



Battery Pack Technical Manual

SeaPower™ 57-Ah Battery Documentation

Document Version History

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1	INTRODUCTION	5
1.1	Architecture and System Overview	5
1.2	System Structure	5
1.3	Monitoring and Control Architecture	5
2	LITHIUM-ION POUCH CELL	7
2.1	Introduction	7
2.2	Kokam Pouch Cells	7
2.3	Key selection criteria for the KCL216060EN1 cell included:	8
2.4	Cycle Life 25°C (1C/1C)	8
2.5	Kokam KCL216060EN1 Cell Specifications	9
2.6	Temperature Characteristics	10
2.7	Charge Characteristics	10
2.8	Charge Temperature Performance	11
2.9	Discharge Characteristics	12
2.10	Discharge Temperature Performance	12
3	CELL MODULE DESIGN	13
3.1	Mechanical Design	13
3.2	Electrical Design	14
4	BATTERY PACK	17
4.1	Electrical and Mechanical Interface	18
4.2	Final Assembly & Potting	18
4.3	Safety	19

5	BATTERY SYSTEM ARCHITECTURE	20
5.1	Decentralized Operation	20
6	LEGAL NOTICES & CONTACT INFORMATION	21
6.1	Copyright and Trademarks	21
6.2	Disclaimer	21
6.3	Feedback / Support	21

1 Introduction

1.1 Architecture and System Overview

The SeaPower™ battery system is built on a clear, hierarchical architecture that ensures reliability, fault tolerance, and seamless integration into demanding environments. This layered design organizes the system into distinct electrochemical and electronic subsystems, each with defined roles in energy storage, monitoring, and protection.

By standardizing interfaces and functional boundaries from the **cell level up to the system level**, SeaPower batteries enable predictable behavior, simplify integration into host platforms, and ensure consistent enforcement of protection thresholds across all operating conditions.

1.2 System Structure

The SeaPower™ battery architecture consists of three primary building blocks:

- **Cell** – The fundamental electrochemical storage unit.
- **Module** – A self-contained group of cells with embedded sensing, balancing, and heaters.
- **Battery Pack** – A complete battery system composed of multiple modules, coordinated by a centralized Battery Management System (BMS).

1.3 Monitoring and Control Architecture

The SeaPower™ system features a **distributed, hierarchical Battery Management System (BMS)** designed for safe, autonomous operation and accurate system-level telemetry. The architecture combines **Cell Monitoring Units (CMUs)**, also known as slave boards or slave BMS, for cell module measurement with a centralized **BMS Master Board** responsible for control logic and coordination.

- In the **7S1P architecture**, each module includes a dedicated **CMU**, which monitors per-cell voltages and multiple temperature sensors embedded in the cell block.
- In the **1S9P architecture**, a single **CMU** is shared across multiple modules, monitoring the voltage and temperature of each cell module.

Balancing control is executed by the BMS Master Board, which activates the **passive balancing boards** located at the module level. The **CMU** serves only as a data acquisition unit—it measures voltage and temperature but does not perform active control.

The **BMS Master Board** functions as the system coordinator. It also:

- Aggregates data from all CMUs via **galvanically isolated ISO-SPI** communication.
- Controls solid-state relays for charge, discharge, and heater circuits.
- Enforces system-level safety thresholds.
- Manages precharge logic and startup.
- Issues balancing commands to the module-level balancing boards.
- Logs telemetry and fault events.
- Interfaces with the host via RS485.

A **token-passing SPI protocol** ensures time-synchronized, collision-free communication between CMUs and the BMS Master. This architecture enables coordinated, fault-tolerant operation even in the absence of host commands.

2 Lithium-Ion Pouch Cell

2.1 Introduction

Lithium-ion pouch cells form the electrochemical foundation of the SeaPower battery architecture. Their selection, configuration, and environmental resilience are central to the system's performance in mission-critical, subsea applications.

