

HYP BATT



Hyper powered vessel battery charging system

Document Title	Scalability and replicability handbook
Document type and number	Quote from Deliverable 5.6
Primary Author(s)	A. Campos, M. Vicente, A. Lázaro Fundación Valenciaport
Document Version Status	2.0 Final
Distribution level	Pub - Public
Project Acronym	HYPOBATT
Project Title	Hyper Powered vessels battery charging system
Project website	WWW.HYPOBATT.EU
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Grant agreement number	101056853
Date of deliverable: [30.03.2026]	Date of submission: [31.03.2026]



**Funded by the
European Union**

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1. REPLICATION AND SCALE-UP HANDBOOK

The decarbonisation of maritime transport requires not only the development of innovative technologies, but also their effective and scalable deployment across ports and vessel operations. In particular, the electrification of short-distance maritime transport depends on the availability of reliable, high-power charging infrastructure capable of operating under demanding port conditions.

This handbook provides a practical framework to support the deployment and replication of automated megawatt-class shore-to-ship charging systems for battery-electric vessels. It is based on the technical and operational experience gained from real-world implementation of high-power charging solutions and translates this experience into actionable guidance for future projects.

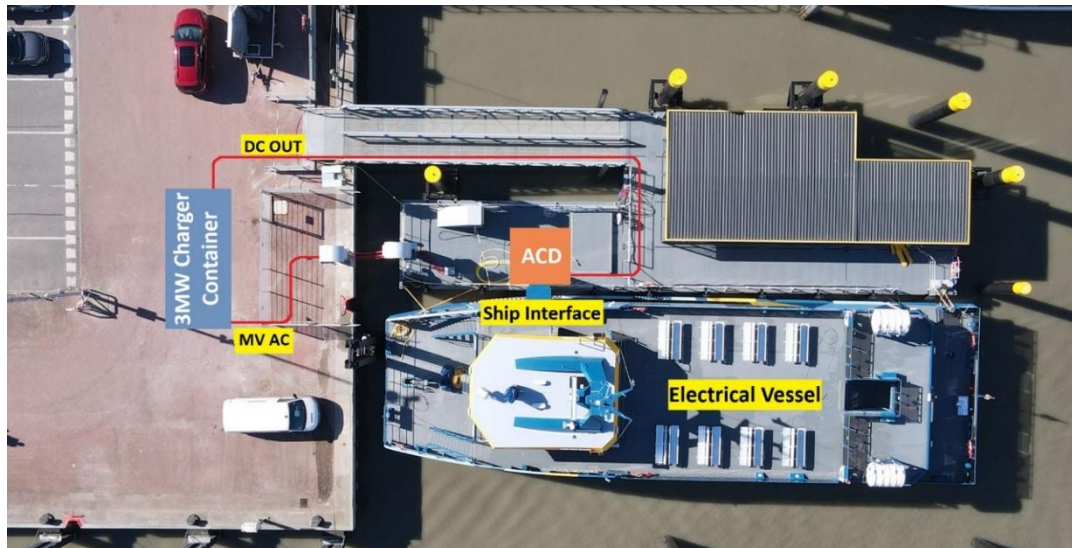
The guidance presented in this handbook builds on the coordinated implementation carried out by the project partners during the demonstration phase. In this context, AG Reederei Norden-Frisia was responsible for the port-side installation environment and operational integration at the demonstration site, ensuring compatibility with harbour infrastructure and vessel docking procedures. Heliox developed and supplied the Power Cabinet, including the AC/DC conversion system and grid interface required to deliver the charging power. Wabtec designed and implemented the Automatic Connecting Device (ACD), which provides the automated mechanical and electrical interface between shore and vessel, enabling safe and repeatable high-power connection operations. On the vessel side, Damen Shipyards Group was responsible for the integration of the onboard charging interface and adaptation of the ship electrical architecture to support high-power charging according to MCS-aligned requirements. Together, these contributions ensured the successful end-to-end deployment of the multi-megawatt shore-to-ship charging chain from grid connection to onboard battery interface.

The document is designed as a standalone reference guide, supporting stakeholders in planning, implementing, and scaling charging infrastructure in different port environments.

The mentioned infrastructure is composed of 4 main full sub-systems that provides a Maritime Multi-Megawatt Charging System architecture. From the grid to the batteries those are;

1. A step-down transformer, usually from the medium to low voltage: 6.6-11kV or up to 35kV converted to the lower 400-690 Vac
2. The Power Cabinet in charge of transforming the AC in charging DC current (up to 1.5 kV)
3. The Automated Connecting Device to reduce charging time in connection phase, increase overall system safety, reduce workforce-wise OpEx, and optimize procedure, and in charging phase connecting big wires and MW-range cables.
4. The Ship Interface for the connection of the power and communication lines.

Figure 1 Layout of real demonstration set-up in the Port of FRISIA from above (bottom left image) from the Power Container side (top right image) and from onboard the vessel (bottom right image)





It addresses the full project lifecycle, from early feasibility assessment to large-scale deployment, and integrates technical, operational, organisational, and regulatory dimensions.

The handbook is structured to guide users through the key phases of implementation:

1. Definition of preconditions and feasibility requirements
2. Planning and system design
3. Installation and integration
4. Operation and monitoring
5. Replication and scale-up strategies

In addition, it provides practical recommendations, good practices, and checklists to support decision-making and reduce implementation risks.

A key principle underlying this handbook is that successful deployment of megawatt-class charging infrastructure requires alignment between port infrastructure, vessel operations, energy systems and stakeholders. Therefore, the guidance provided goes beyond purely technical aspects and addresses the broader system integration challenges associated with port electrification.

This handbook is intended to be applicable to a wide range of port contexts and charging technologies aligned with emerging standards, supporting the transition towards zero-emission maritime transport.

1.1 Purpose and Target Users

This handbook provides a practical, step-by-step guide to support the scalability and replicability of the charging infrastructure demonstrated within the HYPOBATT project. It builds on the experience gained during the design, installation and operation of the pilot system, translating technical knowledge and project insights into actionable guidance for future deployments.

