HYPOBATT

Hyper powered vessel battery charging system

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Project Coordinator	Endika Bilbao | IKE | ebilbao@ikerlan.es
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CONTRIBUTORS AND FORMAL REVIEWERS

	Name | Organisation	Date
Document Manager	A. Maccari, D. Melissinos, E. Morea | RINA	2026-01-28
Contributor 1	T. Gerrits | HELIOX	2026-03-13
Contributor 2	P. Grippi | STT	2026-03-05
Contributor 3	P. Rampen | DAMEN	2026-03-17
Internal Reviewer 1	RSTER	2026-03-18
Internal Reviewer 2	SOERMAR	2026-03-18
External Reviewer 1	FRISIA	2026-03-19
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LIST OF ABBREVIATIONS, ACRONYMS AND DEFINITIONS

Abbreviation	Word
ACD	Automated Connection Device
AMCS	Alarm Monitoring and Control System
BESS	Battery Energy Storage Systems
BMS	Battery Management System
CCS	Combined Charging System
CPO	Charge Point Operator
DC	Direct Current
DT	Digital Twin
EMC/I	Electro-Magnetic Compatibility/Interference
EMS	Energy Management System
ESS	Energy Storage System
EV	Electric Vehicle
EVCC	EV Comm. & Control.
EVSE	EV Supply Equipment
EU	European Union
GFD	Ground Fault Detection
HPC	High-Power Charging
HVSC	High Voltage Shore Connection
ICP	In-rush Current Protection
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMD	Insulation Monitoring Device
IP	Ingress Protection
ISO	International Organization for Standardization
IT	Isolated Terra
LVDC	Low voltage DC
LVSC	Low-voltage shore connection
MCS	Megawatt Charging System
OPS	Onshore power supply
OVP	Over-Voltage Protection
PC	Power Cabinet
PCM	Power Conversion Module
PE	Protected Earth
RCD	Residual-Current Detection
SBC	Shore-side Battery Charging
SECC	Supply Equipment Communication Controller
SoC	State Of Charge
SPE	Single Pair Ethernet
SSE	Shore-Side Electricity
UPS	Uninterruptable Power Supply

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1. EXECUTIVE SUMMARY

This deliverable provides draft regulatory and standardization recommendations to enable the safe, reliable and scalable deployment of hyper-power shore-side battery charging (SBC) for electric and hybrid vessels, based on the technical solutions developed and validated within HYPOBATT.

Building on the regulatory baseline established in D7.1, the consortium confirmed that while the standards framework for OPS is comparatively mature, SBC still faces material gaps in prescriptive requirements, operational references and interoperability guidance. To ensure traceability and maintain development progress without compromising safety, WP7 established a dedicated Task 7.2 Logbook, used to systematically record each encountered gap, the standards consulted and the solution proposed by technology partners.

D7.2 then analyses the Logbook item by item, translating project-specific resolutions into structured recommendations spanning: (i) ship–port communications and minimum data exchange, (ii) operational procedures and responsibility allocation (including charging initiation), (iii) automation safety controls for the automated connector device, and (iv) MW-scale electrical safety topics such as insulation coordination, earthing/corrosion countermeasures, PE continuity, EMC and voltage-range extensions. Where evidence is still pending, the deliverable explicitly identifies validation needs and the role of demonstration testing in confirming final requirements.

Finally, D7.2 defines a practical route to ensure impact beyond the project scope, looping HYPOBATT outcomes back to EMSA guidance and onward to Standards Developing Organisations (SDOs). Operational good practices can be adopted quickly by ports and operators, while technical gaps requiring prescriptive limits and test methods are progressed through formal standardisation channels to support broader market uptake of hyper-power maritime charging.

2. OBJECTIVES

- Consolidate the regulatory baseline and gaps identified in HYPOBATT, building on D7.1, and frame the implications for hyper-power shore-side battery charging (SBC).
- Formulate draft regulatory and standardization recommendations that support safe, reliable and feasible design, approval, commissioning and operation.
- Provide a pathway beyond the project scope, outlining how HYPOBATT outcomes can be fed back into EMSA guidance and progressed through relevant Standards Developing Organisations (SDOs) to support wider market uptake.

3. INTRODUCTION

Improving the environmental performance of maritime transport has long been considered a priority and can be achieved through a variety of possible solutions, such as optimizing operational management (e.g., weather routing, speed reduction), reducing fuel consumption through technical solutions such as air lubrication, new types of propellers, hull modifications, etc. Particular attention is also paid to the use of low- or zero-emission fuels as well as battery-powered electric propulsion.

The choice to renew the fleet through the construction of new ships (or the retrofitting of existing ones) by adopting green fuels (such as hydrogen or ammonia) or opting for battery-powered ships is certainly favoured by the availability of adequate shore-side refuelling infrastructure and appropriate standards and regulations.

The lack of such infrastructure can delay the use of onboard innovations (e.g. in the case of dual-fuel ships that can continue to use traditional fuel while waiting for the availability of the new type of refuelling), lead to a review of the fleet's operational management (with potential cost increases or reductions in the services offered) to plan to call at the best-equipped ports, and delay the return on investments.

Standards and regulations, where they exist, allow demonstrating that innovative solutions are safe and fit for purpose by referring to consolidated requirements, and this favours the diffusion of innovative technologies on the market.

HYPOBATT took care of the two above mentioned aspects:

1) developing a battery charging system that allows for an upgrade of the infrastructure serving the refuelling of battery-powered electric vessels;
2) assessing the adequacy of existing standards and regulations to provide adequate requirements to be adopted in the development of such a system and addressing the gaps identified (represented in deliverable D7.1), in order to develop reliable and safe technologies even in the presence of a lack of reference requirements.

This deliverable represents the result of the activities carried out in the project and related to item 2) above, laying the foundations for a subsequent possible upgrade of the regulatory framework which could allow widespread adoption of the technologies developed in HYPOBATT.

4. REGULATORY ASSESSMENT

This section consolidates the regulatory baseline established in the initial regulatory assessment of the project and the gaps explicitly identified there. The assessment framed the topic as Shore-Side Battery Charging (SBC) for electric/hybrid vessels distinct from "cold ironing" (OPS) because SBC requires control of the battery charging process and communication between ship and shore. In contrast with OPS solutions, SBC solutions are often case specific and lack mature interoperability standards.

The regulatory assessment's main objective was to map the current regulatory framework (regulations/codes/rules/industry standards) applicable to hyper-power ship-to-shore power connections and clarify what is already prescriptive or available as consolidated best practice. Where adequate references/requirements are not available (the "gaps"), developers must still pursue ensuring safe and reliable systems; this can be done through project-specific engineering justification, also verifying the adequacy of similar solutions implemented in other industrial sectors, supported by the technical partners' knowledge and evidence generated through manufacturing, integration, and testing activities. The scope included physical connections, hardware, operating procedures and related controls across all phases: ship-shore set-up, plug-in, plug-out and by implication charging operation and monitoring in between.

4.1 Macro Breakdown

A practical shore vs ship split was adopted to clarify where different authorities apply port standards ashore vs IMO/class/statutory rules onboard.

Table 1: Macro Breakdown of Applicable framework.

Domain	Main Elements
Shore	Shoreside power sources; port grid installations; infrastructure & equipment (T&D, substations, switchboards, circuit breakers, transformers, converters, etc.); (in OPS context: HVSC shoreside sources).
Ship	Ship-shore grid interface; receiving ship network; plug-in of full electric & hybrid ships; battery management system; ship essential services; (in OPS context: HVSC / LVSC); for SBC: AC shore-ship charging interface, charging connection equipment, berth modules, ship-shore data exchange; DC charging context.

This split is important for HYPOBATT because the charger location (onboard vs ashore) drives which parts of the regulatory framework apply (classification/statutory) for ship systems, whereas for shore installations other standards apply. The initial regulatory assessment anchored its legislative mapping in the EMSA Shore-Side Electricity guidance, then summarized key international layers:

- **IMO layer:** IMO provisions are described as not very deterministic for this topic; references included broad SOLAS electrical installation provisions, OPS interim guidelines, Standards of Training, Certification, and Watchkeeping (STCW) competence requirements, and MARPOL Annex VI as the driver for decarbonization but not prescriptive for shore energy supply design.
- **EU layer:** EU Regulations are directly binding, while Directives require national transposition. It highlights Alternative Fuels Infrastructure Directive (AFID) 2014/94/EU and its revision under “Fit for 55” and notes the requirement to assess SSE needs and install shore-side electricity as a priority in TEN-T core ports (and other ports) by 31 Dec 2025, unless demand constraints apply.

4.2 Standards Landscape

4.2.1 Standards from maritime application

During the first phase of HYPOBATT, EMSA issued its "Shore-Side Electricity-Guidance to Port Authorities and Administrations" and it was naturally analyzed and used as the main reference, as depicted in Figure 1. Unfortunately, as it is evident from Table 2, at the time the relevant standards were not yet available or were under development, so the primary regulatory assessment explicitly reviewed also EV conductive charging standards in other sectors (automotive/heavy-duty) as a reference base, alongside marine OPS standards (IEC/IEEE 80005 series). Unlike OPS, these “transferable” inputs are used because SBC must address interconnectivity, interoperability and communications and marine SBC lacks an equivalent mature set of standards.

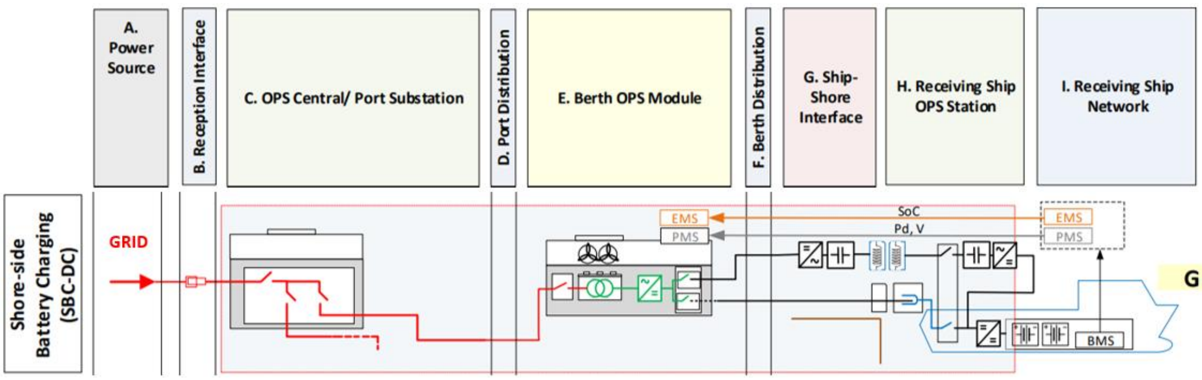

Figure 1: IEC/IEEE 80005 and EMSA definition of SBC-DC (configuration G).

Table 2: Overview of applicable standards from EMSA Guidance (green=active standard, yellow=draft standard, red=no standard).

SSE Type		Interconnectivity	Interoperability	Data Communication	International/EU Regulatory
OPS (Onshore Power Supply)	High-Voltage Shore Connection (**HVSC**)	IEC 62613-1:2016 (General) IEC 62613-2:2016 (Connector geometry/ dimensions)	IEC/IEEE 80005-1 (HVSC)	IEC/IEEE 80005-2 (Data Communication)	IMO OPS Guidelines EU AFID
	Low-Voltage Shore Connection (**LVSC**)	IEC 60309-5	IEC/IEEE 80005-3 (under review/development)	IEC/IEEE 80005-2	IMO OPS Guidelines already refer
	LVSC – Inland Waterways (IW)	EN 15869-2:2019 (up 125A) EN 16840: 2017 (above 250A)		Possible application of IEC/IEEE 80005-2	CCNR CESNI – ES-TRIN2019
	Recreational Craft/ Marinas	IEC 60309-2	Not standardized	Not standardized	Not relevant international standard applicable to
SBC (Shore-side Battery Charging)	SBC-AC (AC charging)	IEC 60309-5/ IEC 62613-2 AC connection (As standard OPS connectivity)	IEC/IEEE 80005 series As OPS – ship-side charging.	Not standardized (possible development/ applicability for IEC/IEEE 80005-2 or ISO15118)	No applicable international regulatory instrument applicable to SBC
	SBC-DC (DC Charging)	Not standardized	Not standardized		

4.2.2 Standards from automotive application

In Table 3 an overview of the relevant standards for SBC-DC charging for the automotive market are listed, where it can be seen that for both manual and automated connections a set of active standards is existing to fully certify a charging system application, consisting of a EVSE, connection device and vehicle. Numerous EVSE and electric vehicle (EV) OEMs independently develop their products for enrolment in combined commercial applications, where mutual interoperability of the different products is achieved by following the respective aspects of these standards.

Table 3: overview of automotive standards for conductive electric vehicle charging in the EU (UL equivalents existing) (green=active standard, yellow=draft standard, red=no standard).

