6.3 Under-Voltage Protection

Under-voltage protection is activated when any individual cell drops below a predefined minimum voltage. The BMS slave boards continuously monitor cell voltages and report them to the master board, which analyzes the data in real time. If even one cell falls below the threshold, the master BMS immediately flags a fault, switches the system to Error mode, and opens all relays to isolate the battery - preventing further discharge.

Li-ion cells naturally self-discharge over time, even when not in use. If a cell becomes fully discharged, it can undergo permanent chemical changes that render it unusable. Under-voltage protection is designed to trigger before this point, but the affected cells should be promptly recharged to prevent irreversible damage.

6.4 Deep Discharge Protection (DDP)

If the battery continues to discharge beyond the under-voltage threshold without intervention, a separate hardware-based protection circuit called Deep Discharge Protection (DDP) is activated. Unlike under-voltage protection-which monitors and reacts to individual low cell voltages-DDP monitors the total pack voltage.

When the total voltage drops below a critical hardware-defined threshold, the DDP circuit triggers independently of the BMS firmware. This mechanism shuts down the BMS entirely and opens all relays, fully disconnecting the battery from the system. This hard cutoff prevents the BMS hotel load from causing irreversible cell damage and ensures complete electrical isolation of the pack.

6.5 Over-Current Protection

Over-current protection safeguards the battery by monitoring both charging (current flowing into the battery) and discharging (current flowing out) against unsafe electrical conditions. Protection is implemented using two firmware-defined thresholds, supported by a non-resettable hardware fuse as a final safety mechanism.

A dedicated current sensor (IVT-S) continuously measures current, enabling the BMS to respond based on the following logic:

1. Safety Fuse (Non-Resettable Hardware Protection)

The battery includes a non-resettable safety fuse rated above both firmware thresholds. This fuse serves as a last-resort hardware protection:

- It activates overcurrent conditions where firmware protections fail or are bypassed.
- Once triggered, the fuse **permanently disconnects** the battery from the system.
- **The fuse cannot be reset.** If it blows, the battery must be **returned for repair or replacement** by qualified service personnel.

2. Critical Overcurrent (Firmware-Based Immediate Shutdown)

A **critical overcurrent event** occurs when the current exceeds the **critical threshold**, as defined by firmware. This triggers an immediate protective response:

- The battery enters an **error state**.
- All relays are opened immediately, disconnecting the battery from the system.
- The only delay is due to the **sensor's measurement time** and a brief buffer to account for signal jitter.
- This condition is typically triggered if the current remains above the critical threshold for approximately **500 milliseconds**.

3. High Current (Firmware-Based Time-Limited Operation)

A high current condition occurs when the current exceeds a defined high-current threshold but remains below the critical overcurrent threshold. This condition is tolerated for a limited time:

- The battery is allowed to operate at this elevated current level for up to T seconds (typically 50 seconds)
- A firmware-controlled timer begins counting as soon as the high-current threshold is exceeded.
- If the current falls back below the threshold before the timer expires, the timer counts down accordingly.
- If the timer reaches its limit while the high current condition persists, the system enters an error state and immediately opens all relays, disconnecting the battery to prevent damage.

6.6 Over-Temperature and Under-Temperature Protection

Temperature sensors are installed at the cell block level, with each BMS slave board continuously monitoring local temperatures and reporting them to the BMS master board, as well as at the system level on each solid-state relay. The BMS firmware processes this data in real time to evaluate whether any sensor readings have exceeded the defined upper or lower temperature thresholds.

If a temperature reading crosses either limit, the BMS immediately transitions the system to Error mode and opens all relays, halting current flow to prevent thermal stress or damage to the battery.

This automatic response protects the system from unsafe operating conditions caused by overheating or operation at excessively low temperatures.

6.7 Short Circuit Protection

Short circuit protection in the battery system is implemented using a non-resettable high-current fuse. This fuse is designed to permanently disconnect the battery in the event of a short circuit by physically breaking the electrical path when current exceeds a predefined threshold.

The fuse is sized to tolerate normal operating conditions, including peak discharge currents, but will rapidly blow if a sudden, sustained overcurrent occurs-such as during a short circuit. Once triggered, the fuse cannot be reset and must be replaced as part of a service procedure.

This hardware-level protection provides a fast, independent response-typically in the millisecond range-offering a final layer of defense against catastrophic faults.

6.8 Protection & Safety Feature Table

Protection Type	Trigger Condition	Detection Level	Response State	Recovery Type
Over-Charge	Cell SOC at 100%	Cell level	STANDBY	N/A
Over-Voltage	Cell exceeds maximum voltage limit	Cell level	ERROR	Host Command
Under-Voltage	Cell drops below minimum voltage limit	Cell level	ERROR	Host Command or Manual technician recovery
Deep Discharge Protection (DDP)	Total pack voltage drops below critical system threshold	System level (total pack voltage)	POWER OFF	Host Command or Manual recovery
Over-Current	Current exceeds maximum safe limit during charge or discharge	System level (IVT-S sensor)	ERROR	Host command
Over-Under-Temperature	Temperature exceeds maximum safe threshold	Cell Module	ERROR	Host command
Short-Circuit	Short Circuit	System level	POWER OFF	Factory

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