Horizon Europe Work Programme

BIG LEAP

Next Generation of Battery Management Systems to increase Interoperability, bridge the Gap between 1st and SL-BESS, Extend Adaptability and emPower battery value chains

D2.3 - ESS conceptual design for SL-BESS use-cases Integration

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Executive Summary

Deliverable D2.3 of the BIG LEAP project presents the outcomes of Task 2.3, focusing on the conceptual design of ESS for SLB applications. This deliverable outlines the integration of Siro, Solitek and Corvus modules for EDF site and MBE modules integrated into cabinets design for Eaton site.

This deliverable is designed to provide a comprehensive framework for the development of modular ESS cabinets, addressing key factors such as rack configurations, module placement, cooling systems, and BMS integration. The design process incorporates CAD-based modelling to optimize the arrangement of battery modules, front plates, and supporting structures, ensuring a balance between performance, safety, and cost-effectiveness.

The EDF demonstrator, based in France, integrates three different types of battery modules: Solitek, Siro, and Corvus. For this site, two custom modular cabinet designs were developed for the Solitek and Siro modules. These designs consider the dimensional, electrical, and thermal characteristics of each module type, with careful attention to rack configuration, front plate accessibility, and BMS integration. Specifically, 16 Solitek modules are arranged in two racks (8 modules per rack, two per shelf), and 18 Siro modules are placed in two 19” racks (9 modules per rack, one per shelf), following standardized height and weight constraints. Each cabinet incorporates air-cooling, filtered ventilation, and space for Battery Protection Units (BPU), aligning with the modular and interoperable approach of the project. The Corvus modules at the EDF DEMO site are housed in their original manufacturer racks. After evaluating the structural and functional features of the existing Corvus infrastructure, it was determined that no redesign was necessary. The rack already meets the dimension, mechanical support, safety, and accessibility requirements for integration.

Moreover, the EATON demonstrator, on the other hand, will use MBE modules integrated into cabinets. These cabinets, also developed under the guidance of Task 2.3, similar to those used at the EDF DEMO site.

This report includes guidelines on mechanical robustness, electrical interconnections, and communication interfaces, supporting the scalability and adaptability of the ESS across various SLB applications.

In conclusion, D2.3 establishes the foundation for the CAD design of modular ESS solutions, ensuring cost reduction, standardization, and enhanced interoperability of SLBs. The insights presented in this deliverable will serve as a reference for the subsequent validation, testing, and deployment phases within the BIG LEAP project.

Organizational Acronyms and abbreviations

BIG LEAP	Next Generation of Battery Management Systems to increase Interoperability, bridge the Gap between 1st and SL-BESS, Extend Adaptability and Empower battery value chains.

CA	Consortium Agreement
GA	General Assembly
WP	Work package

Technical Acronyms and abbreviations

BTMS	**Battery Thermal Management System**
NMC	Nickel Manganese Cobalt
LFP	Lithium Iron Phosphate
PPS	Polyphenylene Sulfide
BPU	Battery Protection Unit
BU	Unit
TIM	Thermal interface material
ESS	Energy Storage System
BMS	Battery Management System
FL	First Life
SLB	Second life battery
CAD	Computer-Aided Design
MBE	Mercedes-Benz Energy

1. Introduction

The rapid growth of renewable energy sources and the increasing demand for energy storage solutions have brought significant attention to the reuse of First-Life Batteries (FLB) in Second-Life Battery (SLB) applications. Repurposing used batteries from electric vehicles and other applications into modular Energy Storage Systems (ESS) offers a cost-effective and environmentally sustainable approach to extending battery life, reducing waste, and optimizing resource utilization. However, integrating SLBs into stationary ESS requires careful consideration of mechanical, electrical, and thermal design aspects to ensure safety, reliability, and long-term operational efficiency.

Deliverable D2.3(ESS Conceptual Design for SL-BESS Use-Case Integration) is a key outcome of Task 2.3 within the BIG LEAP project. It focuses on the design and development of a modular, flexible, and interoperable ESS that accommodates various SLB modules, particularly the Siro, Solitek, and Corvus battery modules for the EDF demonstrator, and the MBE modules for the EATON demonstrator. The cabinet and rack designs were tailored to the specific dimensional and operational requirements of these modules, supporting demonstration needs at each site**.** Key aspects such as rack structure, module positioning, airflow optimization, and Battery Management System (BMS) integration have been analysed to enhance the functionality, maintainability, and cost-effectiveness of the proposed ESS design.

This deliverable provides a comprehensive account of the technical specifications of the selected modules, along with the detailed design considerations for the battery cabinet, racks, and front plate. Additionally, it outlines the BMS architecture and integration strategies, ensuring effective monitoring, communication, and system protection. The report also includes guidelines on mechanical robustness, electrical interconnections, and modularity, making the system adaptable to various use cases.

By establishing a structured and well-defined design approach, D2.3 serves as a foundational step toward the development of a cost-efficient, scalable, and interoperable SLB-based ESS. The design and methodologies presented in this deliverable will be instrumental in guiding future validation, testing, and implementation phases within the BIG LEAP project, ultimately contributing to the advancement of sustainable and standardized SLB applications.

2. Specifications of Siro and Solitek modules

2.1. Detailed technical and physical specifications of the Siro module

The Siro Standard Range Battery Pack features Nickel Manganese Cobalt (NMC) pouch cells, a widely used lithium-ion chemistry known for its high energy density and relatively good thermal stability. Each battery module arranged in a 12s2p (12 cells in series, 2 cells in parallel) configuration, making it suitable for high-voltage applications. These specifications were previously defined in Deliverable D1.4, and they remain unchanged. They are included here to support traceability and justify design decisions related to rack configuration and system integration. Additionally, the CAD file of the Siro module (Figure 1), including the corresponding dimensions, has been integrated into the current design to support the layout and structural planning.

The key specifications of the Siro battery module are as follows:

Table 1. Specifications of SIRO's battery module

Specification	Value
Cell Capacity	74.8 Ah
Module Nominal Capacity	146 Ah
Module Nominal Energy	6.4 kWh
Voltage Range	26.4 V (minimum) – 50.4 V (maximum)
Nominal Voltage	43.8 V
Maximum Charge C-Rate	1.8C
Maximum Discharge C-Rate	3C
Maximum Current	262 A
Mechanical Dimensions	356 mm (D) × 420 mm (W) × 110.5 mm (H)
Weight	27.2 ± 0.8 kg
Cooling System	Integrated cooling plate (requires adaptation for second-life use)

Figure 1 shows the CAD file of the Siro module.

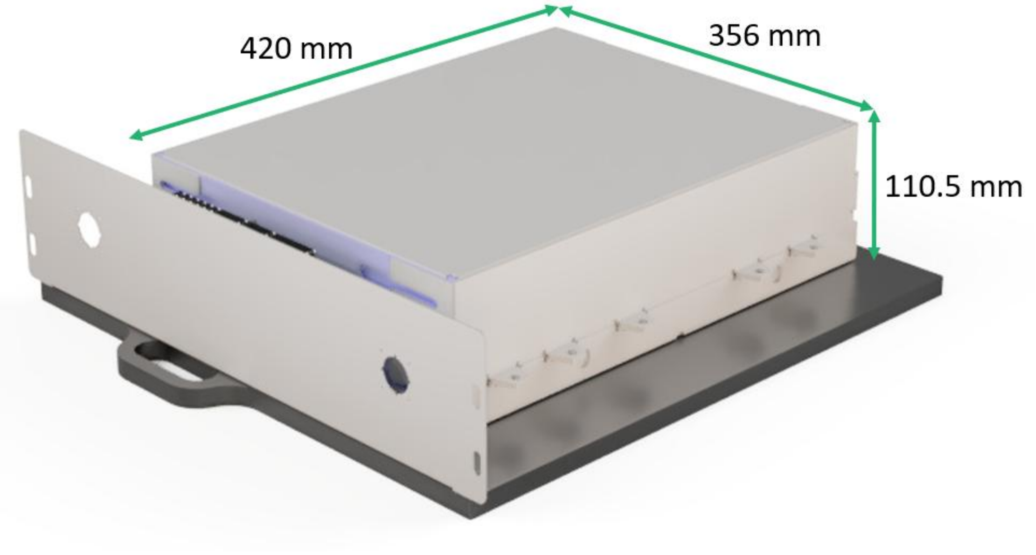


Figure 1: CAD file of the Siro Module with correspondent dimensions

2.2. Detailed technical and physical specifications of the Solitek module

The Solitek Nova module is based on prismatic LFP cells, a chemistry known for enhanced safety, long cycle life, and high thermal stability. It is designed for stackable residential energy storage systems, where multiple modules can be connected to increase capacity. These specifications were previously defined in Deliverable D1.4, and they remain unchanged. They are included here to support traceability and justify design decisions related to rack configuration and system integration. Additionally, the CAD file of the Solitek module (Figure 2), including the corresponding dimensions, has been integrated into the current design to support the layout and structural planning.