SBC-DC types		Interconnectivity	Interoperability	Communication	Safety	
					EV-side	EVSE-side
All		IEC 61851-1	IEC 61851-21- part 1: EV part 2: EVSE	IEC 61851-24 DIN 70121 ISO 15118-2 ISO 15118-20	ISO 6469-3 ISO 5474-3 ISO 17409	IEC 61439 IEC 61140 IEC 62040 IEC 60364-7-722 IEC 61557-8
Manual	**CCS**	IEC 62196-3	IEC 61851-23	ISO 15118-3		
	MCS	IEC TS 63379	IEC 61851-23-3			
Automated	**RMP**	EN 50696	IEC 61851-23			
	IP		IEC 61851-23-1	ISO 15118-8		
	PSC		IEC 61851-27			
	UBC		IEC 61851-26		ISO TS 5474-5	

4.3 Gaps identified in D7.1

Hyper-power chargers for electric ships are still novel, and detailed comprehensive requirements are not always available. The deliverable therefore recommends a balanced approach combining:

- Existing prescriptive references
- Adapted standards from other industries
- Risk-based qualification processes

These are followed in order to capture the project lessons learned as input to this report. These following gaps are the direct "starting inventory" for this report as they explain why HYPOBATT needed a mechanism to capture real development-time gaps, mitigations and evidence.

Explicitly highlights the following gap areas:

- **Digital Twin standardization for energy management**
  There is no widely recognized standard for using digital twins as energy management systems, while noting ongoing ISO/IEC workstreams (e.g., ISO/IEC 30172/30173) and IEC smart-grid communications foundations (IEC 61850 / IEC 61970 series).

- **UL standards limitations for battery chargers at higher voltage and marine contexts**
  UL 1564 covers industrial chargers but addresses only chargers rated 600 V or less, and does not cover battery chargers for marina/boatyard/other marine applications—creating a certification reference gap for marine high-power charging equipment.

- **Vessel-to-Grid (V2G) / bidirectional applications**
  "Real standardization gap" for V2G concepts exists in the marine domain, even though operationally these could benefit ship/port operators (e.g., feeding back power when advantageous, charging at lower prices during night berthing).

- **Earthing isolation and electrical corrosion countermeasures at MW scale**
  Upscaling to the MW range will require further specific consideration to avoid different interpretations and local regulatory barriers—particularly around isolation/earthing choices and corrosion mitigation.

- **Protection against moving objects**
  No marine-related provisions were found for protections against moving objects, and that this should be considered further in the project (potentially derived from automotive standards).

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4.4 Combined applications standards landscape

It would be important to have an updated version of a standards' landscape from port grid connection up to and including electric vessel, basically merging the two.

From the aforementioned maritime and automotive standards landscapes, a combined landscape has been drafted in combination with required industrial standards to provide an overview of the intertwinement and complexity of the overall scope. This is depicted in the figure below:

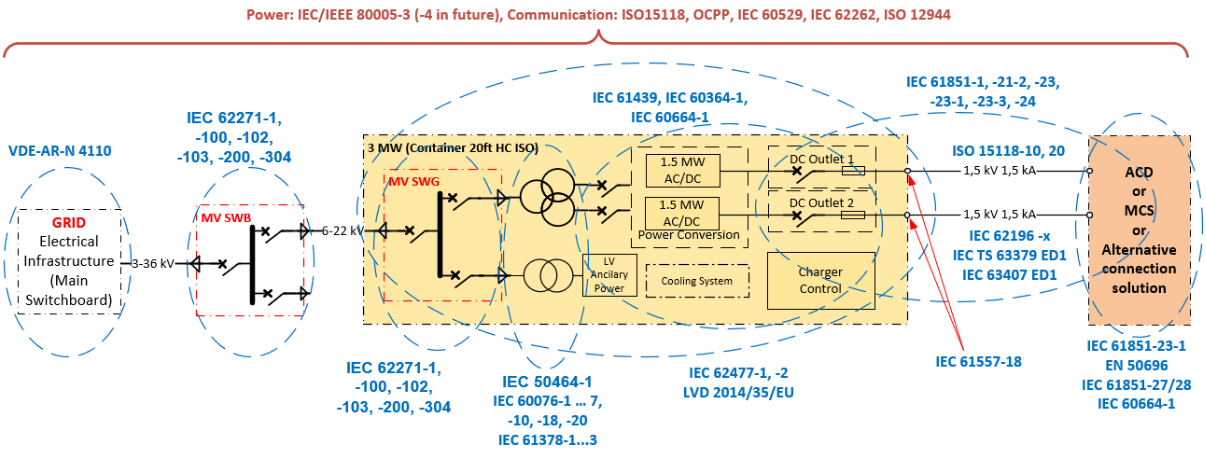

Figure 2: overview of relevant standards for SBC-DC charging in accordance with the logbook items.

5. SOLUTIONS ADOPTED IN THE DEVELOPMENT OF EQUIPMENT

During the design and development of the HYPOBATT system components, the Technology Partners systematically assessed whether regulatory requirements and technical standards established in other transport modes (notably road EV conductive charging) could be safely and appropriately transferred to the maritime context. This was necessary because the set of dedicated, mature standards for DC marine shore-to-ship battery charging remains limited, while HYPOBATT must still ensure interoperability, interconnectivity, safety, and robust communications across shore and vessel side equipment.

A key outcome of this assessment was to use the automotive Megawatt Charging System (MCS) as the primary transferable reference base to close identified gaps in the HYPOBATT SBC-DC standardization scope. In particular, D3.4 explicitly states that, to cover the gaps highlighted earlier in the project, automotive standards are used, specifically the “MCS type”. This choice also enabled the consortium to leverage ongoing standardization work led by **CharIN**, whose MCS initiative addresses plug–socket definitions, including communication, safety, and dimensions aspects and provides a concrete baseline. CharIN is the leading global association with over 300 members dedicated to promote standards in the field of charging systems for charging EVs of all types in as many parts of the world

Based on this cross-sector mapping, the HYPOBATT charging concept aligns the charging process and communications architecture with standards that are central to MCS, including:

- **IEC 61851 series** for conductive charging
- **ISO 15118-10** (Single Pair Ethernet, “SPE”, physical layer)
- **ISO 15118-20** (high-level charging communication)
- **IEC 61851-23-3** (system and safety requirements)

In the ACD final design, the partners similarly converged on a standards-aligned high-level communication approach: the design adopts Single Pair Ethernet (SPE) and explicitly links this decision to recent outcomes in MCS standardization work (including CharIN references), noting that the resulting approach improves robustness and supports multi-MW charging standardization.

The above analysis has allowed us to identify elements of standards and good practices that can be adopted, which have guided the development of HYPOBATT towards some practicable solutions.

For the topics for which no adequate regulatory requirements or suitable standards/best practices were identified, possible design or procedural solutions were identified and proposed, and subsequently discussed for the purposes of their validation as described below.

6. LOGBOOK APPROACH

During HYPOBATT development activities and especially across the technical work packages, partners encountered multiple situations where existing standards or procedural references were missing, incomplete, or not directly applicable to the innovative solutions being developed. To avoid spontaneous decisions and to ensure traceability, the consortium established a dedicated toll (Task 7.2 Logbook) as the central instrument to (i) record each gap, (ii) capture the proposed solution, and (iii) document RINA's assessment and recommendations, in view of converting these into structured regulatory/standardization recommendations in D7.2.

6.1 Methodology

The Logbook was created to provide a controlled mechanism to manage standardization and regulatory gaps encountered during development, ensuring that:

- All gap situations are recorded in a consistent way
- Technical partners can propose viable solutions to continue design/testing while maintaining safety and reliability.
- RINA can perform a classification/certification-oriented review, express an opinion, and add recommendations (e.g., extra evidence, tests, constraints).
- The project builds an evidence base that can later be transformed into draft regulatory recommendations / best practices / standardization proposals.

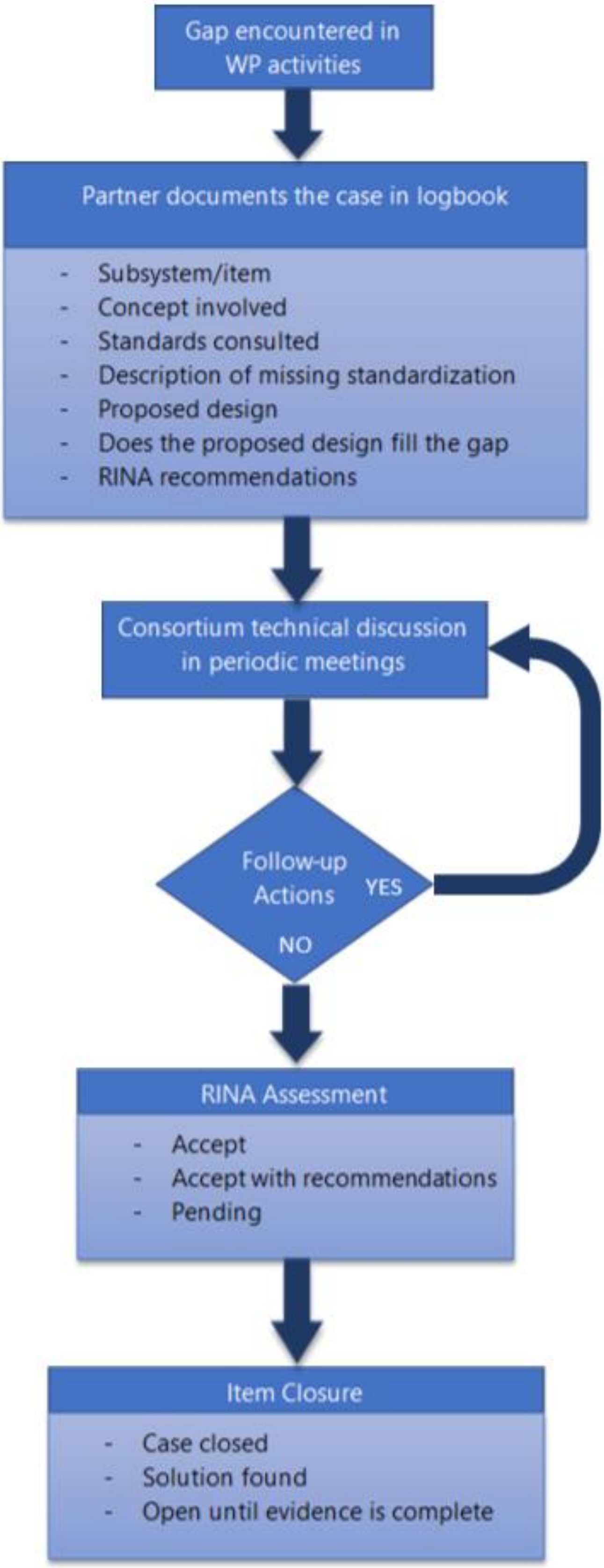

Figure 3: Logbook entries methodology flowchart.

6.2 Logbook Items

For the purpose of this deliverable the Logbook is treated as a case register, each item number is a distinct "case" that becomes a dedicated subsection in Section 6.2. The narrative for each item is built from the Logbook fields and additional partner input that expands the technical detail behind the recorded statements.

The key fields used are:

- **Sub-system(s) involved**
- **Concept & item involved**
- **Standards consulted**
- **Gap topic category**
- **Description of missing standardization**
- **Design approach used**
- **RINA recommendations / remarks and status**

In the Logbook, the column **"Sub-system(s) involved"** uses a numeric coding to identify which part(s) of the HYPOBATT architecture are impacted by each gap/solution. The numbering is used consistently across items to quickly locate the issue within the overall system boundary. In particular:

- **PA Cloud back-office** refers to the Port Authority's cloud/IT back-office functions (planning, scheduling, optimisation and related data services).
- **Port-side charging equipment** is split into:
    - **PC – Power Cabinet** (the main electrical power conversion/control cabinet on shore)
    - **ACD – Automated Connector Device** (the automated contacting/connection mechanism).
- **Ship interface** refers to the ship-side connection interface and associated shipboard elements needed for charging.
- **Charging System** is used when the topic affects the end-to-end charging system across all sub-systems (ship + shore + communications/procedures).

6.2.1 Item 1: Ship-Port communication + cybersecurity prior to arrival

ITEM 1	
Sub-system(s) involved	PA (Port Authority Cloud Back-Office) Ship interface
Concept & Item involved	Communication between offshore (E-Vessel captains) and onshore (Port Authorities) Items involved: Communication channels, software and interfaces
Standards Consulted	IEC 80005-2 ISO 15118
Standardization gap topic	Missing standardized guidelines on how to proceed regarding: -Initial comms channels -Cybersecurity
Description / Missing standardization / Comment	It is to be defined the technology to be used by the ship and the port to communicate prior to the physical arrival into the port.
Design approach used	Within the HYPOBATT demo a successful implementation has been proven with vessel and ship-interface detection from ACD side. However, this method is not according to above mentioned standards.
Recommendations / remarks / validation on the proposed design	- In the absence of standards, the Communication protocols are to be agreed with PAs - New IACS UR E26 and E27 (applicable from July 2024) can be consulted on requirements for ships and systems cyber security. - Proposal to follow the IEC 61851-27/28 parts and developments being conducted within. These parts cover the automatic docking and undocking functions (part 27) and outline the communication between automatic EV supply equipment and vehicles (part 28).