Its objective is to assist ports in planning, implementing, replicating, and scaling up similar solutions under different operational, regulatory and grid conditions. The handbook covers the full project lifecycle, from early-stage planning and feasibility assessment to design, implementation, operation and long-term scale-up, providing a structured framework to support decision-making and reduce implementation risks.

The handbook is primarily intended for:

- Port authorities and port energy managers.
- Terminal operators and logistics operators.
- Technology providers and system integrators.
- Grid operators and energy service companies.
- Vessel operators and shipping companies.
- Engineering, procurement and construction contractors and consultants.



In addition, the handbook may also be relevant for policymakers, regulators and funding bodies involved in supporting port decarbonisation and the deployment of innovative energy infrastructure.

The handbook is designed to be technology-oriented and adaptable, allowing its use beyond the specific HYPOBATT demonstration sites. While it is based on the hyper-charging solution developed within the project, the principles, methodologies and recommendations presented are applicable to a wider range of shore-based charging and electrification solutions in ports. As such, it aims to serve as a reference framework to facilitate the transition towards zero-emission port operations across different geographical and operational contexts.

1.2 Replication Preconditions

Before initiating the replication of automated megawatt-class shore-to-ship charging systems such as the HYPOBATT solution, ports must ensure that a minimum set of preconditions is fulfilled. These preconditions define the baseline conditions required to enable a technically feasible, operationally viable, and economically sound deployment.

The replication of the HYPOBATT concept requires alignment across four main dimensions: port and operational context, technical infrastructure, organisational framework, and regulatory environment. Failure to meet these conditions may significantly increase implementation risks, costs, and integration complexity.

The following subsections define the key preconditions that ports should assess prior to engaging in the planning and deployment of such systems.

1.2.1 Port and Operational Preconditions

From an operational perspective, the deployment of megawatt-class charging infrastructure is only justified when a clear and stable use case exists. Ports must therefore ensure that the operational environment can support frequent and predictable charging events.

The main operational preconditions include:

Defined decarbonisation or electrification strategy

The port should have a clear roadmap aligned with broader energy transition objectives, including electrification of vessels and port operations.

Identified use cases requiring high-power charging

Suitable applications typically include short-distance ferry routes, port service vessels or other maritime operations with:

- High frequency of calls
- Predictable schedules



- Limited turnaround times
- Sufficient berthing time for charging operations

The duration of port calls must be compatible with the energy transfer requirements of the vessels, considering megawatt-class charging profiles. System design allowing vessel departure in case of interrupted charging.

Availability of suitable installation space

Ports must ensure adequate space at quay or pontoon level for installing:

- Charging cabinets.
- ACD systems.
- Auxiliary electrical infrastructure.
- Berth characteristics and environmental conditions.

Factors such as tidal range, vessel movement and berth geometry must be considered.

- Tidal variations may require vertical compensation systems or floating pontoons. Connectors need large tolerances due to vessel movements (translational and rotational)
- Mechanical tolerances must be accommodated in the ACD design.
- Proximity to grid connection points.

The presence of a medium-voltage connection and transformer station close to the berth significantly reduces installation complexity and costs.

In addition to operational conditions, the deployment of automated shore-to-ship charging infrastructure requires several technical prerequisites related to electrical power availability, mechanical integration, and interface compatibility.

1.2.2 Technical Preconditions

Prior to delving into the various specific technical aspects of the Hypobatt project's implementation, it is imperative to establish the requirements and prerequisites that ensure its feasibility and proper operation. This section delineates the criteria, parameters, and technical limitations that must be met to ensure compatibility with existing infrastructure, operational safety, and system efficiency. The following subsections are developed on the basis of the preconditions outlined above, thus enabling a structured and consistent analysis of the various components and technical scenarios.

1.2.3 Electrical Infrastructure Requirements

Deployment of automated shore-to-ship charging systems requires access to electrical infrastructure capable of supporting megawatt-class power transfer. Ports intending to



replicate such systems must ensure that sufficient grid capacity and appropriate power conversion infrastructure are available to deliver stable DC charging power to the vessel.

- Availability of medium-voltage grid connection and transformer station close to the berth location.
- Input voltage range: 6–24 kV AC ($\pm 2.5\%$)
- Grid configuration: Three-phase connection (3P + PE)
- Grid frequency: 50 or 60 Hz ± 1 Hz
- Compliance with applicable standards: The system must comply with the technical and safety standards defined for both the Power Cabinet (PC) and the Automatic Connecting Device (ACD), as described in Table 6 and 7.
- Distance between ACD and Power Cabinet shall be scalable.
- No cooling needs for the ACD.

1.2.4 Mechanical Installation Requirements

The mechanical integration of megawatt-class shore-to-ship charging systems is a critical aspect for ensuring reliable, safe, and repeatable operation under real port conditions. The installation of the ACD and associated infrastructure must be carefully adapted to the physical characteristics of the berth, vessel interface and environmental conditions



Figure 2 - Real Installation of HYPOBATT Solutions at Germany



Unlike conventional cable-based charging systems, the HYPOBATT solution relies on a mechanically controlled connection interface. Therefore, precise alignment, structural stability and adaptability to dynamic conditions are essential preconditions for successful deployment.

Structural Integration at Berth Level

The quay or pontoon structure must be capable of supporting the mechanical loads associated with the ACD system and its auxiliary components. This includes:

- Static loads from the ACD structure and mounting system
- Dynamic loads generated during connection and disconnection cycles.
- Environmental loads due to wind, waves, and vessel movements

Structural verification should be performed to ensure that the installation does not compromise the integrity of the berth infrastructure. In cases where quay installation is not feasible, floating solutions such as pontoons may be considered to improve adaptability.