The key technical specifications of the Solitek Nova module are as follows:

Table 2. Specifications of Solitek's module

Specification	Value
Cell Chemistry	Lithium Iron Phosphate (LFP)
Cell Type	Prismatic
Cell Configuration	16s1p (16 cells in series)
Nominal Capacity	100 Ah
Nominal Energy per Module	5.12 kWh
Voltage Range	43.2 V (minimum) – 58.4 V (maximum)

Nominal Voltage	51.2 V
Maximum Current	100 A
Maximum Charge/Discharge C-Rate	1C
Mechanical Dimensions	511.1 mm (D) × 227.9 mm (W) × 228.1 mm (H)
Weight	38 kg
Cooling System	Passive cooling

Figure 2 shows the CAD file of the Solitek module.

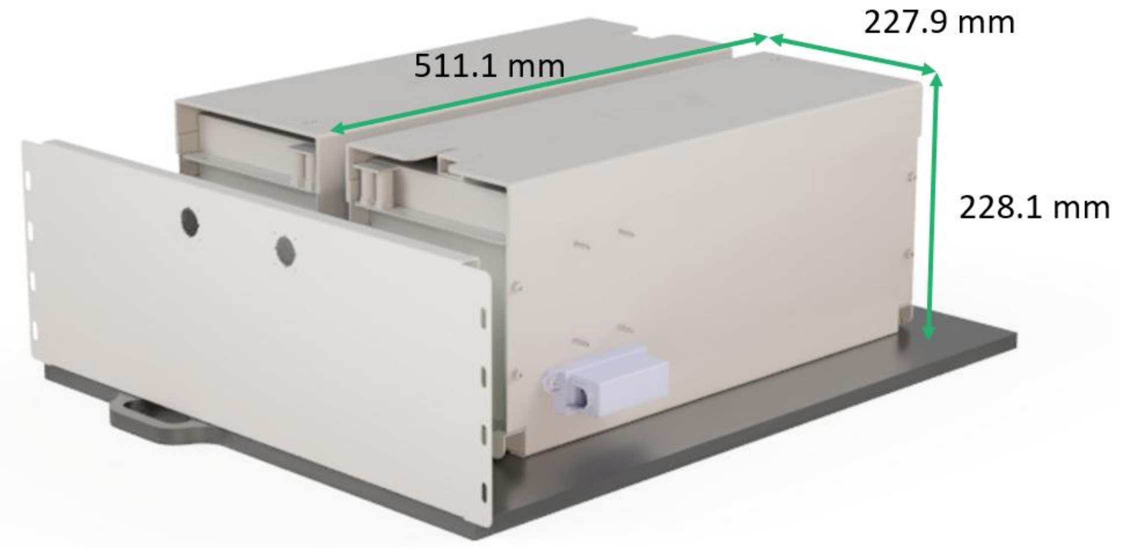


Figure 2: CAD file of the Solitek Module with correspondent dimensions

2.3. Requirements for Specific Use Cases

The EDF demo BESS is housed within a custom-modified container, composed of two 20-ft containers welded together, forming a controlled environment equipped with air conditioning and gas inerting systems. The physical layout and space constraints impose specific height, width, and depth limitations on the placement of battery racks and cabinets.

Key dimensional constraints include:

- Maximum height limit: 2000 mm (including forklift slots)
- Available floor space: 4 meters × 3.4 meters

One of the major challenges in this use case is ensuring all battery racks fit within the 2000 mm height restriction while still accommodating sufficient battery capacity.

Table 3: Rack Specifications

Battery Type	Rack Type	Modules per Rack	Rack Height (mm)
Corvus	Corvus E1850-V1	18 modules	1913 mm
Solitek	Custom rack	16 modules	1793 mm
Siro	Custom rack	18 modules	1793 mm

3. Detail Considerations for CAD Design of Battery Cabinets

3.1. Battery cabinet components

This section presents the detailed cabinet and rack design developed for the integration of Siro and Solitek battery modules in the EDF demonstrator. The design process focuses on ensuring mechanical compatibility, efficient thermal management, modular structure, and ease of installation and maintenance. The components considered and analysed in the following sub-sections include:

1. The module plate that is used to support and fix each battery module within the rack.
2. The front plate that is designed to provide structural support, and protection and facilitate safe external electrical connections via DC connectors.
3. The module layout, which defines the spatial arrangement and stacking of battery modules on each rack shelf.
4. The rack and cabinet structure that is customized to comply with height, weight, and accessibility requirements at the EDF site; and
5. The location of the BMS-slave determined using CAD files to ensure optimal placement for wiring, safety, and maintainability.

Each design element is tailored to the characteristics of the Siro and Solitek modules and contributes to the reliability, modularity, and interoperability of the EDF system installation. Detailed specifications and rationale for each component are provided in the subsections that follow.

3.1.1. Design of module plate

The battery modules are securely mounted onto a specially designed plate made from PPS (Polyphenylene Sulfide), a high-performance thermoplastic known for its excellent mechanical strength, heat resistance, and chemical stability. This material was selected to ensure structural integrity, lightweight properties, and durability under various environmental conditions.

The design of the module plate plays a crucial role in providing mechanical support and stability to the battery modules while also facilitating ease of assembly and maintenance. Each module is firmly attached to the PPS plate using a secure mounting mechanism, ensuring proper alignment and minimal movement during operation. Additionally, the plate design accommodates necessary clearances for electrical and thermal management components, ensuring efficient cooling and safe operation.

The dimensions of the module plates for both Siro and Solitek modules are illustrated in Figures 3 below. These dimensions were carefully determined to optimize space utilization within the cabinet while maintaining accessibility for wiring and integration with other system components. The plates also feature predefined mounting points for secure attachment to the cabinet frame, ensuring compatibility with the modular ESS design.

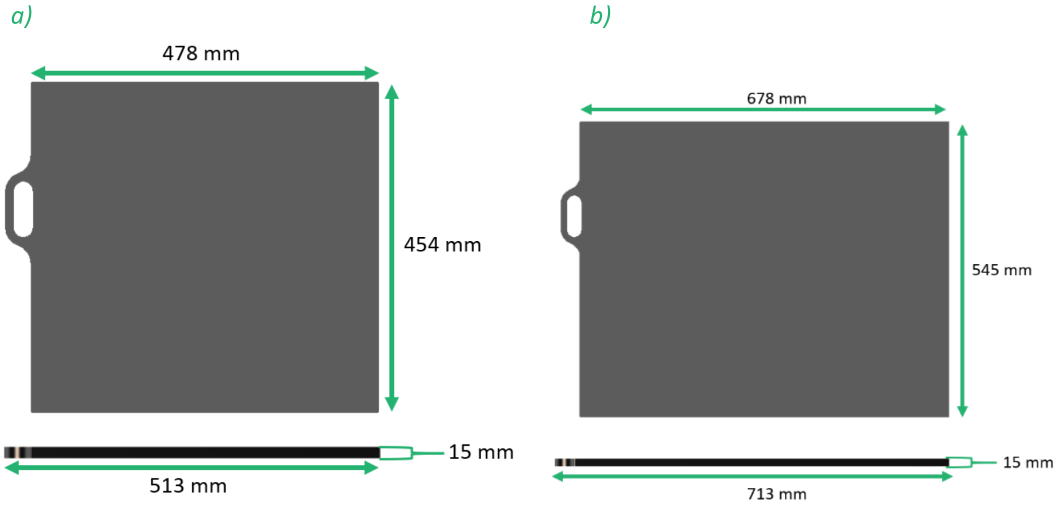


Figure 3: Module plate design with correspondent dimensions for the a) Solitek and b) Siro

3.1.2. Design of front plate

Perpendicular to the module plate described in the previous section, a painted stainless steel front plate is attached to provide structural support and protection. This front plate serves a dual purpose: it shields the module and its poles from external elements while also ensuring safe and efficient electrical connections.

The front plate is designed to accommodate DC connectors, which can be securely fixed onto it, allowing for a reliable interface to connect the battery poles to external circuits. By integrating these connectors into the front plate, a series connection between the modules within the rack can be efficiently established, ensuring proper electrical continuity.

Figure 4 illustrates the dimensions and placement of the front plate within the battery cabinet, showing how it integrates seamlessly with the module plate and other system components.