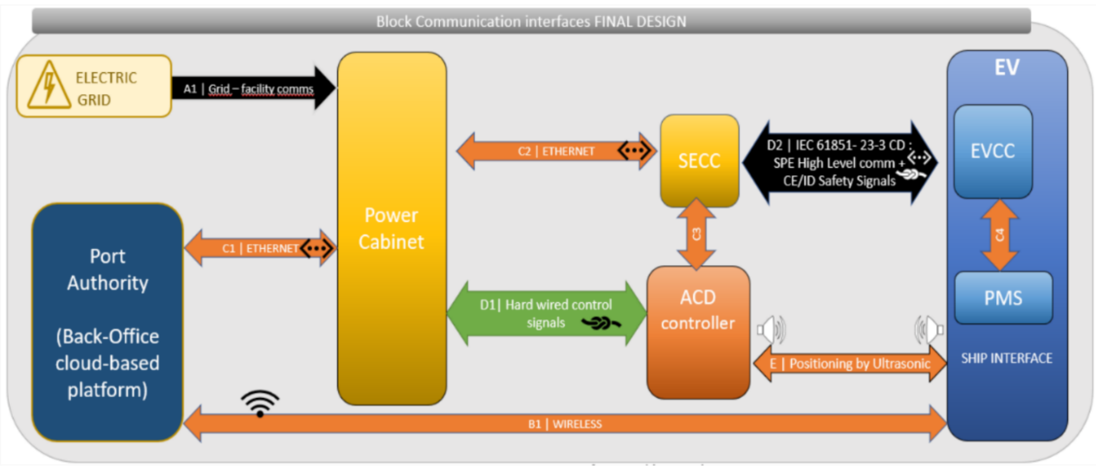

Figure 4: Communication channels block diagram.

6.2.2 Item 2: Cloud-based port software

ITEM 2	
Sub-system(s) involved	PA (Port Authority Cloud Back-Office) PC (Power Cabinet)
Concept & Item involved	Cloud-based port software to optimize the energy management of charging events
Standards Consulted	OCPP 1.6j VAS - value added services VDV261
Standardization gap topic	As for current HYPOBATT's knowledge, there is no standardized guidelines on how to proceed regarding: **-** Operational Procedure
Description / Missing standardization / Comment	Several organizations, including the Digital Twin Consortium and the Digital Energy Partnership, are working to promote the adoption of digital twins in the energy industry and to develop best practices and guidelines for their use. These efforts are expected to lead to the development of industry standards and guidelines soon. However, until now no standards are available to bolster a whole deployment of beneficial digital twins for management and improvement of Energy Systems.
Design approach used	The operational procedure has been designed and developed comprehensively
Recommendations / remarks / validation on the proposed design	Implement a "compatibility assessment" before the first connection to ensure a smooth and safe operation of the connection. VAS has no added value in this ITEM, the OCPP communication is designed and suitable for this.

6.2.3 Item 3: Data itemization & minimum requirements for charging requests (Ship ↔ Port cloud)

ITEM 3	
Sub-system(s) involved	Port Authority Cloud Back-Office PC Ship interfaces
Concept & Item involved	Data itemization & minimum requirements for enhanced digital optimizations Data itemization should include the target state of charge (e.g., 80% or 60%) and the target departure time or end-of-session time. Items involved 3: (1)PC edge-devices, (2)E-Vessel edge-devices and (3)data gateways on PA's cloud software.
Standards Consulted	IEC 80005-2 ISO 15118 IEC 61851
Standardization gap topic	As for current HYPOBATT's knowledge, there is no standardized guidelines on how to proceed regarding: -Data Itemization -Minimum requirements
Description / Missing standardization / Comment	What data should be communicated for making a charging request from the vessel to the port authority, who can then revert information to the vessel as regard of pier ID to dock, time of docking for the charging, others information to be provided to the charging user [Ship] The minimal set of data that needs to be communicated to make the systems works, nor the latency, packaging of dataset, nor nothing related has been addressed so far
Design approach used	The minimum set of data that need to be injected in order to make the three models (Grid, Charger, BESS) work has been identified, to ensure proper optimization and reliable operations from the cloud-based back office. The following stakeholders were consulted to define this comprehensive data set: DAMEN, HELIOX, FIRISA. A set of information to be provided back to the ship has also been identified.
Recommendations / remarks / validation on the proposed design	Testing of the system has given final confirmation that this methodology works and is effective. The Automotive standards ISO 15118 and IEC 61851 have been used for this and were coupled to the vessel control and power management system to assure proper operation and information exchange.

6.2.4 Item 4: Safety communications between Port Authority computing system and Power Cabinet (EVSE tunnelling via VAS)

	ITEM 4
Sub-system(s) involved	Port Authority Cloud Back-Office PC
Concept & Item involved	Port's Ethernet cable (cellular connection) or a 3/4/5G modem connection
Standards Consulted	OCPP 1.6j VAS - value added services VDV261
Standardization gap topic	As for current HYPOBATT's knowledge, there is no standardized guidelines on how to proceed regarding: -Safety communications between devices at ports
Description / Missing standardization / Comment	Communication and providence of the optimized charging profile solutions to the Power Cabinet, from the computational system at Port Authority, through Port's Ethernet cable (cellular connection)
Design approach used	When connected, the EVSE can be used to tunnel info directly from PA to EV using VAS (value added services, like preconditioning, and extended charging functions, best example of this is the VDV261). HELIOX BV proposes to use the EVSE to tunnel these variables when connected since the charging VAS provides the functionality and this makes HYPOBATT solution more strongly aligned with the charging standards. Ideally there is a strong dependency of comm to being (dis)connected. When that is the case, all communications go via the EVSE. OCPP 1.6/2.1 is used to send power profiles from the back-office to the EVSE and communicate these with the EV. More details are reported after the table (a. **Finite-State Machine overview; b. Steps procedure definition)**
Recommendations / remarks / validation on the proposed design	N/A

a. FINITE-STATE MACHINE OVERVIEW

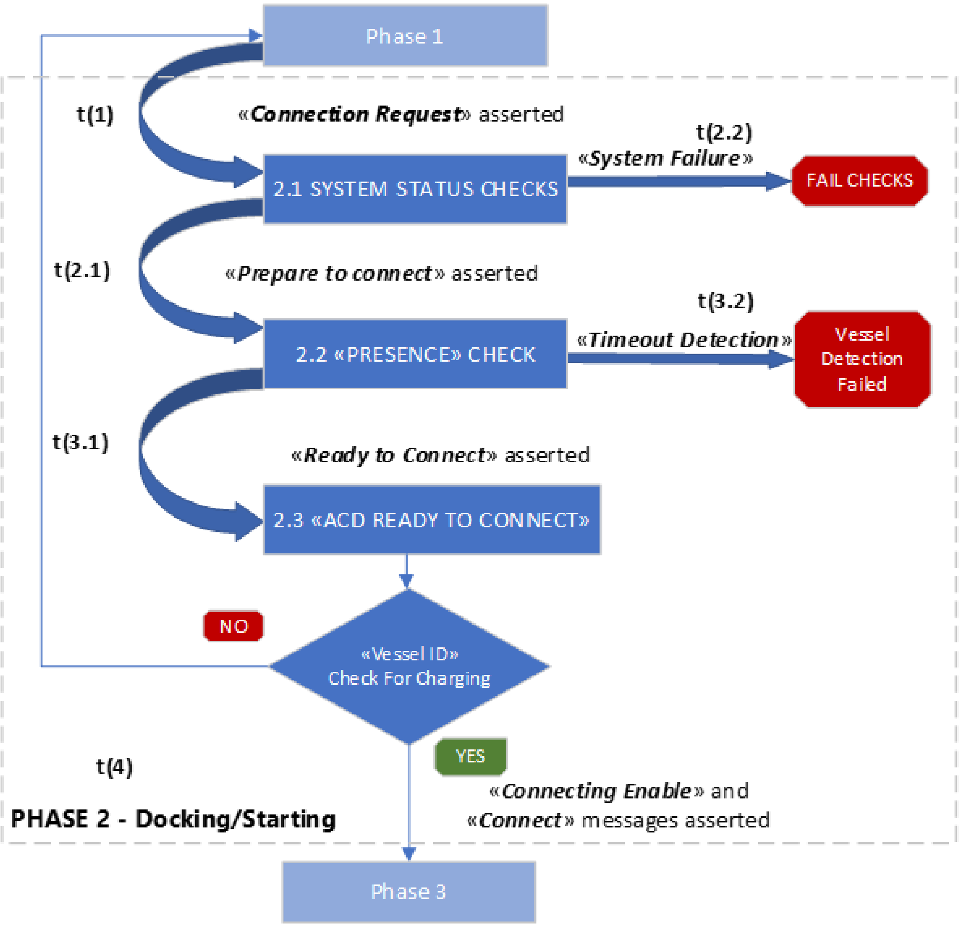

Figure 5: Phase 1 pre-connection workflow for ACD.

System clarifications for all phases with "Connecting enable" asserted

I. Communications from the EV to PA

The Initial communications for optimizing Port's charging profiles and energy usage is going to manually for FRISIA demo-case, and the EV data can be shared as wired connected. The captain will communicate through direct call the estimated SoC at arrival, forecasted time of arrival, forecasted time of departure, and required final SoC at departure.

II. E-Vessel Interface detection.

Vessel ID has not been included for HYPOBATT use-case demonstrator.

[Road to Standardization] In the future these kinds of systems could be improved by linking the positioning signal for vessel detection with the recognition of vessel's ID.

III. Initiation of sub-systems for pre-operation mode.

Signals must be sent to the auxiliary systems (as Thermal management systems and initial safety check devices) to prepare them for proper operation. In this project, this will be settled through embedded signalling at the EVSE system in order to ramp-up these systems, from the existing idle power to the optimal power levels for cooling and charging power.

IV. Procedure to trigger "connect" and "connecting" status

This goes through the utilization of an **EV Remote controller**.

This EV Remote controller will be based on a IMET Radio remote control, composed of a transmitter M880-WAVE2 and a receiver M880-LAC or LDC.

[Road to Standardization] The consortium has discussed the possibility in future to improve further these kinds of systems through setting a fully functional feature into the port authority's software (executable on the different vessels) to communicate more advanced and accurate digital messages through the cloud-based environment.

V. Emergency protections in this phase (default)

The system will be built to execute default checks for protection status. Instead, as per the presence detection, once the rolling gate is opening, the EVSE can detect the Vessel. In home-positioning will enable the same default capability. Timeout series for vessel interface connection has been framed. If not reached, the system will turn back to home-positioning for safety. The connection Failure can arise from both connection domains; electrical and/or mechanical failures.

VI. Emergency Push Button, common to all Phases with "Connecting Enable" asserted

- <u>*At the Power Cabinet:*</u>
  - This is allocated near the cabinet, in accordance with requirements
- <u>*At the Automated Connection Device:*</u>
  - 1st one allocated internally for ACD maintenance purposes
  - 2nd one allocated externally
- <u>*At the E-Vehicle:*</u>
  - This corresponds to the **EV Remote controller** mentioned above, to be used **as a centralized communication gateway** between the onshore (at the pier) and offshore (on the ship) sides.

In case the system is requested to be stopped, the sequences of the interruption will target electrical-wise disconnection actions – safely shutting down the lines and the operations into the power conversion systems – before executing the mechanical-wise disconnection actions – putting the ACD back to home-positioning.

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Table 4: Specifications of Phase 2 Docking/Starting Phase

	Nature of Communication channel	Hierarchy level (if comm. between subsystems)	Timing (s)
Action 0: The captain agrees to the connection	Comms channel B1 (Wireless)	High-level	0
Action 1: PA verifies System Status check	Comms channels C1 (Ethernet)	High-level	~0
Action 2: PA send "Prepare to Connect" or "Fail"	Comms channels C1 (Ethernet)	High-level	~0
Action 3: PC share to ACD "Prepare to Connect" or "Fail"	Comms channels C2 (Ethernet)	High-level	~5
Action 4: ACD verify the presence of the Vessel and send "OK" or "Fail"	Comms channels C2 (Ethernet)	High-level	~5
Action 5: PC share to PA the presence of the Vessel by "OK" or "Fail" + (OPTION) "Vessel ID"	Comms channels C1 (Ethernet)	High-level	~0
Action 6: PA supplies the "Connecting Enable" and send "*Connect*" message	Comms channels E (Ethernet)	High-level	~0
		Phase 2: Total time	~10

The time marked is before the "Connect" msg. Therefore, it is Not included in the 30s targeted for project's KPI achievements.

b. STEPS PROCEDURE DEFINITION

This phase consists of the following steps for the "No Fails" process.