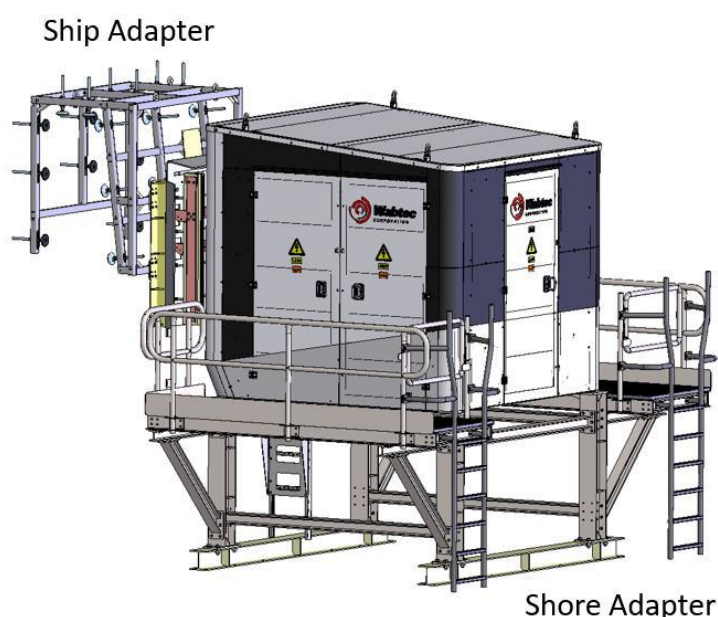


Figure 3: Ship / Shore adapters

There is no universal method to design a fully adaptable ACD for all port configurations. Given the status, HYPOBATT demonstration site required some adapters that are presented above in Figure 3. Those end-user solutions provide full adaptability and scalability aligned with each end-customer ship's and pier's requirements.

Alignment and Positioning Requirements



Figure 4 - Mechanical Movement Compensations

Accurate alignment between the shore-side ACD and the vessel charging interface is a fundamental requirement for safe operation. The system must accommodate:

- Horizontal positioning tolerances during vessel docking.
- Vertical variations due to tidal range and vessel loading conditions.
- Angular misalignments caused by mooring conditions or environmental factors.

The telescopic mechanism of the ACD must be dimensioned to compensate for these variations, ensuring reliable contact engagement without excessive mechanical stress.

HYPOBATT's ACD can accommodate X-directional movement during charging process. It has the capability of also withstanding and counterbalance tidal-based Y- and/or Z-directional forces, from top or side positions thanks to designed charging interface mechanism.

Adaptation to Environmental Conditions

Port environments present a range of dynamic conditions that directly affect mechanical integration:

- Tidal variations may require vertical compensation systems or floating mounting solutions.
- Wind and wave action can induce vessel movement during connection.
- Marine corrosion conditions require the use of appropriate materials and protective enclosures.

The mechanical design must ensure robust operation under these conditions, maintaining alignment and connection integrity over repeated cycles.

Cable Routing and Interface Integration



The routing of high-power cables between the electrical infrastructure and the ACD must be carefully designed to minimise mechanical stress and installation complexity. Key considerations include:

- Minimisation of cable length to reduce losses and costs.
- Protection against mechanical damage and environmental exposure
- Integration with existing port infrastructure (ducts, trenches, cable trays)

The interface between the ACD and the power conversion system should be located as close as possible to reduce installation complexity and improve overall system efficiency.

Installation Footprint and Space Requirements

Adequate space must be available at the berth to accommodate:

- The ACD system and mounting structure
- Power cabinets and auxiliary equipment
- Safety clearance zones for operation and maintenance

Space constraints are a common limitation in existing ports and must be evaluated during the planning phase. Compact and modular system configurations can facilitate integration in constrained environments.

1.2.5 Charging Interface Compatibility

For automated charging to operate reliably, the vessel charging interface must be compatible with the ACD. This includes both the electrical contact configuration and the communication signals required for charging control and safety interlock verification between the vessel and shore infrastructure. The charging interface must ensure flexible, interoperable, and easy-to-handle solutions.

The following table summarises representative technical parameters of the automated ferry charging system. These reference values illustrate the electrical capacity and mechanical characteristics typically required for megawatt-scale shore-to-ship charging infrastructure. Actual system parameters may vary depending on vessel energy demand, port infrastructure, and site-specific installation constraints.

Table 1 - Power Cabinet Electrical and Technical Specifications - Source: Hypobatt Deliverable 4.3

Parameter	Reference Value	Notes
Charging standard	IEC 61851-1/23/23-1/23-3	MCS-aligned standards
Communication standard	IEC 61851-24 / DIN 70121 / ISO 15118-1/2/10/20	EV communication protocols



Optional additions	ISO 15118-6, ISO 15118-8 (Wi-Fi, OppCharge)	Extended functionalities
Compliance and safety	CE / IEC 61851-21-2 / IEC 61439	Safety and compliance standards
DC output voltage range	500 – 1500 V DC	High-power DC charging range
Rated DC output power	3 MW	Nominal system configuration
DC output current range	0.1 – 3 kA (dual 0.05 – 1.5 kA)	High-current configuration
Input connection / frequency	3P + PE, 49 – 51 Hz	Grid connection characteristics
Full load / idle input power	3.15 MVA / 50 kVA	Power consumption profile
Input voltage range	6 – 24 kV AC $\pm$ 2.5%	Medium-voltage input
Power factor	> 0.99	Above 50% rated load
Peak efficiency	97% (MV AC in – LV DC out)	High efficiency
Dielectric withstand	40 / 75 / 125 kV	Depending on voltage level
Communication (back office)	4G modem, LAN, OCPP 1.6J / 2.0	Remote monitoring and control
Temperature range	-40 to +50 °C (derating may apply)	Operating conditions
Cooling system	Dry cooler, HVAC or technical water	Configuration dependent
Operational noise level	< 80 dB(A) @ 5 m	Acoustic impact
System weight	~22,000 kg	Containerised system
Dimensions	20 ft high-cube container ($\approx$ 6.06 $\times$ 2.44 $\times$ 2.90 m)	Standard container footprint
Protection rating	IP65 / IK11	Environmental protection
Environmental classification	ISO 12944: C5-I / C5-M	Corrosion resistance (industrial/marine)

Table 2 - Reference Technical Parameters for Ship Shore Interface - Source: Wabtec

Parameter	Typical Value	Description
Charging power capacity	1 – 5 MW (scalable)	Typical megawatt charging range for ferries
DC system voltage	up to ~1.5 kV DC	Depends on charger configuration
Maximum DC current	up to ~5000 A	Defined by conductor size and cooling concept
Grid connection	Medium-voltage supply	Provided via transformer and power cabinet



Telescopic reach capability	approx. 1 – 2 m	Compensates vessel docking tolerance
Vertical compensation	±0.5 – 1.0 m (scalable)	Handles tide and vessel freeboard variations
Installation type	Quay or pontoon mounted	Depends on port infrastructure
Environmental protection	Marine outdoor rated enclosure	Designed for coastal conditions

1.2.6 Organisational Preconditions

The successful deployment of automated megawatt-class shore-to-ship charging infrastructure requires a well-defined organisational framework ensuring coordination among all relevant stakeholders, clear allocation of responsibilities, and robust operational procedures.