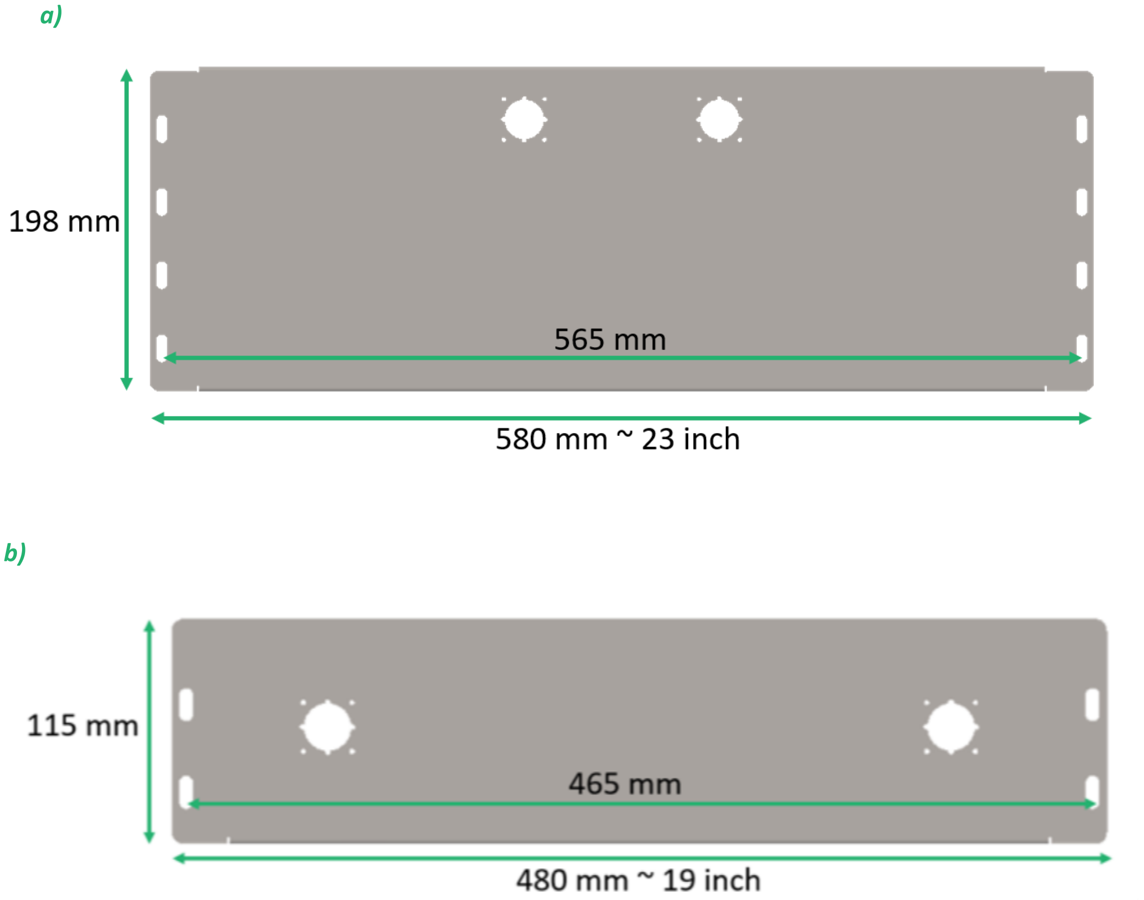


Figure 4: Dimensions and placement of the front plate for the a) Solitek and b) Siro module

3.1.3. Modules layout on module plate

The layout of the battery modules on the module plate was determined based on the dimensions of each module and the design requirements for optimal integration within the cabinet and EDF limitation. After careful evaluation, we decided to adopt different configurations for the Siro and Solitek modules to ensure mechanical stability, space efficiency, and ease of electrical connection.

For Siro modules, a one-module-per-plate layout was chosen. This decision was based on the larger size of the Siro module, which requires sufficient space for secure mounting and proper clearance for electrical components. The single-module-per-plate arrangement ensures that each Siro module is firmly secured without interference from adjacent modules.

For Solitek modules, a two-module-per-plate configuration was selected. Given the smaller dimensions of the Solitek module compared to the Siro module, this layout allows for efficient utilization of space while maintaining structural integrity. Mounting two modules per plate ensures a compact arrangement without compromising accessibility for wiring and thermal management.

This module placement strategy provides a well-balanced layout that optimizes space utilization, simplifies installation, and ensures compatibility with the overall cabinet design. Figure 5 illustrates the positioning of the modules on their respective module plates, highlighting the differences in layout between the Siro and Solitek modules.

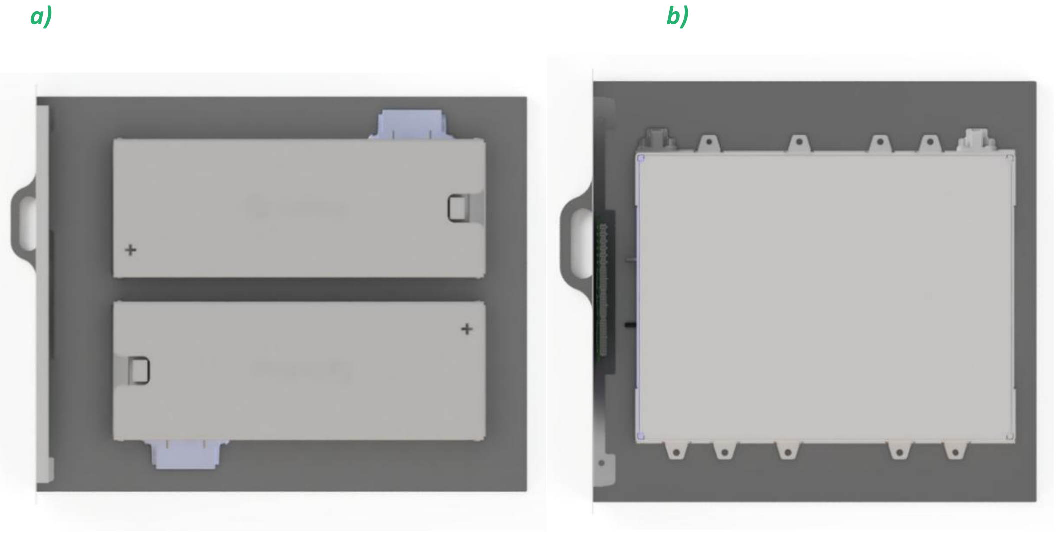


Figure 5: Placement and module layout of the a) Solitek and b) Siro module

3.1.4. Integration of BMS-Slave architecture

In this section, we utilized the CAD file of the BMS-Slave to determine the most suitable location for it within the cabinet design. Given the dimensions of both the BMS-Slave and the battery modules, we initially considered two possible placement options. The first option was to mount the BMS-Slave directly on the surface of the modules. This approach appeared advantageous at first, as it would allow for easier and more direct connections between the BMS-Slave and the modules, minimizing cable length and potential signal losses. Figure 6 shows the initial approach for Solitek and Siro modules.

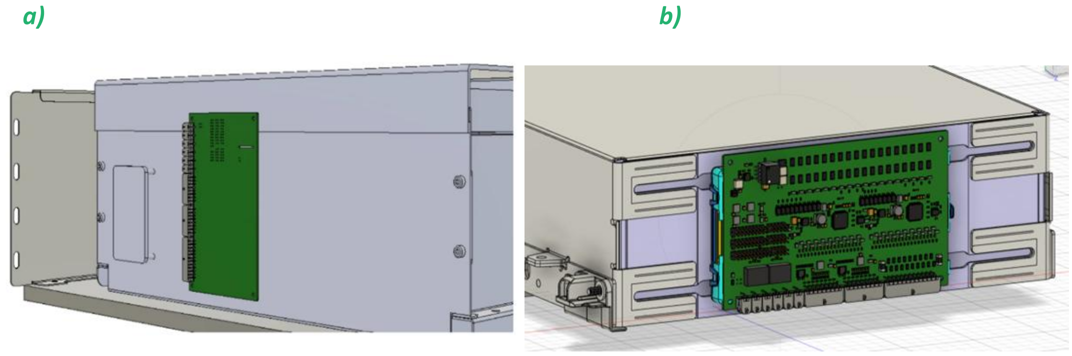


Figure 6: BMS-Slave location on the surface of the a) Solitek and b) Siro module

However, upon further evaluation, this placement proved to be impractical. The modules did not have a designated area or specific design features to accommodate the secure attachment of the BMS-Slave. Furthermore, mounting the BMS-Slave directly onto the module surface would have required adhesive bonding, which is not a reliable or recommended method due to potential long-term durability issues, difficulty in maintenance, and risks associated with thermal expansion and vibrations affecting the integrity of the connection. Given these challenges, we opted for the second approach, which involved placing the BMS-Slave on the front plate.

This solution offered multiple advantages, including better accessibility for installation and maintenance and enhanced structural security. By positioning the BMS-Slave on the front plate, we ensured a well-organized and stable setup while avoiding the issues associated with mounting it directly onto the module. This approach was found to be suitable for both the Siro and Solitek modules, as illustrated in Figure 7, where the front plate provides sufficient space and proper positioning for efficient integration of the BMS.