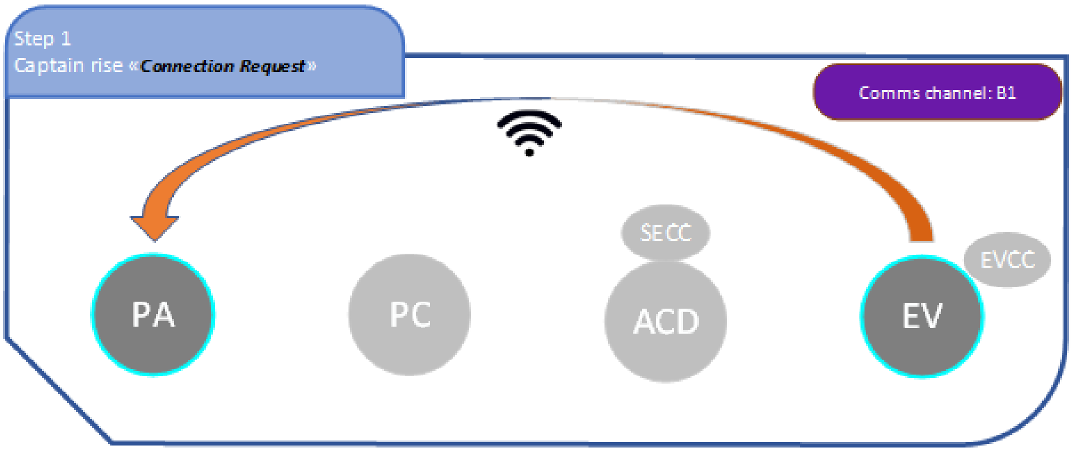

Figure 6 : Connection Request

Step 1. Being launched by the E-Vessel´s bridge of command after safety checks performed, the "***Connection Request***" will be conducted through the B1 communication channel from the EV communication interface towards the Port Authority.

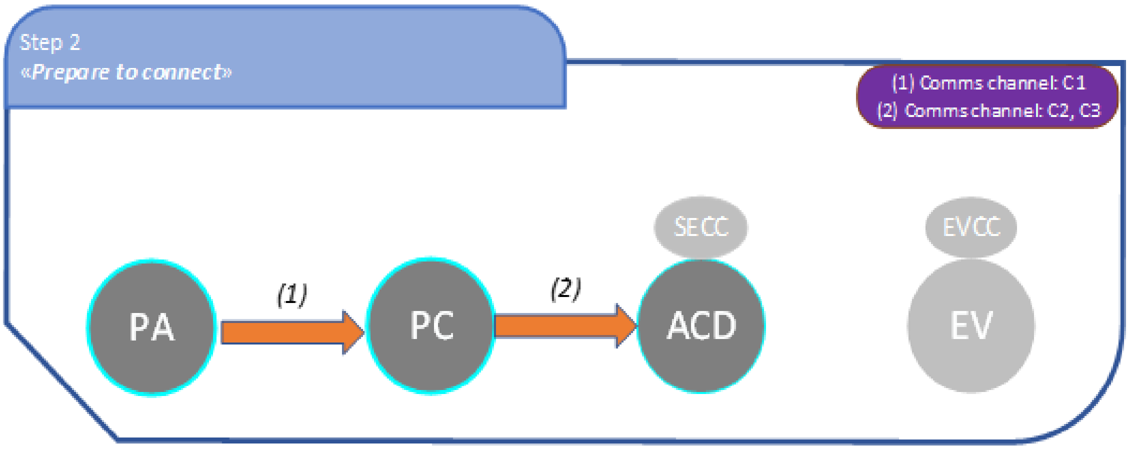

Figure 7: Prepare to connect (1)

Step 2. Being launched by the PA after safety checks performed, the "***Prepare to Connect***" will be conducted through the C1 communication channel from the PA communication interface towards the ACD by the PC forwarding (C2 and C3 interfaces). At that moment the ACD's rolling gate will be opened.

[Road to Standardization] *It is worth noting that action (1) in this diagram is bypassed at FRISIA Demonstrator and has been set as a mechanism to improve and standardized further future systems between TRLs 7 and 9.*

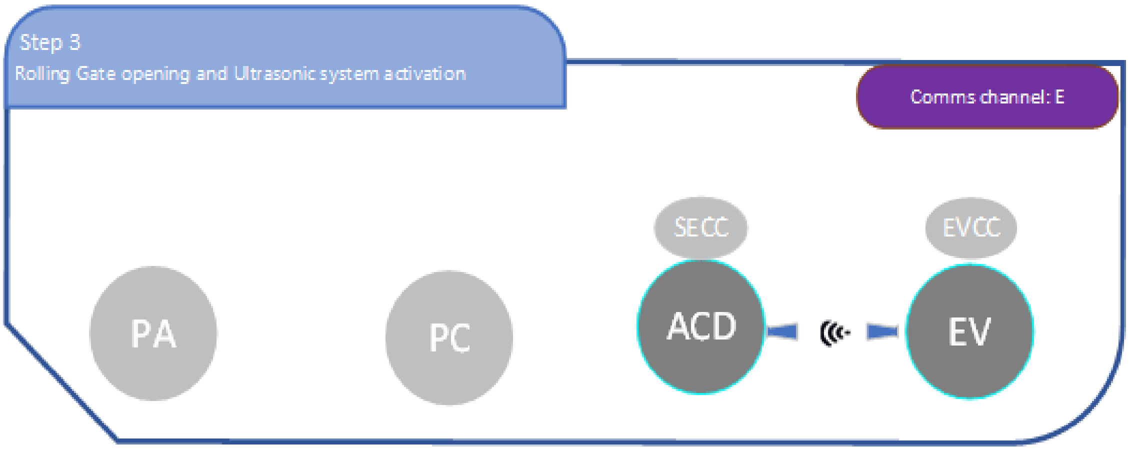

Figure 8 : Prepare to connect (2)

Step 3. The "***Prepare to Connect***" message enables the ACD to go in the vessel detecting mode (Rolling Gate opening and Ultrasonic system activation).

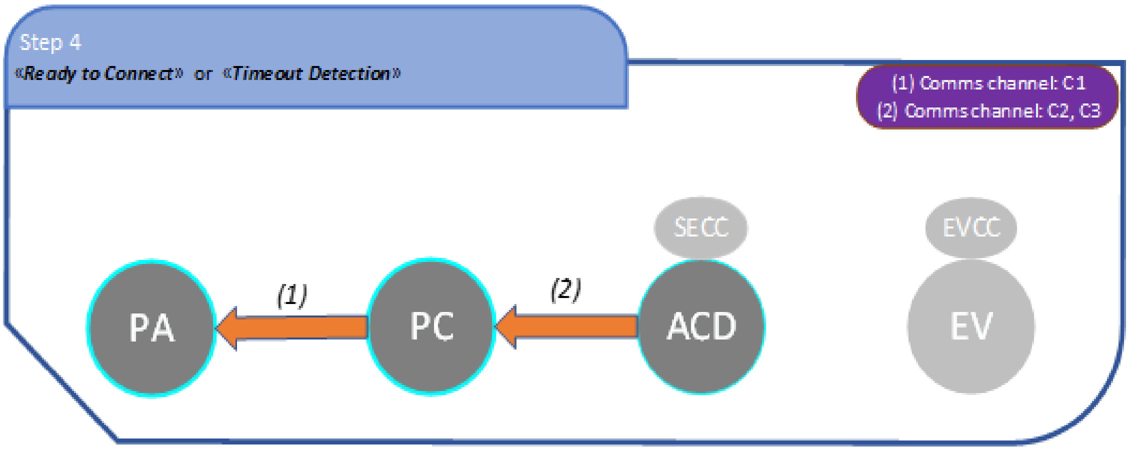

Figure 9 : Ready to connect

Step 4. The ACD provide the feedback about the interface detecting by the message "***Ready to Connect***" or the "***Timeout Connection***".

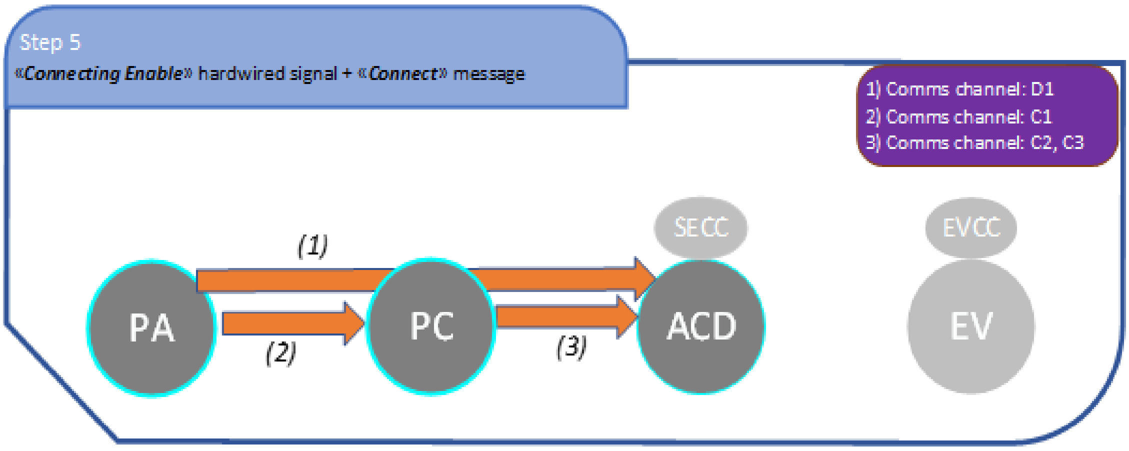

Figure 10: Connecting Enable

Step 5. The Port Authority sends the virtual enable message ("***Connect***") through the EV remote controller or at the pier, and supplies the hardwired enable signal ("***Connecting Enable***") as well. This last signal pass through PC and EPBs (virtual) to be validated. Step X. (**Emergency Mode** is common to all Phases with "Connecting Enable" asserted).

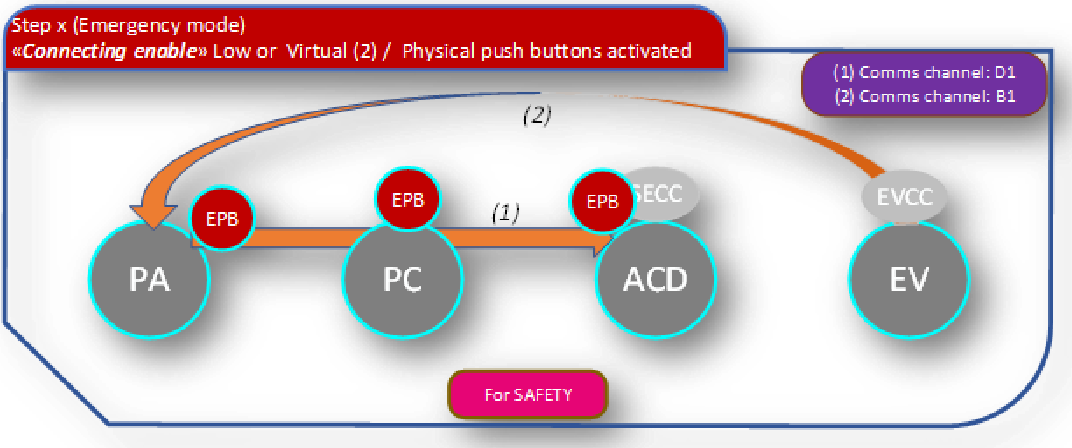

Figure 11: Emergency mode

Step X. The hardwired enable signal ("***Connecting Enable***") is shared among the PA, PC and ACD, through the EV remote controller.