Beyond technical readiness, organisational alignment is a critical precondition for replication, as these systems involve multiple actors across the energy, port, and maritime domains. A lack of coordination or unclear responsibilities can lead to delays, safety risks, and inefficient operation.

Stakeholder Identification and Coordination

Replication requires early identification and engagement of all key stakeholders involved in the planning, implementation, and operation of the system. These typically include:

- Port authority (infrastructure planning and coordination)
- Grid operator (connection and power supply)
- Charging infrastructure providers (technology design and integration)
- Vessel operators (end users of the system)
- Terminal operators (local infrastructure and operations)
- Classification and certification bodies (compliance and safety validation)

A structured coordination framework should be established from the early stages of the project to ensure alignment of technical requirements, timelines, and responsibilities.

Definition of Roles and Responsibilities

Clear allocation of roles and responsibilities must be defined across all project phases:

- *Design phase*: system architecture, interface definition, technical specifications
- *Installation phase*: civil works, electrical installation, mechanical integration
- *Commissioning phase*: system validation, safety checks, performance testing
- *Operation phase*: daily operation, monitoring, maintenance
- *Maintenance phase*: preventive and corrective interventions



The definition of responsibilities should be formalised through contractual arrangements and supported by detailed interface management documentation.

System Ownership and Business Model

A clear ownership model must be defined prior to deployment. Different configurations may be considered depending on the port context:

- Port authority-owned infrastructure
- Terminal operator-managed systems
- Energy provider or utility-driven models
- Third-party “charging-as-a-service” solutions

The selected model will influence investment responsibility, operational control, maintenance obligations and revenue streams. Early definition of the business model is essential to ensure long-term sustainability.

Operational Procedures and Charging Responsibility

The operational framework must clearly define how the charging process is initiated, controlled, and supervised. This includes:

- Assignment of charging responsibility:
 - Definition of who is responsible for:
 - Initiating the charging sequence
 - Performing safety checks prior to energisation
 - Supervising operation during charging
 - Definition of operational workflows
 - Docking and positioning procedures
 - Connection and disconnection sequences
 - Emergency response protocols

Control Interfaces and Communication

The system must define how commands are transmitted (e.g., remote control, automated communication between vessel and shore systems).

Safety checks and operation can be assigned to the vessel crew (e.g., captain), supported by remote control interfaces and emergency stop systems.

Training and Human Resources

The availability of trained personnel is a fundamental precondition for safe and efficient system operation.

Personnel involved in the operation and maintenance of the system must be trained in:

- System operation procedures
- Safety protocols and emergency response



- Fault detection and basic troubleshooting

Coordination with other Stakeholders

Training programmes should be developed as part of the implementation phase and updated during operation.

Energy Supply and Contractual Arrangements

The deployment of high-power charging infrastructure requires a clear strategy for energy sourcing and management. This includes:

- Electricity supply contracts with grid operators or energy providers
- Integration of on-site renewable energy sources (e.g., PV, wind) where available
- Consideration of energy storage systems to manage peak demand and optimise costs.
- Contractual arrangements should also define energy pricing, billing mechanisms and responsibilities for energy management.
- Interface Management and System Integration Governance

Given the complexity of the system, a structured approach to interface management is essential:

- Definition of a shared system architecture
- Development of an Interface Control Document (ICD) covering:
 - Electrical interfaces
 - Mechanical interfaces
 - Communication protocols
 - Safety interlocks

Establishment of a joint risk register, continuously updated throughout the project lifecycle.

This governance framework helps to avoid misalignment between stakeholders and reduces integration risks.

1.3 Planning Phase

The planning phase represents a critical stage in the deployment of megawatt-class shore-to-ship charging infrastructure, as it defines the technical, operational, and organisational conditions under which the system will be implemented. Decisions taken during this phase have a direct impact on system performance, integration complexity, investment costs and long-term operational reliability.

A structured planning approach is therefore required to ensure alignment between port infrastructure, electrical grid capacity, vessel requirements and charging technology specifications. This phase must involve early coordination between all relevant stakeholders,



including port authorities, grid operators, technology providers and vessel operators, in order to minimise risks and ensure a smooth implementation process.

The planning activities can be broadly divided into two complementary perspectives: the port-side perspective, focusing on infrastructure readiness and site conditions, and the technology-side perspective, addressing system design, integration, and vessel compatibility.

1.3.1 Port side

From the port perspective, the planning phase focuses on assessing the suitability of the port infrastructure to host megawatt-class charging systems and identifying the key constraints that may affect installation and operation.

One of the primary aspects to be evaluated is the availability and proximity of electrical infrastructure. Ports must assess whether sufficient grid capacity is available at or near the intended installation location and whether existing substations or delivery points can support the additional load. The distance between the electrical connection point and the berth is a critical factor, as it directly influences cable routing complexity, installation costs and electrical losses.

Another key consideration is the availability of suitable physical space for installing the charging infrastructure. This includes space for power conversion equipment, the ACD, auxiliary systems and required safety clearance zones. In many ports, space constraints at quay level may limit installation options, requiring compact or modular solutions.

The structural characteristics of the berth must also be evaluated to ensure that it can support the mechanical loads associated with the charging system. This includes assessing quay load capacity, existing infrastructure constraints and potential need for reinforcement or adaptation. In environments with significant tidal variations or vessel movement, alternative solutions such as floating pontoons or adaptable mounting structures may be required to ensure proper alignment between shore and vessel interfaces.