Unlike cylindrical geometries, pouch cells offer a lightweight, space-efficient structure that yields high energy density and excellent thermal characteristics, making them well-suited for dense, pressure-tolerant cell block assemblies. The pouch's thin polymer laminate enclosure enables even pressure distribution and efficient heat dissipation across its large surface area, while also eliminating rigid housings that can trap voids or create mechanical stress points.

2.2 Kokam Pouch Cells

SeaPower 57-Ah battery packs utilize the **Kokam KCL216060EN1** lithium-ion pouch cell, chosen for its high energy density, thermal stability, and proven mechanical reliability in harsh conditions. Manufactured by **Kokam**, a subsidiary of **SolarEdge**, the cell was qualified for deep sea (6000 m) pressure tolerant potted batteries application through extensive testing by **Kraken Power GmbH**.

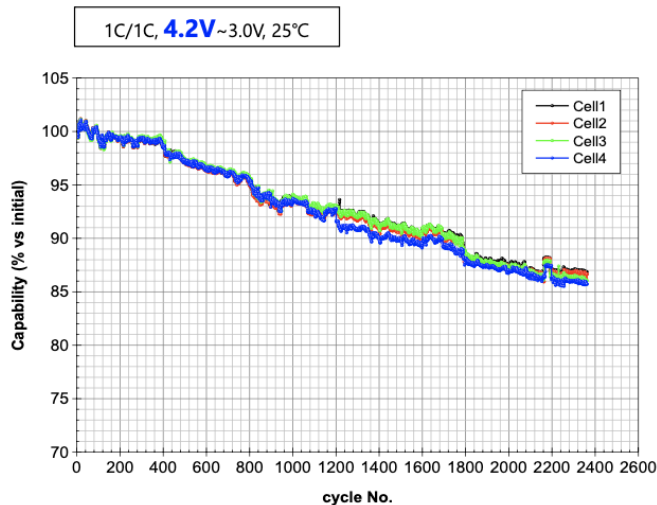
Kraken's broader cell evaluation program has included more than **6,000 individual pouch cell samples** across multiple lithium-ion chemistries. Testing focused on **discharge performance, thermal stability, cycle life, and structural resilience under pressure**. Among the candidates, the **Kokam cell** consistently exhibited outstanding performance, maintaining structural integrity with **no deformation or mechanical failure observed during pressure tests up to 600 bar**. These results validated its suitability for sustained use in **deep-sea and high-pressure industrial applications**.

Kraken conducts full-depth validation on every battery it produces, testing each unit at **660 bar** while performing **charge and discharge cycles under pressure**. To date, over **50,000 pouch cells** have been pressure-tested as part of Kraken's qualification and production process.

2.3 Key selection criteria for the KCL216060EN1 cell included:

Selection Criteria	Outcome
High Pressure Tolerance	Demonstrated reliable discharge performance at external pressures up to 600 bar, validated through tank testing and extended field trials.
Flat Flexible Form Factor	The pouch design ensures even pressure transmission, avoids rigid voids, and simplifies cell block integration.
Thermal Efficiency	The cell exhibits high thermal efficiency primarily due to low internal heat generation , reducing the need for active cooling in most subsea applications.
Long Cycle Life	Proven durability across repeated charge/discharge cycles, supporting long-term deployment in remote environments.
Global Compliance	The cell meets international safety and transport standards, including UN38.3 (KQ13-TC09-01R0), UL1642 (MH 27732), JIS C 8715-2 (JP-S-00016-M2), and EN62133:2013 (MH49914-14-01).

2.4 Cycle Life 25°C (1C/1C)



Test Condition (@ 25±3°C)