[Road to Standardization] *For future scenarios, it may be worthy to explore the possibility of allocating virtual Emergency Buttons based on a wiring line which let each component to negate the hardwired signal in case of Emergency events. Since the EV is still unconnected, the EPB function can be accomplished only by sending a message ("Virtual Emergency Button") by the wireless comms channel B1 (best could be working as a "Watchdog").*

6.2.5 Item 5: Earthing isolation & electrical corrosion countermeasures when scaling up to MW charging

ITEM 5	
Sub-system(s) involved	PC Ship interfaces (minor involvement of ACD)
Concept & Item involved	Standardization of earthing isolation and electrical corrosion countermeasures when upscaling MW range on large chargers
Standards Consulted	Earthing isolation and corrosion prevention: IEC 80005-1/3 (galvanic isolation transformer and connections) IEC 62477-1 (safety requirements) Electrical safety: IEC 61439 (electrical assemblies) IEC 61851-23-3 IT circuit (conductive charging) IEC 61557-18 (Electrical safety in low voltage distribution systems - DC EV supply equipment insulation monitoring device, IMD)
Standardization gap topic	There are not safety standards currently in the market to ensure <u>Insulation and Corrosion</u> when scaling up charging power up to MW scale. Within numerous reference projects of industrial partners, corrosion has proven to be a hazard for a successful transition to electrifying vessels.
Description / Missing standardization / Comment	Work on this topic is going on in the JWG28, even if it is not part of the 80005-3 anymore. Within the IEC 61851-23-3 and related standards, the overall leakage or common-mode (CM) currents are limited to a maximum overall system value of 25 mA in total, which is a combination of the maximum EVSE-EV system leakage current limit during charging (10 mA) and the IMD detection current (15 mA) limit. In an application with a single IT circuit alike vehicle charging, the EVSE-EV system is equal to that one IT circuit, however, on the HYPOBATT Ekat vessel, there are 2 IT circuits in the EVSE system, simultaneously performing a charge session. Based on the marine application, 2 parallel charging circuits are common according to Damen since separate battery systems are required onboard for redundancy Therefore, these two combined IT circuits mutually must keep their leakage below that limit. Considering the increase in power, combined with the surpassing of the vessel Y-capacitance limits and halving of the per-circuit average CM limit presents a significant complexity. In principle, the IMDs could be operated cascaded or out-of-phase, thereby they will not mutually interfere with another, but IMD detection times are already too slow to comply with the standard due to the exceeded Y-capacitance levels. By only allowing each IMD to be

	operational for, at best 50% of the operational time, the detection time in worst-case scenario further increases.
Design approach used	Design approach has been largely discussed in the Consortium and finally was described in D3.1 and D3.4. This is listed in appendix A.
Recommendations / remarks / validation on the proposed design	Suggest consulting Classification Society Rules (Example RINA Ship Rules, Part C, Ch 2, Sec 12 - Earthing of non-current carrying parts) IEC series 60092 From conductive charging perspective, the intention of these strict limitations to CM currents arises from touch-current safety requirements and safe usage of the system for uneducated people. Different approaches can be taken to assure this in alternative ways: • Come up with an alternative leakage detection and compensation method for the marine application. This is, by definition, a different application from automotive since the vessel always has an alternative return path via the water which is non-existing in the rubber-tire isolated case of assumed automotive scenarios. Similarly, for e.g. mining, defence and construction applications, a non-isolated situation with e.g. tracks must be considered, fundamentally different from the now-ruling MCS standards. • Use auto-connect methods or only allow educated people to operate the system. Both these solutions do require additional safety measures e.g. earthed conductive parts such as the hull and walking bridge to enter the ship, and monitoring of insulation between the ship hull and onboard DC bus circuits from EV inlet to batteries.

6.2.6 Item 6: Connector ship-interface positioning for MW-scale charging (location + cable-length constraints)

ITEM 6	
Sub-system(s) involved	Ship interface
Concept & Item involved	Connector Ship Interface
Standards Consulted	IEC 80005 series No standards on the ship interface positioning and for automatic connection.
Standardization gap topic	Connector Ship Interface Positioning for MWs
Description / Missing standardization / Comment	Due to the diversity of vessels, it is difficult to define a standardizable position for the Ship Interface. It would be beneficial to establish some guiding rules, at least for the design of new vessels. Furthermore, the distance between the SECC and the EVCC is critical for stable high-level communication. Since communication cable lengths of up to 17 meters are expected (15 meters outside the vehicle plus 2 meters inside the vehicle), and because site layout and charging-connector positioning are also based on a maximum cable length of 15 meters, CharIN recommends limiting the communication cable to a maximum of 15 meters. For liquid-cooled charging cables, it is recommended to keep the length as short as possible in order to avoid excessive performance demands on the cooling system and to maintain manageable cable handling. Therefore, the charging-inlet position on heavy-duty vehicles, as well as the layout of the charging bay, should be standardized.
Design approach used	To reach a high level of interoperability, it would be preferable to have a side connection to the ship, along the shore edge. It should be better to have the connection in the leaving direction to avoid damages in case of vessel leaving before connectors are properly disconnected. A side connection is easy for vessels with high sides but, in case of low vessels heights, the connection is preferred from the top. For the HYPOBATT demonstrator, a topside connection would have been a better fit; however, due to budget constraints, and considering the vessel's berthing mode, the most feasible option was a side connection, although it required an adapter for the Ship Interface.

<table>
<tr><td rowspan="2">Recommendations / remarks / validation on the proposed design</td><td>Another important aspect related to the connector positioning concerns safety requirements. If, as considered for the HYPOBATT demonstrator, the responsibility for performing the connection safety check lies with the vessel's captain, the entire connector set, both on the shore side and the ship side, must be positioned in a straightforward and easily accessible way to allow proper visual inspection.</td></tr>
<tr><td>Current standards do not define a 'standard' or required position for installation; instead, they specify the safety aspects that must be considered in the design (e.g., minimum distances, protective measures, physical barriers, etc.). It is therefore recommended that the design approach explicitly documents the rationale behind the selected position as well as the justification for the adopted safety measures.
In the absence of prescriptive standards, a risk assessment can support the identification of an appropriate installation location. Rather than prescribing a fixed position for the system, the project outcome should provide a clear overview of the risks that must be considered during design across different operating conditions (connection/disconnection, normal operation). These include, for example: ship motion, weather conditions, clearance and creepage distances, arc-flash risks, electromagnetic compatibility, temperature rise, and others.</td></tr>
</table>

6.2.7 Item 7: Connector movement safety for the Automated Connector Device (ACD)

<table>
<tr><th colspan="3">ITEM 7</th></tr>
<tr><td>Sub-system(s) involved</td><td colspan="2">ACD</td></tr>
<tr><td>Concept & Item involved</td><td colspan="2">Connector Movement</td></tr>
<tr><td rowspan="3">Standards Consulted</td><td>1</td><td>IEC 61851-23-1</td></tr>
<tr><td>2</td><td>EN 50696:2021</td></tr>
<tr><td>3</td><td>IEC 61851-27 CD</td></tr>
<tr><td rowspan="3">Standardization gap topic</td><td>1</td><td>IEC 61851-23-1, Sect. 201.1:
“For case D pairing between EV and charger shall be ensured before the ACD is moved
Additionally, for case D, the position of the vehicle relative to the ACD shall be sufficiently verified before the ACD is moved to ensure that there can be no possibility of hazardous situations. e.g. collision with a moving vehicle or person.”
IEC 61851-23-1 Sect. 3.1.201: “Case D: connection of an EV to a supply network utilizing an automatic coupler which has an ACD on the EVSE.”</td></tr>
<tr><td>2</td><td>EN 50696, Sect D2.4:
"ACD shall provide means of protection which prevent physical bodily harm or damage.
A squeeze or crush protection according to EN 16005 that stops the moving of the ACD's contact unit if an obstacle prevents the system reaching the correct 'working' / 'contact' position. This includes a technique which allows to remove the obstacle in cases the squeeze or crush protection was activated.”</td></tr>
<tr><td>3</td><td>IEC 61851-27 CD, Sect. 11.4: “The force and pressure created by the movement of the ACD shall be limited to values that are considered non-hazardous" [...]
"when the distance between the vehicle connector and the vehicle inlet is smaller than 25 mm, the maximum clamping force is 200N”</td></tr>
<tr><td>Description / Missing standardization / Comment</td><td colspan="2">In automotive sector: IEC 61851-27 CD, 11.4: Applicable force and speed limits are referred with values only when distance of counterparts is < 25mm, or ", "During the remaining motions, the maximum clamping force is 100N". This could work for small vessels, not scope of HYPOBATT.

In Maritime sector the MW charging area is forbidden to people by a fence coverage (usually electrically verified), then it is not expected to have this risk of injury and the limits in terms of force and speed are not strictly</td></tr>
</table>

<table>
<tr><td rowspan="2">Design approach used</td><td>necessary. More the captain of the vessel shall check (maybe by camera) before launching the charging procedure, and during the charging phases.</td></tr>
<tr><td>HYPOBATT proposed measures:
1. Protect the area with a safety fence (optionally an electrically monitored one).
2. Ensure that the Captain or Port Authority performs a visual inspection of the ACD movement area, either directly or via camera systems.
3. Maintain force and speed limits as suggested in IEC 61851-27 CD, to be applied as optional additional risk-mitigation measures.
Perform a dedicated risk analysis, which remains mandatory for the specific application.</td></tr>
<tr><td>Recommendations / remarks / validation on the proposed design</td><td>Risk analysis is considered suitable to demonstrate safe and reliable design. (as it has been done in HYPOBATT)</td></tr>
</table>

6.2.8 Item 8: Charging action initiation responsibilities (who authorizes start) and implications for automated connectors

ITEM 8	
Sub-system(s) involved	Port Authority / Captain of the vessel
Concept & Item involved	Charging System
Standards Consulted	IEC 80005 series
Standardization gap topic	No references to charging action initiation, its responsibilities and automated connectors.
Description / Missing standardization / Comment	Safety: Who should be in charge to enable the charging system to start operations (port authority / captain of the vessel / …)
Design approach used	Discussed with the port and vessel operator about the usual specific rules in the application.
Recommendations / remarks / validation on the proposed design	A compatibility assessment should be foreseen before connection. Specific port Rules to be considered. Last responsibility relies on the ship operator. Since the HYPOBATT demonstration involved only two vessels, the compatibility assessment was carried out ‘by design’. However, for commercial applications, where different technologies may be combined within the connection system, it has been envisioned to implement a vessel ID retrieval from the ACD, to be transmitted to the Port Authority prior to granting connection authorization.

6.2.9 Item 9: Insulation distances for ACD connectors in open environment (Pollution Degree 4 vs up to 1500 V)

ITEM 9	
Sub-system(s) involved	ACD and Ship Interface
Concept & Item involved	Connectors
Standards Consulted	IEC 60664-1 DNV-RU-SHIP-Pt4Ch8
Standardization gap topic	The low voltage range (up to 1500 V max, AC pk or DC) is not fully covered with the Pollution Degree 4
Description / Missing standardization / Comment	Safety: Insulation distances shall be defined for open environmental conditions, consistent with the HYPOBATT design approach. Insulation dimensioning shall comply with IEC 60664-1, Pollution Degree 4 (PD4), since the connector may be exposed to water splashes on the contacts.
Design approach used	The HYPOBATT demonstration design complies with the "DNV-RU-SHIP-Pt4Ch8" rules. Since the upper voltage limit in this standard is 1 kV for AC and 1,5 KV for DC system, the design considered that 1 kV AC (corresponding to 1400 V peak) is reasonably close to 1500 V DC (The Low Voltage Directive (LVD) 2014/35/EU covers electrical equipment with50–1000 V AC or 75–1500 V DC, ensuring safety for components placed on the EU market. For marine applications, specialized equipment, such as that used on ships, is often exempted from the LVD if it complies with international maritime safety bodies (e.g., IMO, Class Societies). This assumption was validated through dedicated FAT tests, which confirmed that the design behaves safely and within acceptable limits at the intended operating voltage.
Recommendations / remarks / validation on the proposed design	The demonstrator ACD and SI were tested at FRISIA under severe weather conditions (rain, wind, and snow) without any issues being observed. However, this cannot be regarded as a comprehensive validation, as the maximum charging voltage applied during the tests was only 1000 V and the system was new, meaning it had not yet undergone prolonged exposure to marine environmental pollution. Dedicated test campaigns should be conducted for each new design in order to achieve a reliable and fully representative validation.

6.2.10 Item 10: Communication technology choice for MCS / maritime SBC-DC (10Base-T1S vs PLC)

ITEM 10	
Sub-system(s) involved	Charging System (all sub-sys)
Concept & Item involved	Communication
Standards Consulted	IEC 61851-23-3 ISO 15118-1/2/20/10 IEC 80005-2
Standardization gap topic	Communication and automation communication
Description / Missing standardization / Comment	IEC 61851-23-3: consulted for general info about DC electric vehicle supply equipment for Megawatt charging systems ISO 15118-1: consulted for general info and use-cases definition ISO 15118-2 and -20: consulted for uni- and bi-directional network and application protocol requirements ISO 15118-10: consulted for getting input about physical and data link layer for 2-w ETH comm.
Design approach used	Since MCS committee has already compared Single ended PLC / Differential PLC and 10Base-T1s technologies against noise margin, the 10Base-T1s has been considered the best choice. Both technologies have been successfully tested during the demonstration phase at Frisia.
Recommendations / remarks / validation on the proposed design	In line with the agreements established at the beginning of the HYPOBATT project, all elements undergoing standardization based on MCS recommendations should also be considered applicable to the maritime sector, with the necessary adaptations. Accordingly, 10BaseT1S technology has been validated. However, since portside layout constraints may lead to situations where the 25meter distance limit cannot be respected, 10BaseT1L has also been validated to provide a longer distance backup solution.

6.2.11 Item 11: Procedures — adapting IEC 61851-23(-1/-3) operational logic from automotive to maritime

	ITEM 11
Sub-system(s) involved	Charging System (all sub-sys)
Concept & Item involved	Procedures
Standards Consulted	IEC 61851-23 parts -1 and -3
Standardization gap topic	Standards defined for Part 1 (bus application) and Part 3 (road truck application)
Description / Missing standardization / Comment	The maritime sector presents unique operational characteristics that clearly distinguish it from other industries. In particular: • **Captain's Authorization:** The ship's Captain typically holds the primary authority to grant approval for both the connection and the start of charging operations. • **Vessel Identification Check:** A mandatory verification of the Vessel ID must be carried out to ensure compliance with charging requirements and confirm that the vessel is authorized for the service. • **Power Demand Assessment:** The vessel's power demand must be validated against the port's grid capacity to ensure that sufficient electrical availability exists before initiating the charging process.
Design approach used	Initially developed with reference to automotive standards, and progressively enhanced to incorporate maritime-specific safety, automation, and regulatory requirements, the HYPOBATT solution evolved toward achieving the highest possible alignment with **IEC 61851-23-3 (MCS)**. Consequently, it will no longer rely solely on **IEC 61851-23-1**, which primarily addresses pantograph-based charging systems.
Recommendations / remarks / validation on the proposed design	It is recommended to align the HYPOBATT procedure with the operator and/or to consider alternative approaches where appropriate. Port operators adopt their own regulations, which often differ from one another.