Operational aspects are equally important during the planning phase. Ports must analyse:

- The expected number of users and potential demand for charging services
- The operational profile of vessels, including frequency of calls and berthing times.
- The temporal distribution of vessel arrivals, which may impact peak power demand.

These elements are essential to determine whether the installation of megawatt-class charging infrastructure is justified and to define the required system capacity.

Finally, ports must consider accessibility and constructability conditions, including:

- Availability of construction areas
- Access for heavy equipment and installation activities



- Integration with existing port operations without disrupting ongoing activities.

The experience from the HYPOBATT demonstration highlighted the importance of early planning of logistics and installation activities, including coordination of equipment delivery and installation works, in order to avoid delays and additional costs.

Overall, the port-side planning process should result in a clear definition of feasible installation locations, infrastructure requirements, and operational constraints, providing a solid basis for the subsequent technical design phase.

1.3.2 Technology side:

During the planning phase, the integration of the shore-side charging infrastructure and the ACD requires early coordination between the charging infrastructure provider, vessel integrator, and port authority. Several technical aspects must be evaluated during this stage including grid capacity, berth geometry, vessel charging interface position, and operational constraints.

Load modelling and energy demand analysis are necessary to determine the required charging capacity. In the HYPOBATT demonstrator case, the charging system was designed to support megawatt-class charging operations enabling rapid charging during short ferry turnaround times. The system architecture allows scalable power configurations depending on grid availability and vessel energy demand. Electrical planning shall confirm compatibility between grid infrastructure, power conversion equipment, and the interface specification. Early coordination between port authority, grid operator, and charging infrastructure provider reduces implementation risk.

The planning phase also includes definition of the installation location for the ACD system, structural mounting requirements, and safety clearance zones required for operation and maintenance. In addition, several technical assessments should be carried out to ensure that the charging infrastructure is correctly dimensioned and compatible with both the port electrical network and the vessel energy systems. In particular, the following aspects should be addressed during the planning stage:

- Preliminary grid impact study
- Load modelling
- Technical sizing methodology
- Modular architecture selection
- Vessel readiness assessment
- Retrofit feasibility considerations

Vessels intended for charging should be made compatible with MCS, if they are not so already. This requires installation of an EVCC and aligning the system behaviour with the MCS standard.



Additionally, the electrical installation should be aligned with the MCS requirements. This includes the voltage range, power ratings, EMC, earthing system and overall system design.

The developed connection system should not only be configured to charge one battery system or the another but shall carry the relative one or two independents new "Low-Level Communication" signals "CE" and "ID" with the relative features. Being signals totally independent from the High-Level Communication ones.

The MCS voltage range is relatively wide and should therefore already cater a lot of existing vessels. The same holds for the power ratings. The system design might not always directly be feasible for MCS. This encompasses the short circuit ratings and touch safety requirements, to name a few. Addressing these topics accurately can be a costly exercise but should not require a system refit from the ground up. For vessels which are currently powered by a combustion engine, a refit could immediately be made to comply with the MCS-standard, making use of the most recent knowledge.

1.4 Design and Implementation Phase

Following the planning phase, the design and implementation phase translates the defined requirements into a fully operational shore-to-ship charging system. This stage includes detailed engineering, procurement, installation, system integration and commissioning activities.

This phase is critical to ensure that the charging infrastructure is safely and efficiently integrated into the port environment while maintaining compatibility with vessel systems and grid infrastructure. It requires close coordination between all stakeholders to manage technical interfaces, installation constraints and operational requirements.

As in the planning phase, activities can be structured into two complementary perspectives: the port-side implementation, focusing on infrastructure deployment and site integration, and the technology-side implementation, addressing system design, integration, and validation.

1.4.1 Port side

From the port perspective, the design and implementation phase focus on preparing the site, coordinating installation activities, and ensuring compliance with local regulations and operational constraints.

One of the main responsibilities during this phase is installation coordination. Ports must manage the sequencing of civil works, electrical installation, and mechanical integration activities, ensuring alignment between different contractors and technology providers. Proper coordination is essential to avoid delays, particularly when multiple system components are delivered and installed at different times.



Permitting management is another key aspect. All required permits must be obtained prior to installation, including those related to electrical infrastructure, civil works and port operations. This may involve coordination with local authorities, grid operators and regulatory bodies. Delays in permitting can significantly impact project timelines if not addressed early.

The port must also ensure that installation activities are carried out in compliance with harbour operational regulations, minimising disruption to ongoing port activities and ensuring safe working conditions.

The experience from the HYPOBATT demonstration highlighted the importance of careful coordination of installation logistics, including equipment delivery and availability of lifting equipment, as well as the need to adapt installation procedures to site-specific constraints such as limited space or existing infrastructure.

1.4.2 Charging infrastructure design and specification

The technical design process includes the definition of system architecture, power ratings and equipment specifications. This involves:

- Selection of appropriate power conversion technology
- Definition of electrical characteristics (voltage, current, power range)
- Specification of protection systems and safety features
- Design of modular configurations to enable scalability.

Equipment specification must ensure compatibility with both the port electrical infrastructure and the vessel interface, while also complying with applicable standards and operational requirements.

1.4.3 System integration and control architecture

Successful integration of the ACD requires early coordination between mechanical, electrical and control subsystems, as the ACD operates as the central interface between the shore-side charging infrastructure and the vessel energy system. During the design phase, a clear system architecture should be defined describing how the charging cabinet, the ACD and the vessel charging controller interact within the overall charging sequence. Particular attention should be given to the definition of communication signals, safety interlocks and activation logic to ensure that electrical power transfer is only enabled once secure mechanical engagement has been verified.

The preparation of an ICD is recommended at an early stage in order to establish a common reference for electrical interfaces, control signals and operational sequencing between subsystems supplied by different stakeholders. Close collaboration between the charging infrastructure provider, vessel integrator and port authority is essential to ensure compatibility between shore-side and onboard systems and to avoid integration issues during commissioning. Validation of communication signals and safety conditions prior to



energisation should form part of the commissioning strategy, ensuring reliable coordination between mechanical positioning and electrical activation of the charging interface.