1. Charge : CC-CV, 1.0C, 4.2V, 1/20C cut off
2. Discharge : CC, 1.0C, 3.0V cut off

2.5 Kokam KCL216060EN1 Cell Specifications

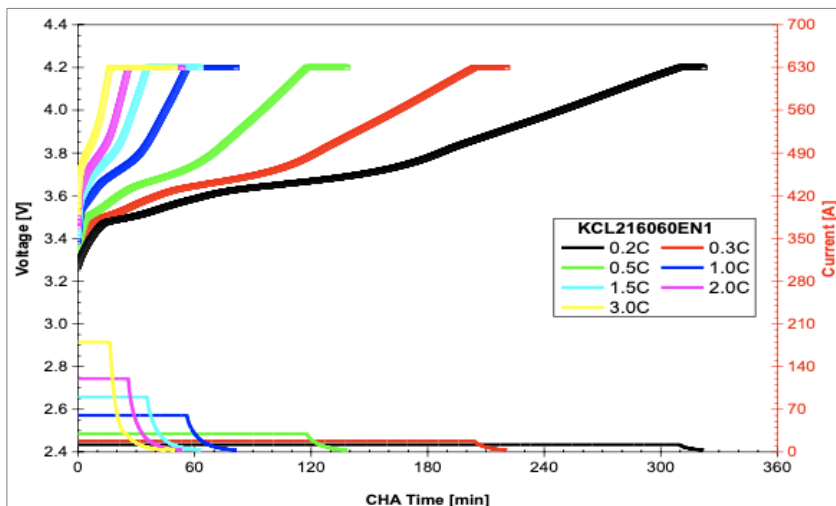
Specification	Value
Cell Model	Kokam KCL216060EN1
Form Factor	Pouch (flat, flexible laminated)
Nominal Voltage	3.68 V
Nominal Capacity	60 Ah
Nominal Energy	220.8 Wh
Typical Voltage Range	2.8-4.2 V
Charge Voltage (Standard)	4.3 V
Cut-off Voltage	2.8 V
Standard Charge Current	30 A (0.5C rate)
Standard Discharge Current	60 A (1C rate)
Maximum Discharge Current	180 A (3C rate)
Peak Discharge Current (10s)	300 A
Weight	Approx. 1,085 g
Cell Dimensions (W x H x T)	226 mm x 227 mm x 11.2 mm
Energy Density (Gravimetric)	203.5 Wh/kg
Energy Density (Volumetric)	493 Wh/L
Maximum Internal Resistance	0.60 mΩ (AC @1 kHz, SOC 30%)
Operating Temperature (Charge)	0°C to 45°C
Operating Temperature (Discharge)	-30°C to 60°C
Storage Temperature (1 Month)	-30°C to 50°C
Cell Type	Rechargeable Li-ion (NMC-based)
Cycle Life (80% Capacity Retention)	≥ 2,000 cycles
Pressure Endurance (Tested)	Up to 660 bar
Certifications	UN38.3, UL1642, EN62133:2013

2.6 Temperature Characteristics

Temperature	Max. Charge Rate	Max Discharge Rate	Storage
-20 °C ≤ T < 0 °C	0.05C	1.0C	1 year
0 °C ≤ T < 10 °C	0.2C	2.0C	
10 °C ≤ T < 25 °C	0.5C		
25 °C ≤ T < 35 °C	2.0C	3.0C	6 months
35 °C ≤ T < 45 °C		2.0C	3 months
45 °C ≤ T < 55 °C	1.0C	1.0C	< 1 week
55 °C ≤ T ≤ 60 °C	Not Recommended		

2.7 Charge Characteristics

C-rate	CC (min)	CV (min)	Total (min)
0.2C	310.5	12.4	322.9
0.3C	204.2	16.3	220.5
0.5C	118.0	21.0	139.0
1.0C	56.3	24.7	81.0
1.5C	35.5	27.7	63.2
2.0C	25.9	27.0	52.9
3.0C	16.3	27.7	44.0