6.2.12 Item 12: Electromagnetic Compatibility (EMC) requirements for the full charging system (MW-scale)

ITEM 12	
Sub-system(s) involved	Charging System (all sub-sys)
Concept & Item involved	Electromagnetic compatibility (EMC)
Standards Consulted	IEC 61851-21; EV: part 1, EVSE: part 2 IEC 61000
Standardization gap topic	IEC 61000 parts are used. From Shore-side perspective the conductive charging standard covers. Compliance with IEC 61800-3:2017 might be required for vessels with machines that remain active during charging (IEC 61800-3:2017 - Adjustable speed electrical power drive systems - Part 3: EMC requirements and specific test methods)
Description / Missing standardization / Comment	Referring to Tab. 101 in IEC 61851-23, during the testing, EMC behaviour has been verified in the form of conducted emissions in voltage and current. These were significantly lower when compared to the commercial charging system, however exceeded the part 21 limits. It is still to be investigated whether this was caused by the EVSE or by the EV-side DC/DC converter connected in between of the on-board batteries and the DC bus to which the EVSE was connected.
Design approach used	Standard industrial equipment reference is used when unconnected. When connected, the IEC 61851 for the respective EVSE as the EV sided requirements apply.
Recommendations / remarks / validation on the proposed design	Reference to IACS UR E10 for type approval EMC Onboard testing will confirm compatibility of the system with onboard equipment.

6.2.13 Item 13: Y-capacitance limits vs maximum system voltage (1500 V DC vs standards up to 1250 V DC)

ITEM 13	
Sub-system(s) involved	Ships interface PC
Concept & Item involved	Y-capacitance in relation to maximum system voltage
Standards Consulted	IEC 61851-23-3
Standardization gap topic	HYPOBATT defines systems up to 1500 V DC whereas the Y-cap limits are defined only up to 1250 V DC
Description / Missing standardization / Comment	1) limits for Y-capacitances are (probably too) low for the electrical power systems on ships 2) Y-cap limits in the 1250-1500 V DC range are missing
Design approach used	Multi-step approach: 1) define it as a non-touched system (ACD) removing the requirement of touch safety 2) generalize towards MCS or R-MCS standards in development. 3) ensure that the limit is defined for manual cable handling in a dock for complete voltage range and Marine suitable Y-capacitance levels.
Recommendations / remarks / validation on the proposed design	See Appendix A for possible recommendations.

6.2.14 Item 14: PE wire break / loss detection for ship–shore connection (floating vessel return-path issue)

ITEM 14	
Sub-system(s) involved	Ships interface PC
Concept & Item involved	PE wire break detection
Standards Consulted	IEC 80005 IEC 61851
Standardization gap topic	PE loss detection required by IEC 61851, however not mandatory in the IEC 80005 (regular check is also allowed)
Description / Missing standardization / Comment	Because ship is floating in conductive water an alternative earth return path makes a loss of PE detection difficult
Design approach used	Assure detection of PE loss irrespective of return path. If not possible to demonstrate it in DEMO still propose it as such towards standardisation.
Recommendations / remarks / validation on the proposed design	N/A

6.2.15 Item 15: Relative Movements Compensation (ship–shore motions impacting ACD capability)

ITEM 15	
Sub-system(s) involved	ACD and Ships interface
Concept & Item involved	Relative Movements Compensation
Standards Consulted	IEC 80005 IEC 61851
Standardization gap topic	Once a vessel is berthed, its relative movements with respect to the quay are not standardized. These motion not only affects the stationary connection but also significantly impact the capabilities of the Automatic Connection Device.
Description / Missing standardization / Comment	Various relative movements occur between the shoreside and the shipside of the Contacting Interface. The most significant challenge is tidal-induced displacement, which can be mitigated either through port infrastructure, such as positioning the ACD on a pontoon as close as possible to the vessel when berthed, or by implementing an ACD with extensive displacement compensation along the relevant axis. This displacement can reach up to 16 meters. Beyond tidal effects on the Z-axis, the berthed vessel experiences three translational and three rotational degrees of freedom in its relative movements.
Design approach used	The demonstrator was initially designed to leverage the existing pontoon positioned adjacent to the vessel. Building on this baseline and drawing on the extensive operational expertise of the HYPOBATT partners, a set of maximum allowable spans for each movement axis of a berthed vessel was subsequently defined. These spans consider the full range of expected operational scenarios, including different vessel classes, mooring configurations, environmental conditions, and practical feedback gathered from ports and industry stakeholders. These parameters play a crucial role in determining the compensation capabilities required from the Contacting System/ACD. They define not only the absolute displacement limits that the system must handle, but also the dynamic performance, namely the response speed and motion tracking accuracy needed to maintain a reliable, safe, and fully automated connection throughout the vessel's stay at berth.

Recommendations / remarks / validation on the proposed design	Considering the HYPOBATT proposed Contacting Interface is for both side and top connection, the movement spans have been defined as for Req_D1.4-121 and Req_D1.4-122 detailed in the Deliverable D1.4. Since HYPOBATT is an Automatic Connection system, the values mentioned above are considered valid for both the stationery and connection phases.
	Refer to RINA Ship Rules, Part C, Chapter 2, Section 4[3] Degree of protection.

6.2.16 Item 16: IP (Ingress Protection), IK (impact kinetic), and EO (environment operating) installation standardization.

ITEM 16	
Sub-system(s) involved	PC and coupling dispenser/device (all shore-side equipment)
Concept & Item involved	Degrees of protection provided by enclosures (IP Code): classification of degrees of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72,5 kV Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code): classification of the degrees of protection provided by enclosures against external mechanical impacts when the rated voltage of the protected equipment is not greater than 72,5 kV Degrees of protection provided by Paints and varnishes — Corrosion protection of steel structures by protective paint systems (EO-code).
Standards Consulted	IP-code: IEC 60529:1989+AMD1:1999+AMD2:2013 CSV IK-code: IEC 62262:2002 EO-code: ISO 12944 (all parts)
Standardization gap topic	Within the CharIN taskforce for ruggedized MCS (R-MCS), it has been discussed and proposed in the R-MCS white-paper to comply to the ratings: IP-code: IP64 (all components when mated) IK-code: IK11
Description / Missing standardization / Comment	Basically, with abovementioned standards, the products used within an EVSE system can be designed and certified. The complete installation, however, might still require a validation from a class society, see recommendations.
Design approach used	For now it has been decided that these parts will NOT be included in the implementation of the DEMO. The allowance and initialization of the actuation movement is done by the captain or representative based on a visual verification of the position of the vessel with respect to the shore. So, at this point a manual/visual verification is used. In later stage the fully automated connection initialization is to be implemented. The complete EVSE has been designed according to, but is not tested/certified as such, the following grades of the different codes: • IP rating: IP65 • IK-rating: IK11 • EO-rating: C5-M (C4 optionally inland)
Recommendations / remarks / validation on the proposed design	Refer to RINA Ship Rules, Part C, Chapter 2, Section 4 [3] Degree of protection. For the product developments for marine SBC-DC charging the above-mentioned ratings are recommended.

7. CONCLUSIONS

HYPOBATT developed a modular, fast, and easy multi-MW recharging system that was successfully demonstrated at FRISIA. The project necessarily took into account the specificities of the site and the vessel intended for installation and testing, but at the same time sought to develop technical solutions with the widest possible application.

To this end, it referenced all available standards and corporate practices, also drawing on those used in other industrial sectors. Chapter 6 of this deliverable highlights element by element, where current regulations, standards, and procedural frameworks were found to be insufficient and which practical solutions were adopted by the partners to ensure feasibility, safety, and reliability. Some partners participate in the work of the regulatory bodies and were therefore able to take into account the evolution of the standards being developed during the HYPOBATT project.

This result therefore allows us to:

- provide useful guidance for those intending to develop recharging systems similar to those of HYPOBATT;
- provide useful elements for the evolution of standards applicable to recharging systems in order to overcome current gaps, considering a positive and proven experience such as that of HYPOBATT.

7.1 Roadmap beyond HYPOBATT

The purpose of this section is to explain how these project-specific solutions can be translated into contributions beyond HYPOBATT. One recommended action is to send HYPOBATT results to EMSA, to share the progress made and jointly consider the possibility of supplementing the existing EMSA Guidance. EMSA has already provided strong baseline guidance for both (i) battery systems on board ships and (ii) shore-side electricity (SSE). However, the Logbook confirms that elements linked to SBC-DC, automation, high-power levels and digital coordination between ship and port, still lack a similarly mature, harmonised standard set, and therefore require structured follow-up after the project.

7.1.1 Standardization initiative CharIN

Within CharIN, a taskforce for the standardization of Marine applications MCS (M-MCS) is formed within their *"roadmap to large-scale MCS appliance"*, as depicted in Figure 12. Within this taskforce, different maritime applications and their (in)equalities with the MCS standard are investigated, requirements for M-MCS are defined and discussed, all with the goal to work towards (part of) a standard aligned with the aforementioned standards and classification requirements set by the registers alike RINA. HYPOBATT project partners actively participate in the M-MCS taskforce to help translating the HYPOBATT learnings to requirements and test definitions in the upcoming standard.

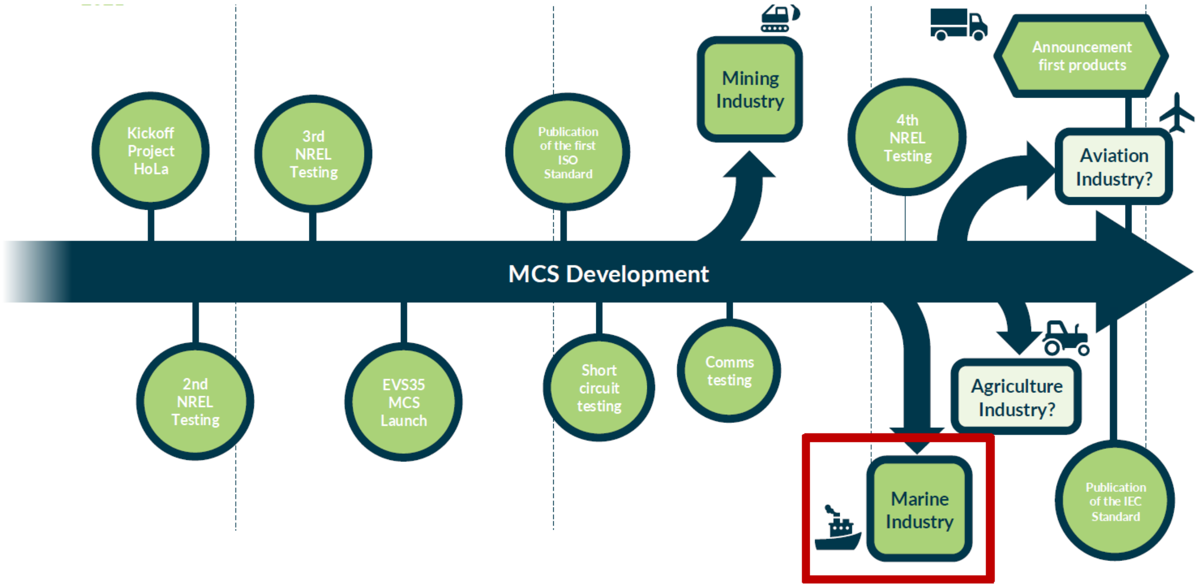

Figure 12: CharIN MCS development roadmap with Marine Industry emphasis (source: CharIN GmbH).

7.1.2 Further standardisation in IEC 80005

A new standard about DC shore power is created, this standard will have the number IEC/IEEE 80005-4.

As said by the IEEE Standard Association "This part of IEC/IEEE 80005 describes low voltage DC shore connection (DCSC) systems up to and including 1500 V DC. It applies onboard the ship and on shore, to supply the ship with electrical power from shore. This document is applicable to the design, installation and testing of DCSC systems and addresses - DC shore distribution systems, - Shore-to-ship connection and interface equipment, - Transformers - Semiconductor/rotating frequency converters, - Ship distribution systems - control, monitoring, interlocking and power management systems"

Project partners (STT, Damen) are member of this standardization committee, so results from HYPOBATT are also contributing directly.