1.4.4 Grid Integration

Grid integration of megawatt-class charging infrastructure requires both electrical compatibility with the port distribution network and accurate physical alignment between the Automatic Connecting Device and the vessel charging interface. During the design phase, the location of the electrical connection point and the positioning of the Power Cabinet relative to the berth should be carefully assessed in order to minimise cable routing complexity and reduce installation losses.

Special attention should be given to berth geometry, vessel positioning tolerances and tidal variations, as these factors directly influence the alignment requirements of the telescopic ACD mechanism. The installation layout must therefore ensure that sufficient flexibility is available to accommodate horizontal and vertical vessel movements while maintaining reliable engagement of the charging contacts. Structural compatibility of the installation area, including available space and mounting conditions, should also be verified prior to installation.

Experience from the Frisia demonstration site in Norddeich showed that practical constraints such as limited quay space, integration with existing electrical infrastructure and the need for precise alignment between the ACD and the vessel interface can significantly influence installation procedures. Close coordination with the port authority was required to ensure compliance with harbor operational regulations and safe execution of installation activities. Iterative alignment checks and commissioning procedures proved essential to validate mechanical engagement, safety interlock signals and electrical integration between the ACD system and the DC charging cabinet before the system entered operational service.

1.4.5 Onboard integration and interface validation

The onboard integration should first focus on the mechanical implementation of the charging interface. This will be relatively easy for new-build vessels but can be hard for existing vessels. This was also found during the HYPOBATT demonstration, where significant effort was needed to mount the shipside interface to the existing vessel.

The focus should then shift to the software layer and the safety of the electrical system. Protections should be in place according to the MCS protocols, such that the system behaviour is accurate and predictable. In general, electrical systems do not need to change enormously to be ready for MCS, however the charging principle assumes a certain baseline. Focus points should be the EMC levels of the system and the touch safety limits under MCS. Additionally, short circuit levels of the vessel should match the standard to comply.

Validation of the interface from the vessel can be done on software level using accurate shore charger simulators for communicating with the vessel's EVCC. System leakage capacitance, which determines the touch energy, can be measured using existing devices such as the



insulation monitoring device. Finally, short circuit levels can be calculated or evaluated through simulation.

1.5 Operation and Monitoring Phase

The operation and monitoring phase ensures the safe, reliable, and efficient functioning of the shore-to-ship charging system over its lifetime. This phase is critical not only for day-to-day operation, but also for validating system performance, optimising energy usage and supporting long-term scalability.

A structured operational framework must be established, combining real-time monitoring, preventive maintenance, and performance assessment. Continuous data collection and analysis enable early detection of faults, optimisation of charging strategies and informed decision-making for future deployments.

The operation phase involves coordinated actions between port operators, technology providers and vessel operators, each contributing to system supervision, maintenance, and performance evaluation.

1.5.1 Port side

From the port perspective, operation focuses on the day-to-day management of the charging system, including energy monitoring, operational supervision, and coordination with technology providers.

Daily operation requires the establishment of monitoring routines and operational procedures, including:

- Scheduling of charging operations in line with vessel arrivals
- Monitoring of energy consumption and power demand
- Forecasting of energy costs and optimisation of electricity usage

Energy consumption data should be continuously recorded and analysed. The tracking of consumption profiles enables:

- Economic evaluation of the system
- Optimisation of charging strategies
- Support for reporting and certification processes

The experience from the HYPOBATT demonstration shows that local operational autonomy, supported by trained personnel and clear procedures, is essential for efficient system management.

1.5.2 System operation and monitoring

During the operational phase the ACD operates as a controlled interface between the shore charging system and the vessel. The engagement sequence is managed through a



deterministic control logic ensuring that mechanical engagement occurs prior to electrical energization.

The system continuously monitors mechanical position sensors, electrical safety interlocks, and communication signals between the charging system and the vessel control system. This ensures that charging power is only transferred when all operational safety conditions are satisfied.

Operational monitoring includes diagnostics of contact engagement, electrical current transfer, and system status signals. These monitoring capabilities support preventive maintenance and enable early detection of potential faults.

1.5.3 Maintenance and diagnostics

Preventive maintenance is essential to ensure long-term system reliability and performance. Maintenance strategies should be based on both scheduled interventions and condition-based monitoring.

Key elements include:

- Regular inspection of electrical components and connections
- Verification of protection systems and safety devices
- Maintenance of power conversion equipment
- Diagnostics of system performance and fault conditions

A structured diagnostics framework should be implemented to:

- Identify and classify faults
- Support troubleshooting and corrective actions
- Provide feedback for system optimisation

Remote diagnostics capabilities can further improve response times and reduce operational disruptions.

1.5.4 Onboard monitoring and performance assessment

On the vessel side, it is important to monitor the battery during charging, to ensure compliance with the battery ratings. Battery temperatures should be monitored closely as well, such that immediate action is possible in case of overheating.

Although the vessel dictates its limits, it is possible that system limits are not well set for vessels which were only recently converted to MCS charging. This could lead to accelerated aging of the batteries. Over time, the State of Health (SoH) of the batteries should be monitored to evaluate the impact of the charging sequence on the battery health.

Connection devices need to be regularly inspected on damages and contact wear and tear.



On a higher level, monitoring of parameters such as the State of Charge (SoC) and vessel power demand could be used to evaluate the impact of the fast-charging solution on the operational performance of the vessel. This data can be used to optimize the schedule of the vessel or to update the requirements for similar vessels. For example, a battery which is never fully discharged because the charger is available more often could result in lower battery capacity requirements for sister vessels.

1.6 Replication and Scale-Up Phase

The HYPOBATT charging interface has been developed with scalability and replicability as core design principles. The ACD–Ship Interface system is conceived as a modular and standardised infrastructure component that can be deployed progressively across different port environments and vessel applications.

The replication approach is based on maintaining the core standardised elements of the system—namely the telescopic mechanism, electrical contacting interface, and safety architecture—while adapting only site-specific components such as structural integration and grid connection interfaces. This approach significantly reduces engineering variability and enables predictable implementation timelines.