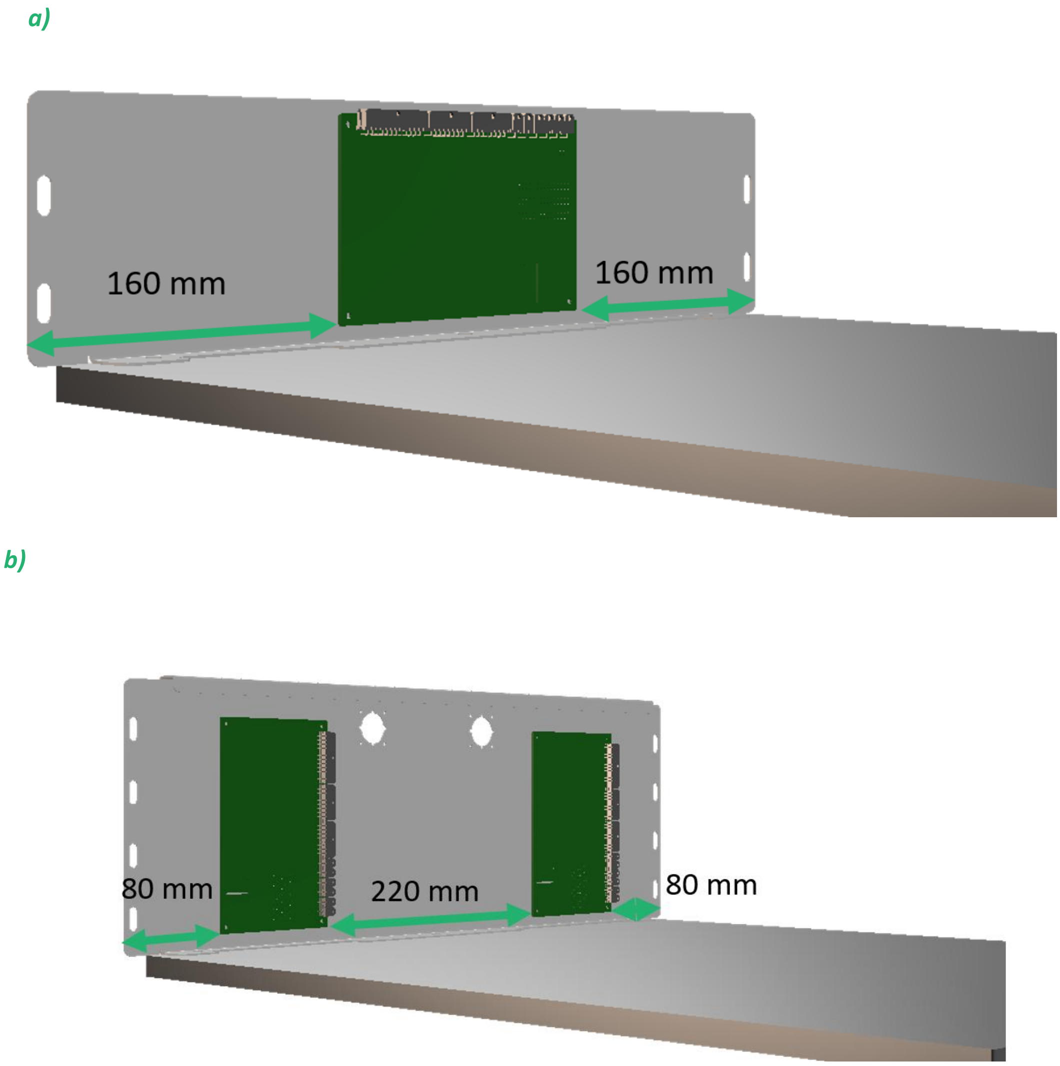


Figure 7: BMS-Slave location on the front plate for a) Siro and b) Solitek module

3.1.5. Design of the rack and cabinet for Siro modules

The design of the rack for the Siro modules was carefully developed to comply with the 2000 mm height limit, ensuring an optimal balance between modularity, structural stability, and accessibility. Given that the total system will integrate 18 modules, the configuration was determined to include two racks, each containing 9 modules to comply with the height limit.

To align with standard practices in battery energy storage systems, a 19" rack was selected, providing a universally accepted structure for modular installations. The rack consists of several units that each have a height of 44.5 mm. The rack incorporates rails positioned every 3U (133.5 mm), making it suitable for securely mounting battery modules (110.5 mm) while allowing enough flexibility in future adaptations. With a total height of 33U (1468.5 mm), the rack provides adequate spacing not only for the battery modules but also for additional protective and management components.

Each rack accommodates nine Siro modules, with each module occupying 3U of height, ensuring a stable and evenly spaced configuration. Additionally, one slot of 3U is dedicated to housing the Battery Protection Unit (BPU), which is essential for managing the electrical safety and performance of the system. This structured layout ensures that the system remains well-organized, easy to maintain, and scalable for future modifications.

The mechanical design of the rack incorporates 500 mm-long rails with a static load capacity of 30 kg per pair, providing the necessary strength to securely hold the battery Siro modules. The rack is also equipped with a front door featuring three inlet filters, which serve to improve airflow and prevent dust accumulation, thereby ensuring a clean operating environment. To enhance cooling efficiency, a roof-mounted fan is integrated into the design, supporting active ventilation and heat dissipation.

For structural support and ease of installation, the rack is mounted on a base plinth with a height of 100 mm, which provides additional stability and ensures sufficient clearance for airflow at the bottom of the cabinet. This design consideration not only enhances the mechanical durability of the system but also optimizes thermal management by promoting better air circulation around the battery modules.

The overall design of the rack for Siro modules prioritizes robustness, safety, and ease of integration while maintaining compliance with height and structural constraints. Figure 8 illustrates the layout and detailed specifications of the rack, demonstrating how the modules, rails, and protection systems are arranged within the cabinet.

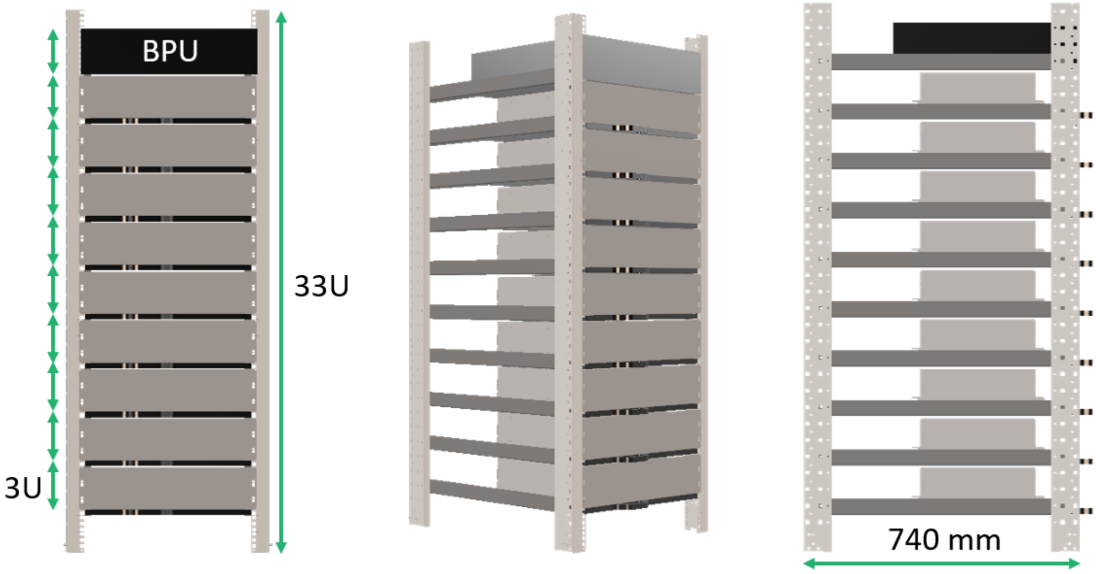


Figure 8: Rack design of the Siro module from a different perspective

The rack designed for the Siro modules will be enclosed within a sturdy cabinet that ensures protection, accessibility, and thermal management. The cabinet shows in Figure 9 and is designed with external dimensions of 800 mm × 800 mm and a height of 1700 mm, providing sufficient space to accommodate the 33U rack while maintaining a compact footprint for ease of installation and deployment.

To facilitate convenient installation and maintenance, an additional 3U (133.5 mm) of extra space is left unoccupied within the cabinet. This reserved space allows for ease of wiring, adjustments, and future modifications, ensuring that installation can be carried out without mechanical constraints.

At the top of the cabinet, a 93 mm protective lid is incorporated to shield the roof-mounted cooling fan from external elements while ensuring unobstructed airflow for heat dissipation and ventilation. This design consideration helps to maintain optimal operating temperatures for the battery modules, preventing overheating and enhancing overall system reliability.