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9. APPENDIX A: EARTHING ISOLATION & ELECTRICAL CORROSION COUNTERMEASURE RECOMMENDATIONS

9.1 Safety and protection

The safety and protection requirements that need to be considered for the charger architecture originate from different sources and cannot be defined exhaustively at this point in time since they are partly dependent on the outcome of this and other work packages. The requirements listed in D1.1, D1.2, D1.3 and resultingly in D1.4 are considered as main requirements. As listed in D1.1, no marine specific standard exists to date on low-voltage safety for SBC-DC. Additionally, the MCS defined requirements known to date are considered.

From the design and operational requirements in D1.1, it is learnt that the following aspects must be considered in the safety and protection design of a shore-to-ship EVSE architecture:

- Earth bonding and related issues in case of earth fault currents and electrical corrosion.
- In ships or units where the main source of electrical power is based on battery installations only, the battery installation is to be divided into at least two independent battery systems located in two separate battery spaces, each having a capacity sufficient for the intended operation of the ship.
- Installation of a back-office Energy Management System (EMS) at the port authority or charge point operator, and a Power Management System (PMS) in the form of a power conversion controller per section and overall PMS in the system manager
- An emergency shut down system, being a separated hardwired circuit, independent from the control system, is to be provided.

9.1.1 Earth bonding and EMC

As explained in D1.2, the earthing system of a shipboard power system is typically employed as IT-system with the inclusion of high-frequency grounding capacitors, providing a preferential return path for high-frequency current as provision in addressing EMC. In order to comply with safety regulations, all conductive charger and vessel parts must be connected to PE. Additionally, during charging, an equipotential PE connection must be present between charger and vessel according to D1.2 - 6.5.7.1-#1 to ensure that the EVSE-EV combination and all equipment within properly earthed.

Typically, an electric vessel has a micro-grid in itself since it contains numerous electric supplies and consumers (D1.2). Irrespective whether components connected to the vessel grid are of AC or DC nature, they all contain PE referenced decoupling capacitors (D-cap, C_D) needed to meet the vessel EMC regulations, and contribute to the presence of unintended stray capacitance (S-cap, C_S) (Post, 2014) which is determined by insulation, isolation, creepage/clearance distances, and physical location. Therefore, the overall Y-capacitance (C_y)

$$C_y = C_D + C_S$$

Equation 1: Y-capacitance C_y.

as seen by the vessel insulation monitoring device (IMD) is unknown and large when comparing this to the limits as defined for vehicles (ISO 17409), being less than 2 µF per line conductor for supply voltage up to at 500 V DC. The overall Y-cap is determined by the capacitance between the DC+ and PE (C_{y+}) and that between the DC- and PE (C_{y-}) for both the EVSE ($C_{y(EVSE)}$) and EV ($C_{y(EV)}$) side, resultingly;

$$C_y = C_{y+(EVSE)} + C_{y-(EVSE)} + C_{y+(EV)} + C_{y-(EV)}$$

Equation 2: per-system, per-pole capacitance leading to overall C_y during charging

therein neglecting the small influence of the differential DC+ to DC- capacitance, C_x. The main reason for limiting the overall resulting C_y in automotive applications is to prevent hazardous situations by keeping the touch current in case of an insulation breach below life threatening values according to the c1 limit of figure 22 (DC) in IEC 60479-1. That is also why it is specified in combination with the supply voltage; the touch current will be determined by the body impedance and the discharge energy (E_D)

$$E_D = \frac{1}{2} C_y V^2$$

Equation 3: Discharge energy of C_y

where V is the instantaneous voltage across the capacitor, here V DC. Because the maximum supply voltage in MCS will be significantly higher than 500 V DC, additionally forced symmetrisation is required as will be explained in section 9.2.

9.1.2 IEC 80005 substation related earthing requirements

Since the EVSE MV/LV section is considered as a substation, the following EMSA guidance is applicable. To ensure the safety of the persons an equipotential system must be created within the substation. It is realized according to the following recommendations:

- Creation of an earthing electrode under the substation by burying copper conductors
- Inter-connection by means of protective conductors of all the exposed conductive parts of the installation:
  - Enclosures of the electrical equipment
  - Screens of the MV cables
  - Frame of the transformer
  - Metallic doors
  - Etc.
- Connection of all protective conductors at one single common point
- Connection of the common point of the protective conductors and the reinforcing rods of the concrete slab supporting the substation, should be connected to the earth electrode.

9.2 Insulation monitoring in EVSE-EV charging IT system

9.2.1 Basic principle of operation

To verify whether an isolated-terra (IT) circuit is floating with respect to PE, isolation measurements are required. The insulation of an IT system is typically measured by determining the common-mode (CM) impedance (Z_{IT-PE}) between the IT circuit potentials and PE. In case of an AC circuit, the IT potentials are L1, L2, L3, whereas in a DC circuit, the IT potentials are DC+ and DC-. A common method to determine Z_{IT-PE} is by superimposing a CM block-shaped voltage (v_{CM}) on top of the IT circuit potentials to be measured, as shown in Figure 13. By measuring the CM current (i_{CM}) in the circuit, Z_{IT-PE} can be calculated based on v_{CM} and the RC-time of i_{CM} resulting in an estimated overall value for

$$\frac{1}{R_y} = \frac{1}{R_{y+(EVSE)}} + \frac{1}{R_{y-(EVSE)}} + \frac{1}{R_{y+(EV)}} + \frac{1}{R_{y-(EV)}}$$

Equation 4: per-system, per-pole resistances leading to overall R_y during charging

as depicted in Figure 13. The equipment responsible for determining R_y is an IMD. A minimum value for R_y is required to ensure an insulation can be considered safe. This value is defined dependent on the applicable safety standard and maximum voltage in the IT system. Within the automotive conductive charging standard, IEC 61851, an IT system is considered isolated if R_y > 100 Ω/V. For e.g. a 1000 V DC maximum system voltage this results in R_y > 100 kΩ. The allowed capacitance C_y in an IT system must be limited as aforementioned in section 9.1.1 because this affects the time an IMD needs to determine R_y using the RC-decay of i_{CM}. The maximum time an IMD has to detect an insulation value R_y < 100 Ω/V is limited in the standard leading to limitations for C_y.

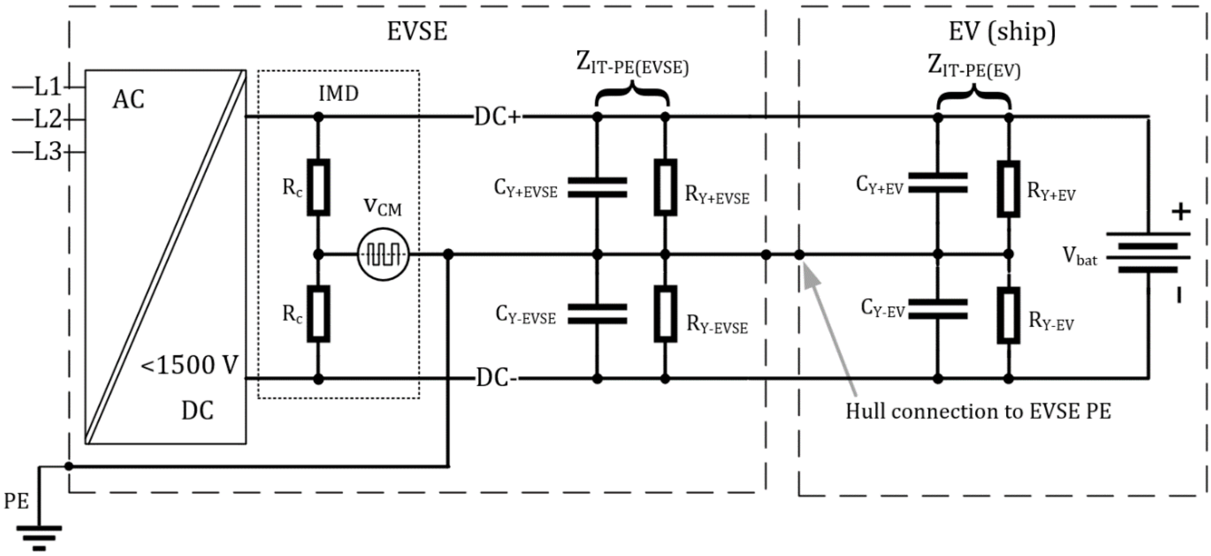

Figure 13: Schematic representation of Y-cap and Y-res of EVSE and EV combined IT-system with IMD

9.2.2 IMD requirements

From D1.4 it is learnt that an IMD is required based on requirements;

- **D1.2 - 6.5.3.1-#2**; The power system will be floating (IT).
- **D1.2 - 6.5.7.2-#6**; Earth fault monitoring is required in floating electrical systems (IT systems), by Insulation Monitoring Devices (IMDs).
- **D1.1 - 5.2.3-#2**: Insulation resistance and dielectric strength: The insulation resistance should exceed 5 MΩ.
- **Req_D1.4-021**; The DC bus for the battery charging shall be floating (IT).
- **D1.1-4.2.1-#2**; The safety precautions of the system are therefore different when comparing the TT and the IT side. At the AC-side, the leakage of current can be measured to earth with the RCD while at the DC-side this is replaced by the IMD determining the insulation of DC+ and DC- w.r.t PE.
- **D1.2 - 6.5.7.2-#6**; Earth faults; Earth fault monitoring is required.
- **D1.2 - 6.5.7.6**; Multiple earth fault monitors can interfere with each other, thus coordination before and during shore connection is required to ensure only one IMD per (isolated) power system is operational.

9.2.3 GFD and IMD sequence of operation

Looking at the combination of EVSE and EV in a typical charging session, there are three systems to be defined as indicated in Figure 14;

- **Unconnected EVSE (TT and IT system)**; GFD ($GFD_{EVSE-AC}$) required for MV TT circuit, AC IMD ($IMD_{EVSE-AC}$) required for IT circuit.
- **Unconnected EV (IT system)**; DC IMD (IMD_{EV-DC}) required for IT circuit.
- **Connected EVSE-EV (TT and IT system)**; $GFD_{EVSE-AC}$ required for MV TT circuit, DC IMD ($IMD_{EVSE-DC}$) required for EVSE-EV combined IT circuit.

A ground fault detection (GFD) device is required on MV AC side to measure whether the insulation level is ensured. If breached, the MV switchgear will be opened accordingly. On the EVSE side, both an AC and DC IMD are required because of the different states in the charging process. Before activating the AC/DC converter, the insulation of the transformer secondary-side circuit must be assured with $IMD_{EVSE-AC}$. After activation of the AC/DC converter, $IMD_{EVSE-DC}$ will monitor the EVSE insulation. According to the IEC 61851-23, the EVSE IMD is active during the charging process, the EV IMD will be turned off. The motivation behind this is the continued presence of the PE connection at the EVSE at all time. Therefore, during the charging process, $IMD_{EVSE-DC}$ monitors the overall connected IT system as indicated in Figure 14. As will be explained in section 9.2.5, the possibility exists that multiple IMDs are required at EV side. This will not influence the sequence of IMD (de)activation as defined here; all EV IMDs will be turned off prior to the start of the charging process.

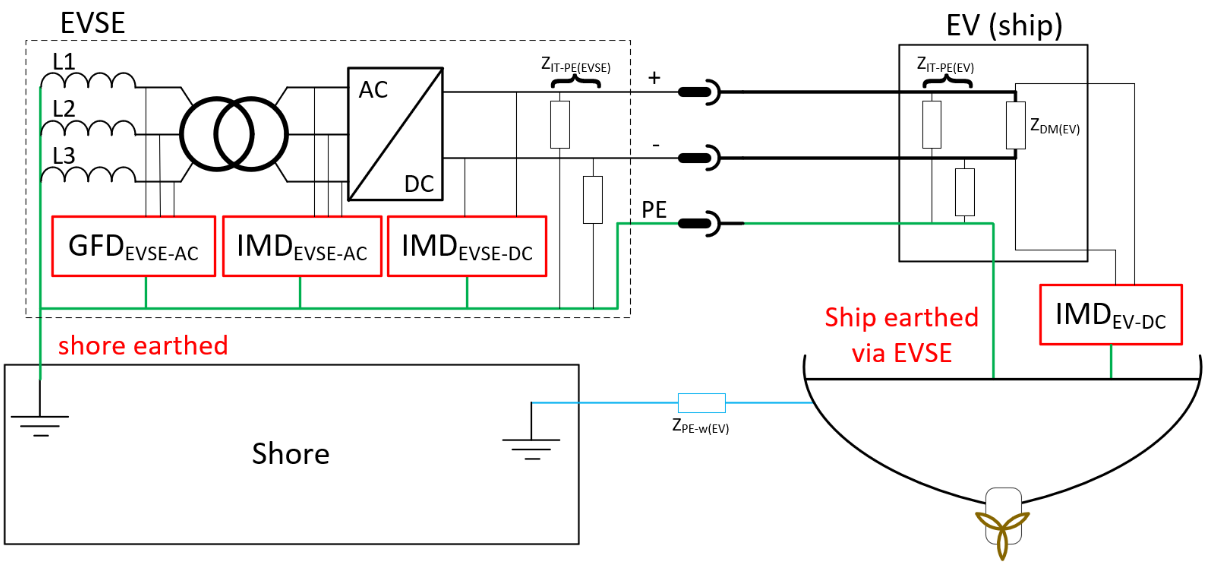

Figure 14: schematic representation of the EVSE-EV IT-system with required ground fault detection and IMD measurements

9.2.4 Forced symmetry

To ensure MCS becomes an interoperable, safe, and standardized solution in-line with all currently existing relevant standards, a descriptive summary has been written by the MCS taskforce in the form of a whitepaper (CharIn MCS taskforce, 2022). In this paper, numerous recommendations and requirements are given on several technical and non-technical aspects of the Megawatt Charging System (MCS). It is meant to provide information in a unified and cooperative manner to bridge the time gap until the requirements are defined in the relevant standards.