- Scaling of the HYPOBATT concept can be achieved through a phased and structured deployment model:
- Single berth deployment, targeting specific use cases (e.g. pilot ferry routes)
- Multi-berth installation within a single port, enabling increased utilisation and operational flexibility
- Fleet-level standardisation, where multiple vessels are equipped with compatible interfaces
- Multi-port corridor deployment, supporting regional or transnational zero-emission maritime corridors

This progressive scaling pathway enables gradual investment while reducing technical and operational risks.

1.6.1 Replication roadmap and deployment model

From the port authority perspective, replication requires a structured roadmap that aligns infrastructure deployment with demand evolution, regulatory requirements and business viability.

A phased deployment model should be adopted, allowing ports to:

- Start with pilot-scale installations
- Validate operational performance and user acceptance
- Gradually expand infrastructure based on demand growth
- Reduce upfront investment risks while enabling learning-by-doing.



Replication must also be supported by a clear business case evolution, as highlighted in D6.5 on business models. Initial deployments may rely on public funding or innovation support mechanisms and pilot-based operational models. As utilisation increases, the business model can transition towards more sustainable configurations, including:

- Charging-as-a-service models
- Energy supply contracts with vessel operators
- Integrated energy management solutions

According to the analysis developed in D6.5, scalable business models are strongly linked to utilisation rates, energy pricing structures and infrastructure sharing mechanisms, which improve economic viability as deployment expands.

A replication model should therefore consider:

- Demand aggregation across multiple users
- Standardisation of interfaces to reduce costs
- Interoperability across ports and vessels

This ensures that infrastructure investments are aligned with long-term market uptake.

1.6.2 Standardisation and interoperability as enablers

Standardization of the mechanical interface and control logic reduces engineering variability and supports predictable implementation timelines. The modular architecture allows integration into different infrastructure models, including direct equipment deployment or long-term service-based arrangements, without altering the core technical concept. These characteristics enable the HYPOBATT charging concept to be replicated across ferry terminals and maritime electrification corridors supporting the transition toward zero-emission ferry operations.

1.6.3 Replication potential and future outlook

The HYPOBATT concept is particularly well suited for replication in:

- Ferry terminals with high-frequency operations
- Short-sea shipping routes
- Port service vessels with predictable duty cycles

Its modular and scalable design enables deployment across different port typologies, supporting the development of zero-emission maritime corridors by combining standardised technology, phased deployment strategies and scalable business models.



1.7 Risk Management and Mitigation

The deployment, replication and scale-up of automated megawatt-class shore-to-ship charging systems involve a range of technical, operational, economic and regulatory risks. Early identification and structured management of these risks is essential to ensure successful implementation and to minimise delays, cost overruns and performance issues.

The following table summarises the main risks identified, together with their potential impact and recommended mitigation measures.

Table 3 - Identified Risks Summary - Source: Fundació Valenciaport

Risk Category	Risk Description	Probability	Impact	Potential Consequences	Mitigation Measures
Technical – Grid Capacity	Insufficient electrical capacity at port or terminal level	Medium	High	Inability to operate at required power levels; project delays due to grid reinforcement needs	Early grid assessment; coordination with grid operator; integration of energy storage systems; phased power deployment
Technical – Power Quality	Harmonics, flicker or grid instability caused by high-power charging	Medium	High	Impact on port electrical systems; non-compliance with grid requirements	Perform detailed electrical studies (harmonics, short-circuit, flicker); install filtering and compensation systems
Technical – System Integration	Incompatibility between shore system, ACD and vessel interface	Medium	High	Delays in commissioning; operational failures	Develop an ICD; early integration testing; standardisation of interfaces (MCS alignment)



Technical – Mechanical Alignment	Misalignment between ACD and vessel interface due to berth conditions	Medium	Medium	Failed connections; increased wear; operational delays	Design for tolerances; use telescopic/flexible systems; adapt installation (pontoon, adjustable mounting)
Operational – Lack of Suitable Use Case	Absence of vessels with appropriate operational profile (frequency, dwell time)	Medium	High	Low utilisation of infrastructure; poor business case	Pre-identify users; align with vessel operators; target high-frequency routes (ferries, service vessels)
Operational – Downtime and Reliability	Failure of charging system affecting availability	Low–Medium	High	Disruption of vessel operations; loss of confidence in system	Preventive maintenance; redundancy in critical components; remote monitoring and diagnostics
Operational – Installation Constraints	Limited space or complex installation conditions at quay	Medium	Medium	Increased CAPEX; delays in installation	Early site assessment; modular/compact design; optimised layout planning
Regulatory – Permitting Delays	Delays in obtaining permits or approvals	Medium	High	Project delays; cost overruns	Early engagement with authorities; clear compliance strategy; alignment with existing regulations (LV/MV, safety)
Regulatory – Lack of Standards	Immature regulatory framework for high-power DC maritime charging	Medium	Medium	Uncertainty in design and certification	Align with emerging standards (MCS); involve classification bodies early; adopt best practices
Economic – Low Utilisation	Insufficient demand to justify investment	Medium	High	Long payback period; financial non-viability	Demand aggregation; phased deployment; flexible business models (CaaS)



Economic – High CAPEX	High upfront investment for infrastructure and grid connection	High	Medium–High	Barrier to deployment	Public funding support; modular deployment; reuse of existing infrastructure (e.g. OPS integration)
Organisational – Stakeholder Misalignment	Lack of coordination between port, grid operator, vessel operator and technology providers	Medium	High	Delays, integration issues, unclear responsibilities	Establish governance structure; define roles/responsibilities; regular coordination meetings
Organisational – Lack of Skilled Personnel	Insufficient training for operation and maintenance	Medium	Medium	Operational errors; safety risks	Develop training programmes; provide operational guidelines; ensure technical support availability
Safety – Electrical Risks	High-voltage DC hazards during operation	Low	High	Safety incidents; system shutdown	Implement safety interlocks; compliance with standards; emergency procedures; safety training
Cybersecurity	Vulnerability of communication systems and remote control interfaces	Low–Medium	Medium	System disruption; data breaches	Secure communication protocols; network segmentation; access control policies



1.8 Lessons Learned and Good Practices

This section offers a synopsis of the fundamental lessons garnered during the developmental process and demonstration of the HYPOBATT solution, accompanied by the identification of best practices. These insights are intended to support future implementations by highlighting effective strategies and identifying challenges to be avoided. The objective of this initiative is to promote knowledge transfer and enhance decision-making processes, with the aim of replicating these practices in other ports.