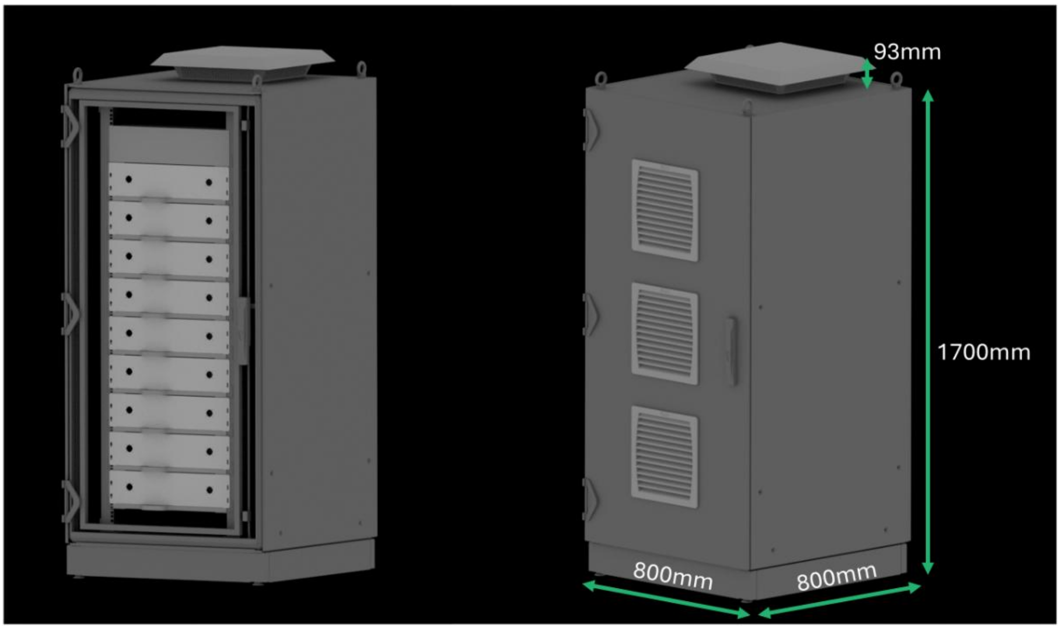


Figure 9: Cabinet design of the Siro modules with corresponding dimensions

3.1.6. Design of the rack and cabinet for Solitek modules

The design of the rack for Solitek modules was developed with careful consideration of height limitations, weight distribution, and efficient thermal management. To comply with the 2000 mm height limit, a total of 16 modules were integrated into the system, distributed across two racks, each containing 8 modules. This configuration ensures structural stability, modularity, and ease of maintenance while optimizing the available space within the energy storage system.

Unlike the Siro module rack, the Solitek rack follows a 23-inch standard, providing a wider structure to accommodate the module dimensions effectively. The rack features rails positioned every 6U (267 mm), allowing for the placement of two modules per 6U slot, leading to a well-organized and space-efficient layout. With a total height of 33U (1468.5 mm), the rack is structured to support both battery modules and essential system components.

Each rack contains four sets of 6U slots, with each slot housing two Solitek modules, making the best use of vertical space while ensuring adequate clearance for wiring and ventilation. Additionally, a dedicated 3U space is reserved for the BPU, which plays a critical role in ensuring electrical safety and system monitoring.

To provide a robust and reliable mechanical structure, the rack is equipped with 700 mm-long rails, designed to withstand a static load of 80 kg per pair. This increased load-bearing capacity is essential for handling the heavier Solitek modules while ensuring long-term durability and mechanical integrity.

Effective cooling and ventilation are also key considerations in the rack design. The front door is fitted with three inlet filters, which help maintain a clean airflow and prevent dust accumulation inside the cabinet. Additionally, a roof-mounted fan is integrated to enhance heat dissipation and maintain an optimal operating temperature for the battery modules.

Same with Siro the base of the rack is supported by a 100 mm-high plinth, which provides extra structural reinforcement and ensures proper clearance for air circulation. This plinth also facilitates easier transportation and installation of the rack within different energy storage environments.

Overall, the rack design for Solitek modules balances mechanical strength, space optimization, and effective cooling while maintaining compliance with height and weight constraints. Figure 10 illustrate the rack layout, detailing the arrangement of modules, rail placement, and ventilation systems within the cabinet.

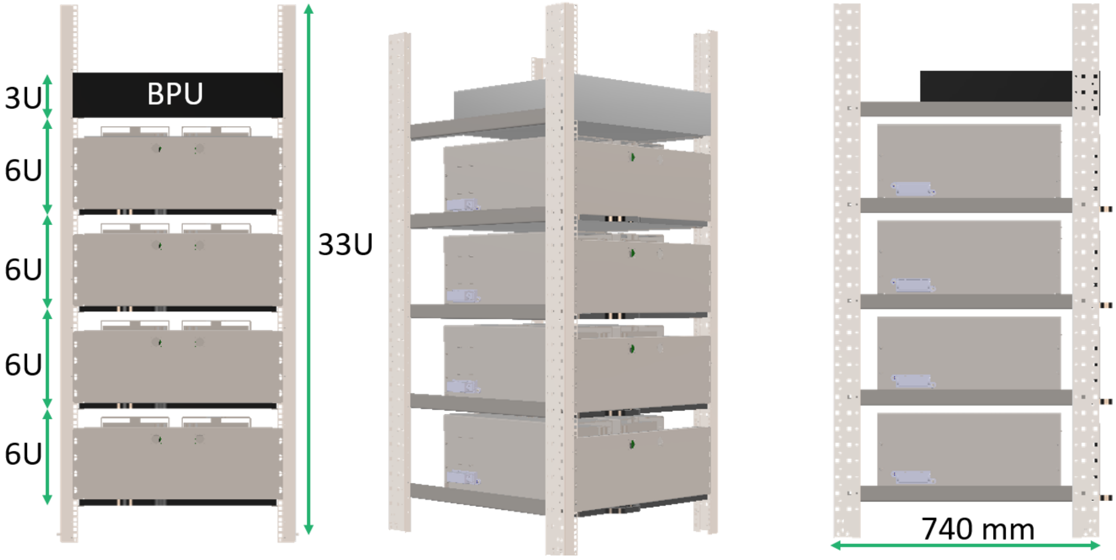


Figure 10: Rack design of the Solitek module from a different perspective

The rack designed for the Solitek modules will be enclosed within a robust and well-structured cabinet that shows in Figure 11. It is ensuring mechanical stability, protection, and efficient thermal management. The cabinet has external dimensions of 800 mm × 1000 mm with a height of 1700 mm, providing ample space to house the 33U rack while maintaining a modular and adaptable design for second-life battery applications.

To facilitate convenient installation, wiring, and future modifications, an additional 6U (267 mm) of extra space is left unoccupied within the cabinet. This extra space ensures ease of access for cable routing, system adjustments, and maintenance operations, minimizing complexity during installation.

At the top of the cabinet, a 93 mm protective lid is incorporated to shield the roof-mounted cooling fan from external elements. This design ensures optimal airflow and heat dissipation, preventing overheating and maintaining stable operating conditions for the battery modules.

Figure 11: Cabinet design of the Solitek modules with correspondent dimensions

4. Design Guidelines for Modular ESS

4.1. Design methodologies for recombining FL-BTMS into SLB ones

There are various methods for managing battery temperature, generally categorized into passive and active techniques. Among the active methods, forced air and liquid cooling are the most commonly used to maintain battery temperatures within the optimal range. The choice of an appropriate BTMS depends on ambient conditions and operational requirements, as it can significantly reduce battery degradation over time. When considering thermal management for SLB applications, it is important to evaluate the cost-effectiveness of available options. A structured methodology can help ensure that BTMS infrastructure from FL applications is effectively repurposed for SLB systems. This includes adapting and refurbishing components to suit SLB configurations, integrating thermal systems with the SL-BMS) for optimized control, and prioritizing sustainable, cost-efficient design choices throughout the process. Systematic evaluation of FL BTMS components

Before integrating FL-BTMS components into SLB applications, a thorough evaluation of their remaining usability is critical to ensure the reliability, safety, and overall performance of the repurposed BTMS infrastructure. The evaluation process focuses on three main aspects: structural integrity, thermal conductivity, and electrical and mechanical compatibility.

The structural condition of the components must be carefully assessed, starting with a visual inspection. Cooling plates should be examined for signs of corrosion, mechanical wear, or leaks that could compromise their function. Corrosion can degrade surface conductivity and lead to inefficient heat transfer, while leakage and mechanical damage can result in uneven cooling or localized thermal hotspots, increasing the risk of thermal runaway or accelerated battery aging.

Another critical aspect is the thermal conductivity of TIMs. Over time, TIMs undergo chemical aging, leading to changes in their material properties, most notably, a decline in thermal conductivity. Standardized test methods specifically designed to assess TIM degradation over a battery's lifetime are currently lacking. However, several established techniques, commonly referenced in international standards and used by the semiconductor and automotive industries, can help to characterize material changes [7]. Standard steady-state methods used to measure thermal conductivity include the guarded hot plate method (ASTM C177), the heat flow meter method (ISO 8301:1991), and the “cut bar” method (ASTM D5470). In addition to these, a variety of transient methods are available, such as the transient hot wire (ASTM C518), transient plane source, laser flash method, the 3-omega (3-ω) method, and transient thermoreflectance techniques. Each method offers its own level of accuracy, along with distinct advantages and limitations depending on the testing environment and the specific characteristics of the materials being evaluated [8].