Test Condition

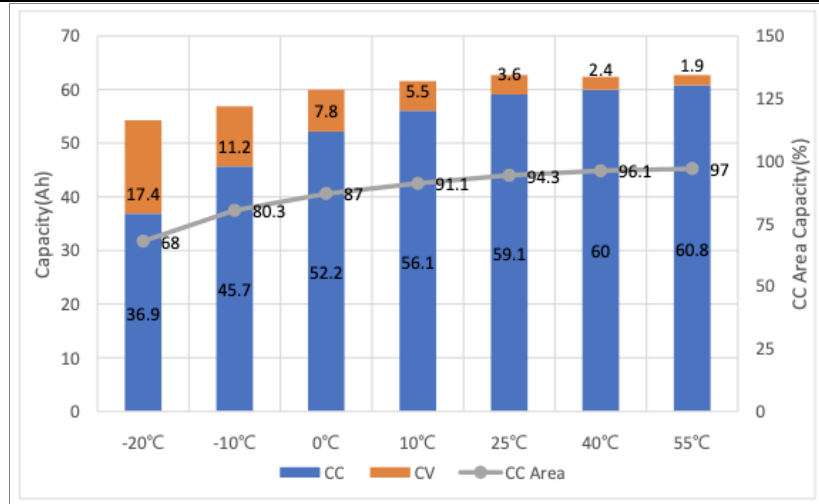
1. Discharge : CC, 0.5C, 2.7V cut off @ $25\pm3\text{ }^{\circ}\text{C}$
2. Rest : 20min @ $25\pm3\text{ }^{\circ}\text{C}$
3. Charge : CC-CV, variable current, 4.2V, 1/20C cut off @ $25\pm3\text{ }^{\circ}\text{C}$
4. Ambient temperature : $25\pm3\text{ }^{\circ}\text{C}$

2.8 Charge Temperature Performance

C-rate	Temperature (°C)	Capacity (Ah)		
		CC	CV	Total
0.5C (30A)	-20	36.9	17.4	54.3
	-10	45.7	11.2	56.9
	0	52.2	7.8	60.1
	10	56.1	5.5	61.6
	25	59.1	3.6	62.6
	40	60.0	2.4	62.5
	55	60.8	1.9	62.6

Test Condition

1. Discharge : CC, 0.5C, 2.7V cut off @ 25±3°C
2. Rest : 20min @ 25±3°C
3. Charge : CC-CV, variable current, 4.2V, 1/20C cut off @ 25±3°C
4. Ambient temperature : 25±3°C

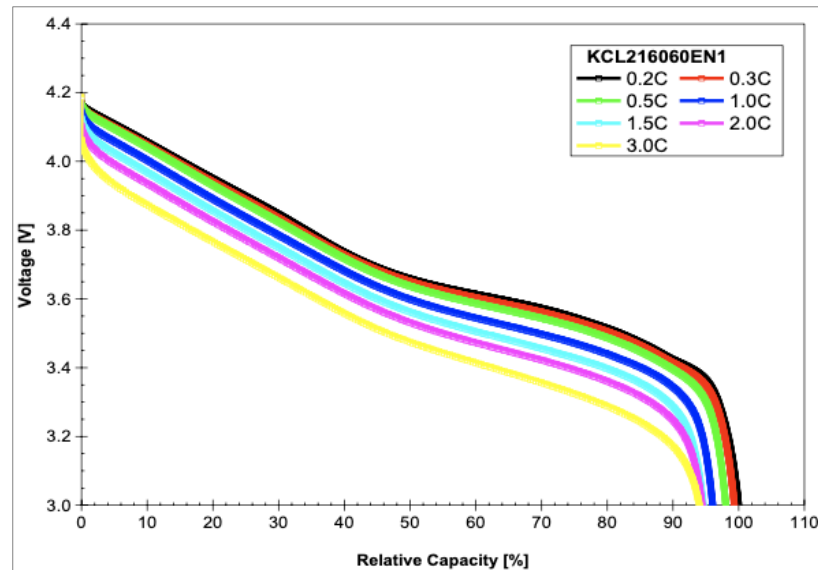


2.9 Discharge Characteristics

C-rate	Relative Capability [%]
0.2C	100.0
0.3C	99.4
0.5C	98.1
1.0C	96.2
1.5C	94.6
2.0C	94.6
3.0C	94.3