Technical and integration aspects

- Vertical adaptability must be considered to account for tidal variations and vessel movement, particularly in ports with significant tidal ranges.
- Locating electrical infrastructure close to the charging interface (ACD) significantly reduces cable routing complexity and installation efforts.
- Mechanical integration is highly site-specific, requiring early assessment of berth conditions and potential need for customized mounting solutions (e.g. pontoons or adapted structures).
- Separation between mechanical interface and power conversion enhances modularity and facilitates integration in different port configurations.

Installation and implementation

- Early planning of installation logistics is essential, including synchronization of equipment delivery and installation activities to avoid delays and additional costs.
- Space constraints at quay level can represent a major challenge, requiring careful layout design and coordination with port authorities.
- Adaptability of the installation concept (e.g. fixed vs mobile solutions) can improve deployment flexibility under different port conditions.

Vessel Integration, Operational and Organizational Aspects

- The integration of onboard systems is a more intricate process for retrofitted vessels in comparison to newly constructed vessels. This complexity necessitates a greater investment of effort to ensure the seamless integration of mechanical components and control systems.
- Ensuring compatibility between vessels and shore-side systems is imperative. This encompasses alignment of electrical configurations, physical interfaces, and communication protocols.
- The absence of standardized charging solutions contributes to increased integration complexity, underscoring the significance of emerging standards to ensure interoperability.
- Early and continuous coordination between stakeholders is critical, involving port authorities, vessel operators, grid operators, and technology providers throughout the project lifecycle.



- It is imperative to establish a clear delineation of roles and responsibilities, including charging operations, safety procedures, and system control, to ensure safe and efficient operations.
- The availability of trained personnel is a critical factor in ensuring the reliable operation and maintenance of systems.
- The implementation of structured interface management and governance frameworks, such as Interface Control Documents, has been demonstrated to result in a substantial reduction in integration risks and an enhancement in coordination between subsystems.

Replication and scalability

- Replication potential strongly depends on operational profiles, particularly the presence of vessels with regular routes and sufficient port stay time.
- Phased deployment strategies reduce investment risks, allowing gradual scaling based on demand growth.
- Standardization and interoperability are key enablers for reducing costs and facilitating large-scale deployment.
- Alignment between infrastructure deployment and vessel electrification is essential, requiring coordinated investment decisions between ports and operators.

A comprehensive review of the extant literature reveals that the successful deployment of megawatt-class charging infrastructure is contingent not only on technical readiness, but also on early planning, stakeholder coordination, and alignment between port infrastructure and vessel operations.

- Early stakeholder engagement workshops
- Pilot-based validation before scaling
- Modular system design
- Integration with port energy strategies
- Use of standardized interfaces

1.9 Replication Checklist

In this section a practical checklist is provided to support stakeholders in assessing their readiness for the deployment of charging infrastructure. It compiles the key aspects to be considered across the different phases, from planning to operation and scale-up. The checklist is intended as a user-friendly tool to guide implementation and ensure that critical elements are not overlooked.

Table 4 - Checklist Mandatory Elements - Source: Fundació Valenciaport



Mandatory Elements	Done / Pending
Planning Checklist	
• Charging demand and suitable vessel profiles identified	
• Port space and infrastructure availability assessed	
• Preliminary grid capacity and regulatory requirements identified	
• Initial business case and funding options considered	
• Alignment with port energy strategy ensured	
• Scalability potential preliminarily assessed	
Implementation Checklist	
• Technical design validated (power, interfaces, concept)	
• Compatibility between vessel and shore systems ensured	
• Grid connection secured	
• Permits and regulatory compliance achieved	
• Equipment layout and installation planning defined	
• Safety procedures and roles/responsibilities established	
Operation and Monitoring Checklist	
• Charging operations and procedures defined	
• Monitoring and data collection systems in place	
• Maintenance strategy established	
• System performance evaluated (KPIs)	

Table 5 - Checklist Recommended Elements - Source: Fundación Valenciaport

Recommended Elements	Done / Pending
Planning Checklist	
• Decarbonisation objectives defined	
• Key stakeholders engaged	
• Alignment with port energy strategy ensured	
• Scalability potential preliminarily assessed	
Implementation Checklist	
• Modular and scalable design principles considered	
• Use of standardized interfaces and protocols ensured	
Operation and Monitoring Checklist	
• Operational data collected to support future replication	
• Lessons learned documented.	

1.10 Final Remarks

The deployment of automated megawatt-class shore-to-ship charging systems represents a key enabler for the decarbonisation of short-distance maritime transport. The experience



gathered demonstrates that high-power, automated charging is technically feasible and operationally viable under appropriate port and vessel conditions.

This handbook provides a structured framework to support the replication and scale-up of such systems, integrating technical, operational, organisational and regulatory aspects. It highlights that successful deployment depends not only on technology readiness, but primarily on the alignment of key factors such as grid capacity, suitable operational use cases, stakeholder coordination and economic viability.

The modular and standardised architecture of the HYPOBATT concept enables flexible integration and phased deployment, allowing ports to start with pilot installations and scale infrastructure progressively as demand grows. In this context, standardisation and interoperability—particularly through alignment with emerging frameworks such as the Megawatt Charging System (MCS)—will be critical to reducing costs and facilitating large-scale adoption.

Looking ahead, the replication of high-power charging systems will require coordinated action between ports, vessel operators, technology providers and grid operators. When aligned, these systems can support the electrification of ferry routes, port service vessels and the development of zero-emission maritime corridors.

The HYPOBATT solution provides both a validated technological concept and a practical implementation framework, demonstrating that automated megawatt-class charging infrastructure can play a significant role in the transition towards sustainable maritime transport.



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