In addition to structural and thermal considerations, the electrical and mechanical compatibility of the FL-BTMS components with the SLB system must also be verified. Components such as heat exchangers, pumps, temperature sensors, and wiring interfaces must be evaluated to ensure they can be integrated without introducing incompatibility or requiring extensive modifications. This includes checking that connectors, communication protocols, and control interfaces are aligned with the requirements of the SL system. Any mismatches could lead to issues such as communication failures, erratic thermal regulation, or safety hazards.

Furthermore, dimensional compatibility must also be addressed. The physical size, shape, and mounting configurations of reused components must fit within the spatial constraints of the SLB system. Misalignment or spatial conflicts can complicate assembly, impair airflow, or prevent proper thermal contact between surfaces.

4.1.1. Thermal Interface Material reuse strategy

TIM's are used to enhance heat transfer between battery cells and cooling components. In FL battery applications, TIMs are subjected to a range of operating conditions and environmental influences throughout their service life, which can lead to both physical and chemical aging. Over time, they may experience mechanical and thermal degradation due to factors such as thermal cycling, applied pressure, and contamination. Loss of adhesion, drying out, or compression damage are indicators that a TIM has deteriorated and should be replaced. Additionally, compatibility with SLB must be considered. Changes in the layout of battery modules may result in improper fit of previously used TIMs, and differences in thermal expansion properties may necessitate the use of upgraded materials. When it comes to maintenance, some TIMs, such as graphite sheets, graphene-based materials, and liquid metal TIMs, can often be cleaned and reused. In contrast, thermal pastes and adhesives typically cannot be recovered and must be reapplied with new material [9].

Table 4 provides a comparison of commercially available TIM types, highlighting their composition, typical aging issues, and whether they can be reused after initial application.

Table 4: TIMs aging and Reusability Characteristics

TIM Type	Composition	Typical ageing issues	Reusability potential
Thermal Pastes/greases	Silicone-based, metal oxides	Drying, separation, contamination	Not reusable, must be replaced
Thermal Pads	Silicone, elastomers	Compression set, loss of adhesion	Limited reuse, if intact and flexible

Phase-change material (PCM)	Waxes, paraffins, organic compounds	Chemical degradation, leakage	Rarely reusable, but recoverable in some cases
Graphite sheets/Graphene TIMs	Flexible graphite, graphene enhanced polymers	Mechanical wear, oxidation	high reusability, with minor cleaning
Liquid metal TIMs	Ga-based alloys	Oxidation, metal contamination	Reusable, but needs cleaning
Thermal adhesives	Epoxy- based or polymer bonded fillers	permanent bonding	Not reusable must be removed

4.2. Guidelines for the electrical interfaces of the battery cabinet and the Battery Protection Unit

To illustrate the interfaces between the BMS-Master, the BMS-Slaves, the BPU and the battery cabinet the following system design is assumed for reasons of simplicity of the explanation as these parts translate straight forward to all other architectures (Figure 12).

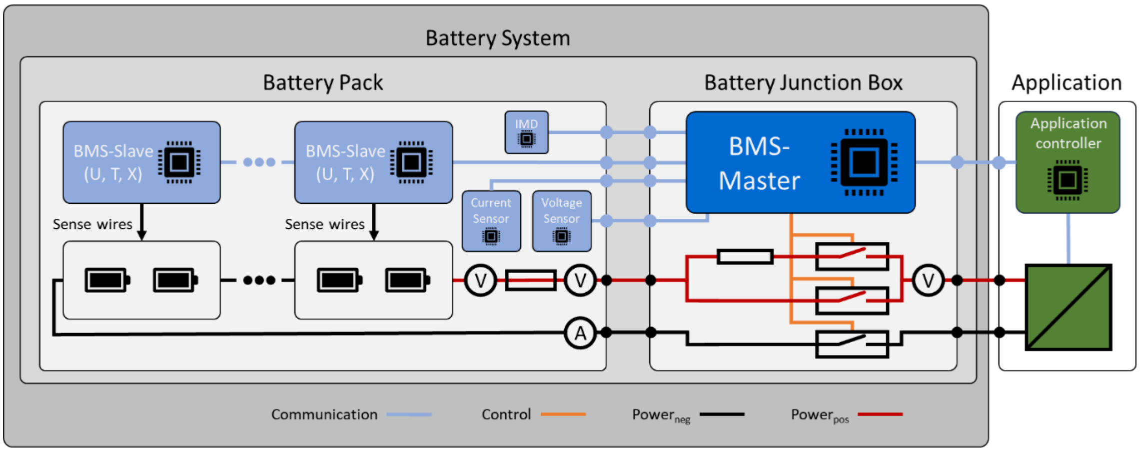


Figure 12: Classic architecture with a single power path and internal precharging (BIG LEAP D2.1)

4.2.1. BMS-Master and BMS-Slave

The BMS-Master is connected to the BMS-Slave through the BMS-Interface, which is part of the BMS-Master. The connection from the BMS-Interface to the first BMS-Master is done via a twisted-pair shielded cable. All remaining BMS-Slaves are connected to the first one in a daisy chain also using a twisted-pair shielded cable.

The BMS-Master is connected to a CAN-based current sensor (Isabellenhütte IVT-S), which transmits the current, and the three high voltage measurements (before the pack fuse, after the pack fuse, and after the contactors) information.

The BMS-Master is connected to a PWM-based insulation monitoring device using Molex Micro-Fit 3.0 connectors at the BMS-Master side

The BMS-Master is connected to the application controller using CAN, Modbus RTU or Modbus TCP (through a gateway) dependent on the application's interface.

The BMS-Master as well as the BMS-Slaves use Molex Micro-Fit 3.0 connectors for the daisy chain.

The contactors inside the BPU are also connected to the BMS-Master using Molex Micro-Fit 3.0 connectors.

The connector and interface overview from the BMS-master perspective is shown in Figure 13.

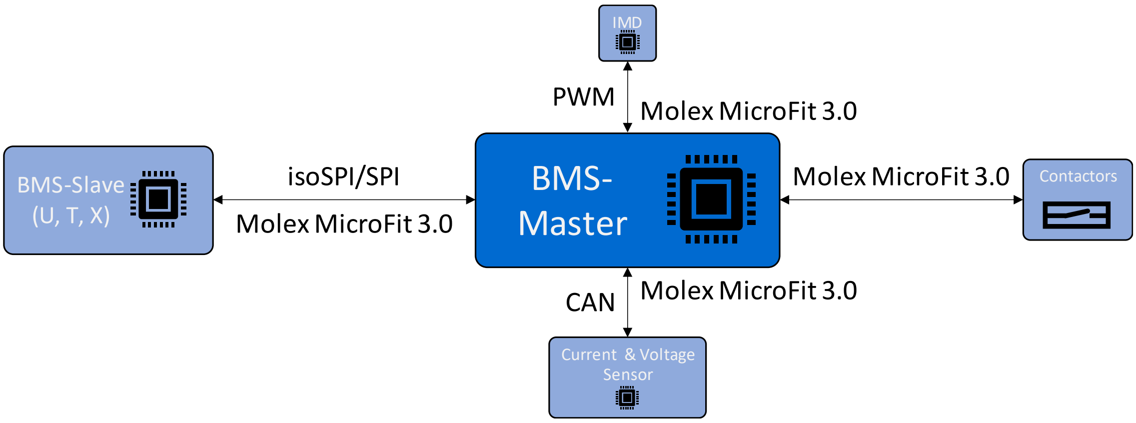


Figure 13. Connector overview for the BMS-Master, BMS-Slave and attached sensors and actors

4.2.2. Battery Protection Unit

The power connectors from and to the BPU shall provide an interlock contact, apart from that the power connectors are not further restricted. The power and precharge contactors shall provide feedback. The contactors shall be forced-guided/mechanically linked. Further, inside the BPU the three system voltages need to be measured. An overview is provided in Figure 14.

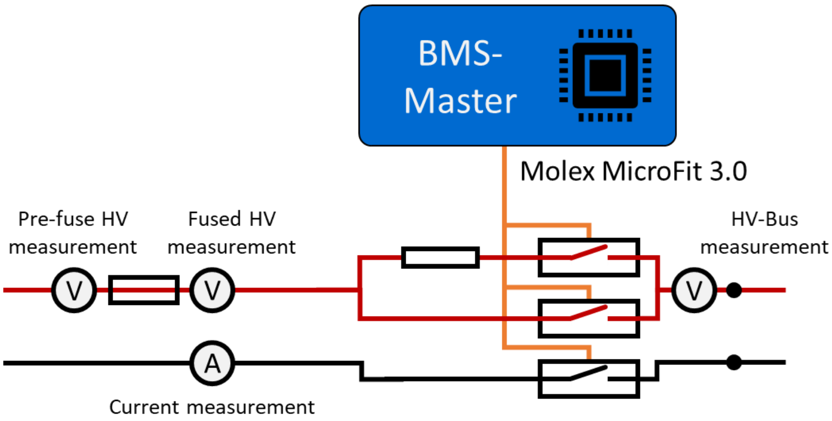


Figure 14. BPU connector and measurement points overview

4.3. Guidelines on enhanced mechanical designs and HW development

As mentioned in Deliverable 1.4, we selected to use batteries at the module level for the Eaton ESS Demo application to reduce effort and cost. These modules will then be assembled into complete battery cabinets.