Test Condition

1. Charge : CC-CV, 0.5C, 4.2V, 1/20C cut off
2. Rest : 20min
3. Discharge : CC, **variable current**,

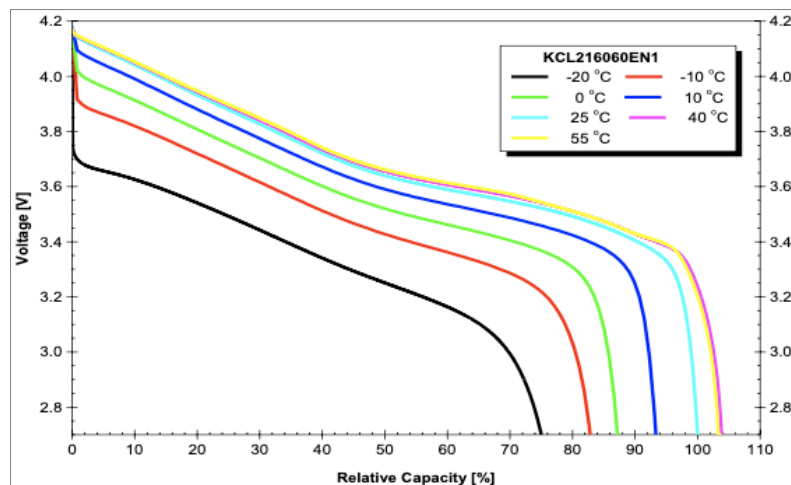


2.10 Discharge Temperature Performance

Temperature (°C)	Relative Capability (%)
-20	75.3
-10	82.3
0	87.8
10	93.7
25	100.0
40	103.4
55	103.4

Test Condition

1. Charge : CC-CV, 0.2C, 4.2V, 1/20C cut off @ 25±3°C
2. Soaking : 5hr @ Variable temperature
3. Discharge : CC, 0.5C, 2.7V cut off @ Each temperature



3 Cell Module Design

In the SeaPower™ battery system, a Module is the intermediate building block between the individual lithium-ion cells and the full Battery Pack. Each module integrates a specific arrangement of electrochemical cells with embedded electronics for sensing, control, and safety management. Modules are designed for mechanical ruggedness, electrical protection, and operational flexibility in demanding subsea environments.

SeaPower currently supports two module configurations:

- **7S1P Module — Voltage-Optimized Configuration**
- **1S9P Module — Current-Optimized Configuration**

3.1 Mechanical Design

All SeaPower™ modules share a consistent mechanical platform focused on thermal safety, structural integrity, and electrical isolation.

Component	Specification / Description
Pouch Cell (KCL216060EN1)	Lithium-ion pouch cell; vertically stacked in uniform orientation; up to 12 cells per module
Fire-Resistant Spacer	2 mm mica sheets between each cell and at both ends of the stack to prevent thermal propagation and abrasion
Terminal Hardware	Machined copper busbars bolted to cell tabs using stainless steel screws; provides electrical interconnects and structural anchoring



Figure 1 - Cell Module

3.2 Electrical Design

7S1P Module — Voltage-Optimized Configuration Figure 2

Feature	Specification / Description
Cell Configuration	7 cells in series, 1 parallel path (7S1P)
Nominal Voltage	25.76 V
Monitoring PCB	One cell monitoring PCB with two redundant monitoring ICs (primary and secondary) per cell module.
Voltage Monitoring	Individual taps from each cell routed to both ICs for continuous dual-path sampling
Temperature Monitoring	12 NTC temperature sensors (6 per monitoring IC) thermally bonded to pouch cell surfaces per cell module
Passive Balancing	Resistor-based circuit integrated to each cell module for balancing
Heaters	Resistive heating elements thermally bonded between cells for each cell module.
Communication Interface	Dual-channel ISO-SPI, galvanically isolated; primary and secondary buses daisy-chained to BMS Master
Safety Features	Internal fuses, directional diodes, fire-resistant spacers, and silicone potting for water ingress protection