Dismantling at the module level was completed as optimal, allowing the rearrangement of primary modules into a secondary structure with uniform form factors, adaptable voltage levels, and a hierarchical control system.

The integration of modules in the Eaton demo was considered from 3 areas: mechanical design, electrical parameter setting, and control system setup. It was concluded that the mechanical design based on a 19" rack is the most versatile platform for modular solutions, it is already used in Eaton products as well as by other companies supplying complete system or battery system components. This allows for standardization of the design and utilization of stationary secondary module construction elements available on the market, with easy replicability and scalability. As the batteries will be housed in a container and in a controlled environment, a high level of intrusion protection can be avoided, simplifying the design.

4.3.1. Key considerations for enhanced mechanical designs are:

Key considerations to be taken to enhance the mechanical design include structural integrity, modularity, thermal management, material selection and integration with other systems.

Regarding Structural Integrity the following concepts must be considered:

- Load Capacity: Ensure the design supports the weight of all components.
- Durability: Use materials that withstand environmental conditions.
- Compliance: Adhere to industry standards for safety and performance.

Regarding modularity the following concepts must be considered:

- Standardized Components: Use connectors and interfaces that facilitate easy assembly and disassembly.
- Scalability: Design for the addition or removal of modules without major modifications.
- Maintenance Access: Ensure easy access to components for maintenance and replacement.

Regarding thermal management the following concepts must be considered:

- Cooling Systems: Integrate effective cooling solutions like fans or liquid cooling.
- Ventilation: Ensure adequate airflow to prevent overheating.
- Thermal Insulation: Use materials that protect against external temperature fluctuations.

Regarding material Selection the following concepts must be considered:

- Strength and Weight: Choose materials like aluminium or composites for a good balance.
- Cost-Effectiveness: Select materials that fit within the budget while meeting performance needs.
- Sustainability: Opt for recyclable or environmentally friendly materials.

Regarding integration with Other Systems the following concepts must be considered:

- Compatibility: Ensure the design works well with electrical and thermal systems.
- Ease of Integration: Design for straightforward integration with other components.
- Cost Reduction: Focus on design improvements that lower overall costs.

From our experience, a freestanding cabinet with a 19" rack aligns very well with the key consideration for enhanced mechanical design:

- Load Capacity: These cabinets are designed to support significant weight, ensuring they can handle the load of multiple battery modules and associated components.

- Durability: Typically made from robust materials like steel, these cabinets can withstand environmental stresses such as temperature variations and mechanical shocks
- Compliance: Many 19" rack cabinets meet industry standards for safety and performance, ensuring reliable operation.

- Standardized Components: The 19" rack format is a widely accepted standard, making it easier to integrate various components and modules.
- Scalability: These cabinets allow for easy addition or removal of modules, supporting scalability without major modifications.
- Ease of Maintenance: The design often includes features like quick release locking sides and accessible front and rear doors, facilitating easy maintenance and replacement of components.
- Cooling Solutions: Many 19" rack cabinets come with built-in ventilation and options for integrating additional cooling systems like fans or liquid cooling.
- Ventilation: Adequate ventilation is typically provided through vented tops and sides, helping to manage heat effectively.
- Thermal Insulation: Some cabinets offer thermal insulation properties to protect the internal components from external temperature fluctuations.
- Strength and Weight: Materials like steel and aluminium are commonly used, offering a good balance of strength and weight.
- Cost-Effectiveness: These materials are cost-effective, ensuring the cabinets are affordable while meeting performance requirements.
- Sustainability: Many manufacturers offer cabinets made from recyclable materials, supporting environmental sustainability goals.
- Compatibility: The 19" rack format ensures compatibility with a wide range of electrical and thermal management systems.
- Ease of Integration: The standardized design simplifies the integration process with other components, such as BMS and inverters.
- Cost Reduction: The use of standardized components and materials can help reduce overall integration and manufacturing costs.

4.4. Conceptual battery pack integration into cabinets for cost-effective design

4.4.1. Battery modules:

As officially announced at GA, the battery supplier for the Eaton Demo was changed from Nissan to Mercedes Benz Energy - MBE.

MBE has several types of battery modules available for the Eaton Demo. These modules contain different types of battery cells in different configurations.

The properties of the battery modules are different. Differs in their electrical properties, mechanical dimensions, or the cooling system of the battery modules (with integrated cooling plate, with external cooling plate, without cooling plate, etc..).

For our visualization for the Eaton Demo, we used the MBE module with the designation MBE312, the dimensions of which are shown in the image below. This is a module with an integrated cooling plate.

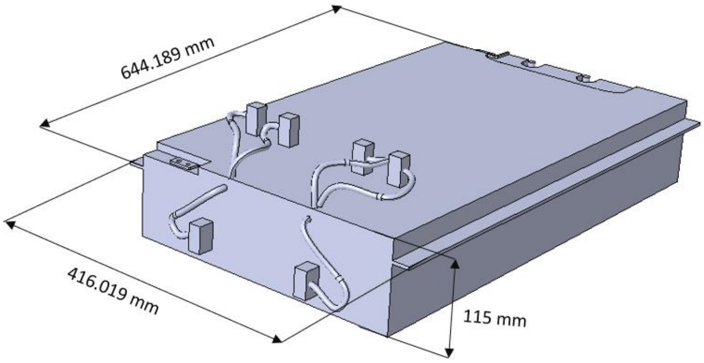
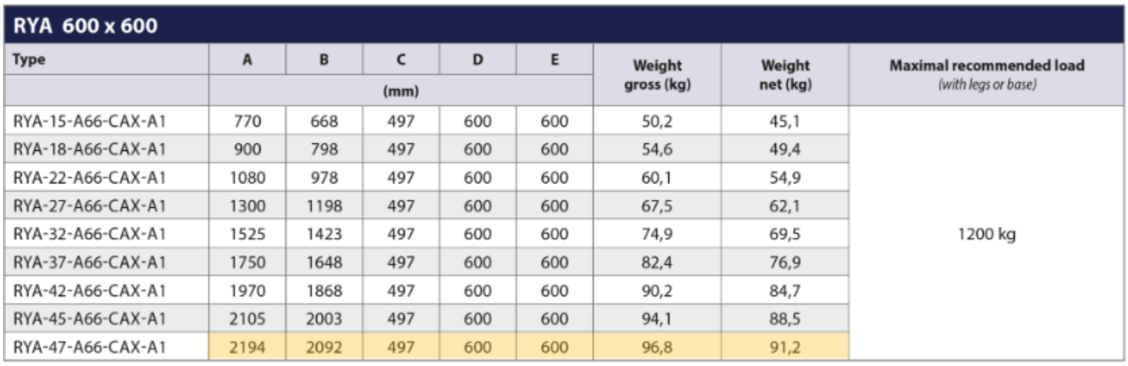


Figure 15: MBE module with integrated cooling plate

4.4.2. Battery rack:

For integration of the battery modulus, we chose Free-standing cabinet RYA from Triton with loading capacity of 1200/1500 kg.



RYA 600 x 600								
Type	A	B	C	D	E	Weight gross (kg)	Weight net (kg)	Maximal recommended load *(with legs or base)*
	(mm)							
RYA-15-A66-CAX-A1	770	668	497	600	600	50,2	45,1	1200 kg
RYA-18-A66-CAX-A1	900	798	497	600	600	54,6	49,4	
RYA-22-A66-CAX-A1	1080	978	497	600	600	60,1	54,9	
RYA-27-A66-CAX-A1	1300	1198	497	600	600	67,5	62,1	
RYA-32-A66-CAX-A1	1525	1423	497	600	600	74,9	69,5	
RYA-37-A66-CAX-A1	1750	1648	497	600	600	82,4	76,9	
RYA-42-A66-CAX-A1	1970	1868	497	600	600	90,2	84,7	
RYA-45-A66-CAX-A1	2105	2003	497	600	600	94,1	88,5	
RYA-47-A66-CAX-A1	2194	2092	497	600	600	96,8	91,2	

Figure 16: Specification of the free-standing cabinets.

We chose this cabinet as it offers several advantages that align with our target of enhanced mechanical designs of ESS:

Rigid construction: Robust bolted construction, which is made completely of 1.3 mm thick material. High-quality workmanship and the latest technology ensure excellent design of the cabinet.

High loading capacity: With a loading capacity of 1200 kg, extendable to 1500 kg, the cabinet can support heavy battery modules and other components, making it suitable for high-capacity ESS applications.

Disassemblability
The individual parts of the RYA are bolted together to form a compact unit with the same load capacity as a welded cabinet. Most of the parts are connected by TAPTITE thread-forming bolts. This ensures high strength of the bolted connection even after several disassembles.

Demountable panels: removable side panels and rear cover, allowing for quick access to the internal components. This facilitates maintenance, upgrades, and reconfiguration.

Adjustable vertical rails: Vertical 19” rails can be adjusted freely in any depth of the cabinet. This simplifies mounting of the device and configuration of cables.

Flexible door opening: The hinge system allows the door to open 165°. The door can be easily removed and re-mounted to change the direction of opening.

Break-out blanking panels: Entry openings for cables are covered with breakout-type blanking panels. To prevent dust penetration, cables can be sealed in the opening with a brush strip, or simply secure by a protective fringe edge (both supplied with the cabinet).

Protective enclosures: The robust construction and demountable panels provide a secure enclosure for the ESS components, protecting them from physical damage and unauthorized access. This helps in meeting safety standards and regulations.

Ease of maintenance: The design allows for easy access to components, making it simpler to perform regular maintenance and inspections, thereby ensuring the system remains safe and operational.

With a high loading capacity of 1200/1500 kg, the cabinet can support heavy-duty applications, making it a versatile and cost-effective choice for various uses.

4.4.3. Battery electrical interconnection

For HV interconnection, it is possible to use common HV cables with cable lug or Busbar interconnections. It is also a universal system that can ultimately be chosen according to the final choice of battery module and its connection options on the battery module itself.

As an example for this visualization, we have chosen a series connection of 12 modules to achieve a nominal voltage of one rack/string of approximately 800V, which will then be suitable for connection to the inverter.

Each rack will also contain a Power Distribution Unit / Battery protection unit which will ensure connection and disconnection of the given string, pre-charging and protection. The design of the Battery protection unit itself is then integrated into the WP6 Task 6.2

In order to achieve a total capacity of 500kWh for the entire system, 6 battery racks will be placed in the battery container and connected in parallel.

4.4.4. Battery rack integration into the rack

12 battery modules to be assembled inside the cabinet. To assemble the modules, we are planning to use L-shape panels, the panels will be first assembled to the rack rails, then the battery modules will be assembled to the panels.

L shape panel can be customized made of steel with 3 to 5 mm thickness, which will be fixed to the rack rail by M6 screw. Using of L-Shape panel allows for a more compact and organized setup, this can free up space for additional equipment within the rack. Other advantages are better weight distribution and support for the battery, better airflow around the battery, easier to access and maintain the battery.

This integration is cost-effective because standard 19" IT racks are used. Mechanical integration is realized using common connecting material.

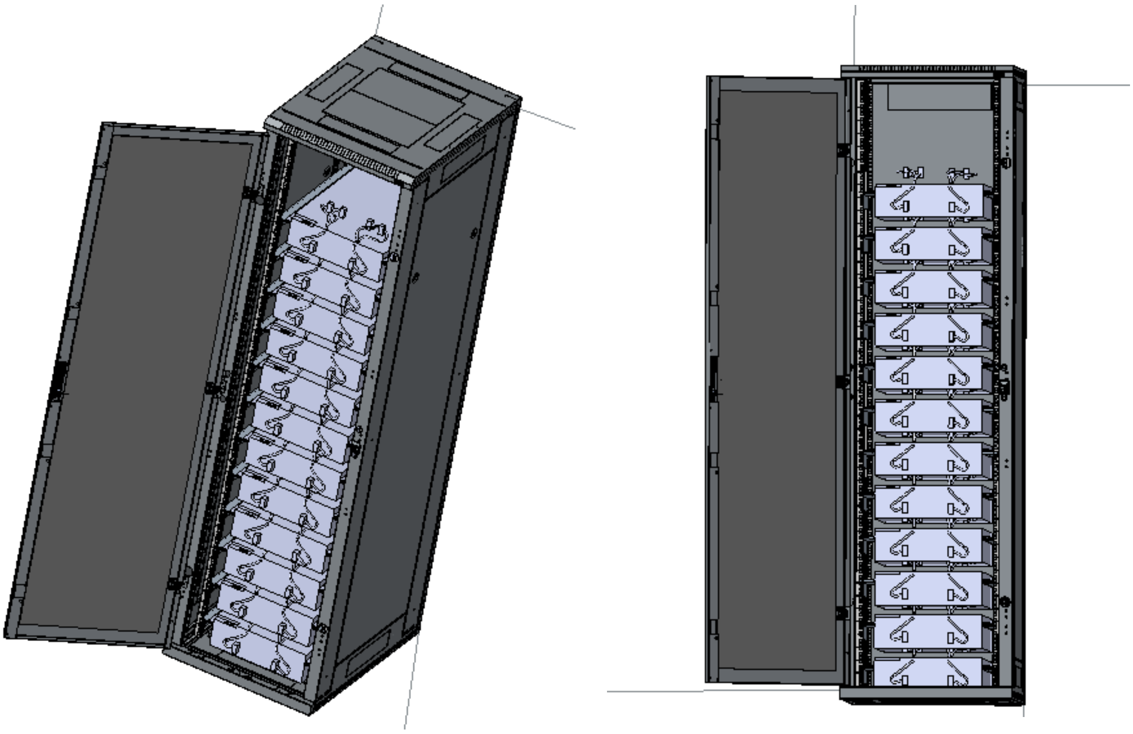


Figure 17: Battery rack integration

4.4.5. Thermal comfort for Battery modules:

To make good use of battery energy, it is also necessary to take care of its thermal comfort. For this reason, cooling plates are integrated into the battery modules or can be added later.

Therefore, it is also important to connect a cooling/heating unit that will ensure ideal thermal conditions for each battery module.

Considering the modularity system, it is ideal to connect such a unit for each battery rack. This unit will then cool/heat the battery string according to the temperature of the battery modules and their thermal requirements.

For subsequent water cooling/heating connections, pipes or hoses can be used, which are also readily available on the market. The result is an affordable modular system.

4.5. ESS communication compatibility with DEMOs

As presented in the previous deliverables, the BMS of the BIG LEAP DEMOs will mainly be structured around 3 layers of control and communication:

- ○ One or several Slave BMS per subunit of SL-BESS, developed in the project.
- ○ One or several Master BMS per SL-BESS, developed in the project.
- ○ One edge device, the uppermost layer of the BMS developed in the project.

On the side of the test facility, an application controller (sometimes referred to as Energy Management System) is in charge of communicating with the edge device and controlling the power sources. This application controller is managed by the partner performing the test and is outside the scope of development of the BIG LEAP project.

The purpose of this section is to ensure the alignment between requirements of communication between the application controller and the edge device, and the BMS development strategy followed so far.

In D1.1 “FL & SL-BESS requirements for interoperation”, the requirements for the testing of the 3 DEMOs were listed as summarized in the table below:

Table 5: Overview of Demonstration Tests

	Partner in charge of the test	Type of DEMO (physical vs. virtual)	Communication requirement
DEMO 1	EDF	Physical	CAN
DEMO 2	EATON	Physical	Modbus TCP or RTU
DEMO 3	MASEN	Virtual	Not Applicable

When it comes to the DEMO 3 that will be virtual, the Big Leap BMS will only be implemented as software in the test environment of MASEN. Therefore, there won’t be any communication between “physical” devices and thus no communication requirements to discuss here. Instead, the software interfaces between the BMS and the test environment will be covered in the software development deliverables.

Currently, the edge device under development in WP4 is planned to include communication interfaces for CAN and Modbus TCP or RTU. This development path should ensure that the partners in charge of the physical tests for DEMO 1 and DEMO 2 will be able to communicate with the SL-BESS via their application controller.

This discussion illustrates the importance of aligning the technical specification with the requirements derived from the considered use case. In addition, it proves that featuring multiple communication interfaces on the BMS and especially on the edge device layer contributes to making it more interoperable.

5. Conclusion

The development of a modular and flexible ESS for SLBs presents both technical challenges and significant opportunities for cost reduction and sustainability in battery reuse. Deliverable D2.3 has provided a comprehensive conceptual design framework for integrating Siro and Solitek battery modules into a standardized ESS architecture. By addressing key aspects such as cabinet structure, rack design, module layout, front plate configuration, and BMS integration, this report establishes the foundation for a scalable and efficient energy storage solution.

Through detailed CAD models, various mechanical, electrical, and thermal considerations have been analysed to ensure optimal performance, safety, and interoperability. The proposed 3D models and sketches for the battery cabinet not only define the structural layout but also incorporate essential features such as cooling systems, electrical connectivity, and modular adaptability to support different SLB configurations. These design outputs will serve as critical inputs for WP6, where they will be further refined and implemented in the manufacturing and validation phases of the project.

In addition to the design aspects, D2.3 outlines methodologies for integrating the BMS-Slave, ensuring real-time monitoring, efficient communication, and enhanced safety features. The structured layout of the system allows for ease of assembly, maintenance, and scalability, making it adaptable for various stationary energy storage applications.

Moving forward, the insights and methodologies presented in this deliverable will support the transition from conceptual design to physical implementation in WP6, where the developed battery cabinets will be manufactured and integrated into real-world demonstrators. This work contributes to the overall objectives of the BIG LEAP project, promoting cost-effective, standardized, and sustainable solutions for SLB applications, ultimately facilitating the broader adoption of modular energy storage systems.

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