1S9P Module — Current-Optimized Configuration, Figure 3

Feature	Specification / Description
Cell Configuration	1 cell in series, 9 in parallel (1S9P)
Nominal Voltage	3.7 V
Monitoring PCB	Shared Cell Monitoring Unit (CMU) with two monitoring ICs (primary and secondary) for up to 12 cell module, one IC per 6 modules.
Voltage Monitoring	Each module voltage is independently monitored and aggregated by the CMU
Temperature Monitoring	Single NTC temperature sensor per cell module
Passive Balancing	Resistor-based circuit integrated to each cell module for balancing
Heaters	Resistive heating elements thermally bonded between cells for each cell module.
Communication Interface	ISO-SPI link to BMS Master; single shared CMU handles module telemetry
Safety Features	Internal fuses, directional diodes, fire-resistant spacers, and silicone potting for water ingress protection

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The diagram illustrates the BMS architecture, showing the connection between the Millipede Board, Slave Board, and Balancer Board.

Millipede Board: This board interfaces with 12 cells (Cell 1 to Cell 12+). It includes two NTC sensors (6x NTC, 10K) and a DC-DC Supply/Heater Supply section. The DC-DC Supply is connected to the Heater Folds (between cells). The Heater Supply is connected to the Heater Folds (between cells). The Millipede Board is connected to the Slave Board via a 2mm Pin Header.

Slave Board: This board contains two LTC6811 chips (Primary and Secondary). The Primary LTC6811 handles Voltage Measurement and Temperature for the first set of cells. The Secondary LTC6811 handles Voltage Measurement and Temperature for the second set of cells. It also includes a Bal Ctrl Prim, Bal Ctrl Sec, and a FB Supply & Mux. The Slave Board is connected to the Balancer Board via an Edge Card Connector.

Balancer Board: This board includes a 12x Balancing Circuit and a CellBus. It is connected to the Slave Board via the Edge Card Connector. The Balancing Circuit is connected to the CellBus, which is connected to the cells.

Notes:

- This fuse is used 12 times with cells from 1 to 12.
- Balancer and Slave board are connected through edge card connector.
- Millipede Board and Slave Board are connected through 2mm Header.

The schematic diagram illustrates the architecture of a 12-cell Battery Management System (BMS). It consists of three identical CellBlock units (CellBlock 1+, CellBlock 2+, and CellBlock 12+) connected in series. Each CellBlock contains a 3-cell string (3 Cells per Block) and a BMS module. The BMS module includes a Resistor, Feedback_Cell, and a 3-cell string. The BMS module outputs are connected to a MasterBlock, BMS Slave, which provides feedback to the CellBlock. The MasterBlock also outputs to a 12-cell string (12 Cells per Block).

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4 Battery Pack

The SeaPower™ Battery Pack is the final, fully integrated assembly that combines pre-qualified cell modules, high-current busbars, a centralized Battery Management System (BMS), and subsea-rated connectors into a compact, rugged, pressure-tolerant energy system. Designed for operation at depths up to 6000 meters, this solid-state architecture delivers high energy density, reliability, and maintenance-free performance for demanding subsea applications.

Each battery pack is assembled to order and includes:

- **Cell Modules** configured in series and/or parallel to meet customer-defined voltage and capacity specifications.
- **Master BMS**, which aggregates telemetry from all modules, monitors global system health, and executes safety-critical logic across all operating states.
- **Connectors** rated for 6000-meter subsea operation, consisting of one low-profile communication connector and two fully redundant power connectors—each carrying both positive and negative terminals to support fail-safe power delivery.
- **Frame**, carbon fiber for structural support and mechanical protection for the battery pack.



Figure 4 - Battery Pack

4.1 Electrical and Mechanical Interface

- **High-current copper busbars** connect modules in series or parallel, enabling efficient power distribution with minimal resistance and heat generation.
- **Optimized internal** routing reduces electromagnetic interference (EMI), manages thermal load, and minimizes cable complexity.
- **Mica spacers** between modules maintain consistent physical separation, improving passive thermal dissipation and limiting the risk of thermal propagation between modules.

4.2 Final Assembly & Potting

Following integration of all internal components—including modules, busbars, BMS, and connectors—the complete assembly is encapsulated using Kraken’s proprietary silicone elastomer. This potting process fills the internal volume, fully surrounding all components to form a unified, flexible structure.

The cured silicone compound provides:

- **Hydrostatic pressure equalization** for full ocean depth operation
- **Shock and vibration damping** to protect internal components during deployment and operation
- **Thermal insulation** and **delayed thermal propagation** in the event of a fault
- **Buoyancy-neutral behavior** in seawater (density $\sim 1.1\text{--}1.2\text{ g/cm}^3$)
- **Passive overpressure relief** in case of gas generation or internal fault
- **Electrical isolation**, preventing leakage currents and ensuring stable operation across all subsea environments

The final step is the installation of the **carbon fiber frame**, which provides mechanical support, defined lifting points, and protection during handling and deployment. The frame does not serve as a pressure housing; all environmental protection and depth tolerance are achieved via the elastomeric potting material.

This fully solid-state design eliminates the need for pressure housings, oil compensation, or mechanical seals—resulting in a robust, compact, and maintenance-free battery system optimized for long-duration subsea missions.

4.3 Safety

The SeaPower™ Battery Pack employs a **multi-layered safety architecture** that integrates mechanical design features, embedded firmware logic, and hardware-level protections to ensure safe operation in all deployment scenarios.

1. Mechanical Safety

The battery uses **female-style subsea connectors**, eliminating exposed pins and preventing accidental contact with live terminals. All connectors are secured with hard covers that screw into place after mating, preventing accidental disconnection or mechanical stress on the contacts during deployment or operation.

The **solid-state relays (SSRs)** remain open by default and only transition to an active (closed) state when:

- The dedicated safety interlock pins are shorted, and
- The power-on signal is asserted by the host system via an electrical pin or command.

The silicone potting provides full electrical isolation of all internal conductors, preventing leakage currents and ensuring protection against moisture ingress or short circuits.

2. Embedded Firmware Protection

The SeaPower™ BMS continuously monitors all system parameters—including individual cell voltages, module temperatures, and pack-level metrics—and enforces strict operational boundaries.

- If any measurement exceeds safe thresholds, the BMS autonomously transitions the system to a SAFE state, opening the relays and disconnecting power from the external terminals.
- This firmware layer ensures real-time fault detection and response, reducing the risk of cascading failures or external damage.

3. Hardware-Level Fail-Safes

Each SeaPower™ Battery Pack includes **fast-acting fuses** on the high-current power paths. These fuses are designed to **fail open** in the event of a severe electrical fault—such as a short circuit or overcurrent condition—providing a final layer of passive protection independent of firmware or system control.

5 Battery System Architecture

SeaPower™ Battery Packs are designed to operate not only as standalone units but also as part of a larger, distributed battery system. The architecture supports **parallel connection of multiple battery packs** without requiring a centralized or system-level BMS. This enables scalable energy systems—from a few kilowatt-hours to megawatt-hour capacities—while preserving modularity, fault tolerance, and ease of integration.

5.1 Decentralized Operation

Each battery pack contains a fully autonomous SeaPower™ BMS that governs internal monitoring, protection, and relay control. When multiple packs are connected in parallel:

- **Each battery maintains independent control**, enforcing safety and operational logic locally.
- Packs **do not require balancing across SoC** at startup; they can be connected and operated even if individual batteries are at different charge levels.

This is made possible by two key features:

1. Directional Current Control

- Each pack includes an **internal directional diode** on its output power path.
- This hardware-level diode ensures **current flows only outward** from the battery during discharge, preventing any backflow into lower-voltage packs.
- As a result, there is **no cross-charging** or energy redistribution between packs with mismatched SoC, eliminating the need for pre-balancing or active current sharing circuits.

2. Addressable Communication Interface

- Every battery pack communicates on a shared **RS485 bus** using a **dedicated IP address** (configurable per pack).
- This allows external controllers, mission planning systems, or topside monitoring software to **query and manage individual packs** independently or collectively.
- The system supports real-time telemetry, health reporting, and command execution (e.g., coordinated shutdowns or SoC polling) without requiring a master BMS node.

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