CharIN proposes a concept of limiting the touch current for a given DC voltage range while trying to maximize the allowable C_y in the system based on forced symmetrisation. If the isolated voltage between DC+ and PE (V_{DC+}) and between DC- and PE (V_{DC-}) respectively in Figure 13, are of equal amplitude ($|V_{DC+}| = |V_{DC-}|$), a given Y-cap combination of equal values will lead to the smallest possible touch discharge energy. Therefore, E_D is minimized for a given differential voltage (V_{DC}), where

$$V_{DC} = V_{DC+} - V_{DC-}$$

Equation 5: Differential DC voltage

Considering V_{DC} = 1250 V DC, this results in C_y = 10 µF. Presuming an equal capacity budget for both the EVSE and EV this leads to

$$C_{y+(EVSE)} = C_{y-(EVSE)} = C_{y+(EV)} = C_{y-(EV)} = 2{,}5\ \mu F$$

Equation 6: equal capacity distribution

An overall tolerance of +/- 50 V with respect to equal amplitude is allowed, being 675 V per pole. Equivalently to the Y-cap, the overall resistance per side per pole is represented in Figure 13 by $R_{y+(EVSE)}$, $R_{y-(EVSE)}$, $R_{y+(EV)}$, $R_{y-(EV)}$, respectively.

Although it is highly unlikely that the HYPOBATT demonstrator EVSE and Damen E-ferry for Frisia can both comply to this limitation of C_y, forced symmetry is presumed as requirement to the power conversion architecture to minimize touch current risks in any case and to prevent exclusion of the solution for use as an MCS charging system.

9.2.5 IMD distribution

To cope with an increasing level of C_y in maritime applications, an distributed IMD principle is proposed. As explained in section 9.1.1, for EMI filtering C_D capacitors are used, where HF capacitors are connected between each pole and the Earth (preferable close to the disturbing EMI source, i.e. power electronic converters). These capacitors should be much larger (C_D > 3 C_s) than the system stray capacitances to effectively suppress CM supra-harmonic noise in the frequency bandwidth 2-150 kHz (T.M.H. Slangen, 2022). An indication of stray capacitance levels on electric vessels:

- For a battery system typical value: 1nF/kWh, thus for a 2 MWh battery system; 2 µF.
- For an electric machine (motor or generator); 100 nF/MW machine power.

All the stray capacitances together in an EV ship electrical IT system can add up to several tens of µF, requiring the y-capacitors to be quite large to effectively filter stray currents and ensure low-impedance CM return paths close to the distorting converter. A possible solution to cope with the numerous sources of stray capacitance on the vessel is dividing the system into smaller monitoring cells and installing independent IMDs per cell as indicated in Figure 15 per cell:

- Cell 1: Onshore charger
- Cell 2: Battery pack 1
- Cell n: Battery pack n-1

On the charger side, pre-charge contactors and/or AC breakers would disconnect the converter from the grid and therefore, before connecting to the battery system, an isolation check can be performed to the converter itself. If for EMC purposes on charger side a larger than 5 µF overall Cy is needed, it can also be divided into multiple cells as will be detailed in the following. On the vessel side, every battery pack should have circuit breakers to allow disconnection in case of failure and modular operation and by means of these devices, battery packs could have their isolation tested on their own before connecting to the shore. Traction chains could also be disconnected by means of contactors and/or breakers, reducing the isolation measuring cell size. In the same manner, if any auxiliary converter or other equipment was connected to the same DC bus, it should be disconnected from it, also by means of a breaker or contactor.
Cell disconnection shall be made in a manner that ensures operation, i.e., not disconnecting all battery strings at once to avoid power shut-down or not disconnecting all auxiliary converters at once to ensure critical loads are fed. Additionally, and if the system is IT, both poles shall be disconnected to ensure that no stray capacitances are parallel connected to the measuring device. To date, commercial IMDs (e.g. Bender ISO 685)are available that can cope with an

overall Cy up to 1 mF, however, the allowed detection time is to be defined still in D7.2 as an additional requirement to the EVSE-EV combination during charging.

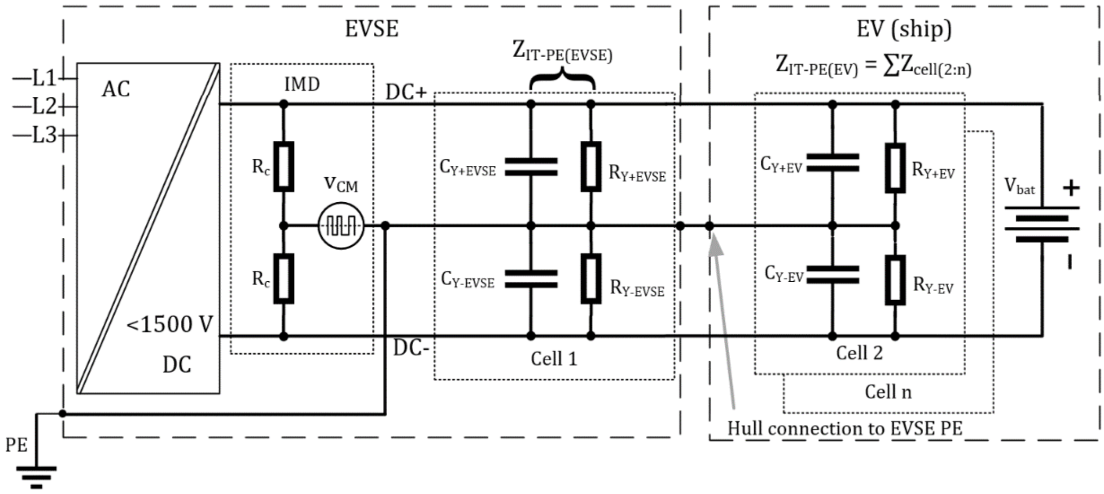

Figure 15: Simplified depiction of IMD distribution

Measurement would be done to every single cell depicted in Figure 16 while the vessel is not connected to shore. As a result, this decouples charger isolation issues with respect to vessel issues. An insulation check should not take more than a couple of minutes, therefore in case of periodical checking, it should not reduce effective charging time by a significant amount of time (few minutes checking vs few hours charging). Two way 'handshake' can be implemented to allow charging or not by checking onshore and vessel insulation statuses increasing security. Vessel insulation check should be managed by onboard BMS and/or main control computer and communicated to the shore. Full flow chart is proposed in Figure 17.

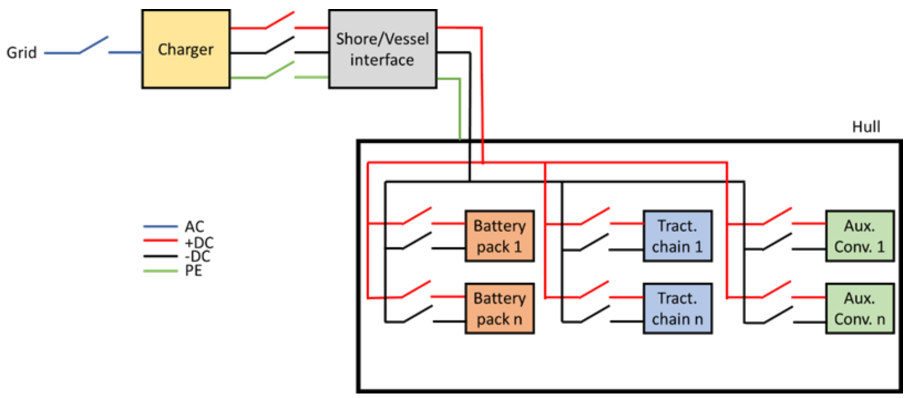

Figure 16: More detailed depiction of IMD distribution.

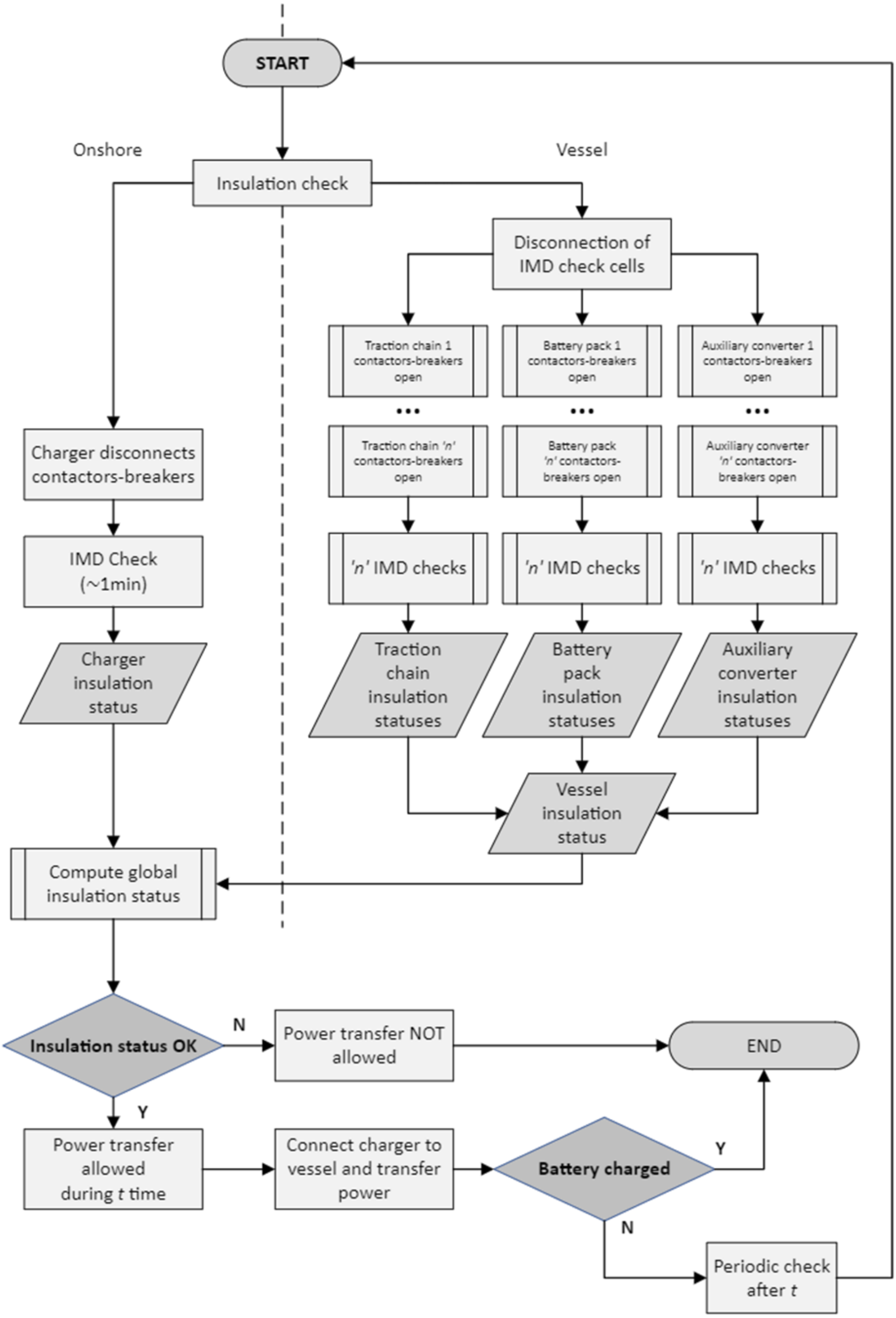

Figure 17: Distributed IMD work flowchart

9.3 Ship corrosion risks related to EVSE-EV system

9.3.1 Corrosion failure mechanisms

Fundamentally, two corrosion mechanisms can be distinguished in case the presence of an electrical system is part of a corrosion problem, namely galvanic and electrolytic. Galvanic and electrolytic corrosions are both an electrochemical process in which one metal corrodes when it is in electrical contact with another, in the presence of an electrolyte.

Galvanic corrosion requires two metals that have a different potential in the galvanic table (electrodes) to be immersed in a current carrying solution (electrolyte) and be interconnected by a current carrying conductor. The galvanic process is started by the phenomena of different natural potential of the metals, leading to a shore-ship galvanic DC voltage (V_g), as indicated in section 6.5.6 of D1.2. The risks of galvanic corrosion are not typically a significant problem, and vessel protective anodes can be used to counteract this effect, as shown in Figure 18. Therefore, no additional measures are required in the EVSE.

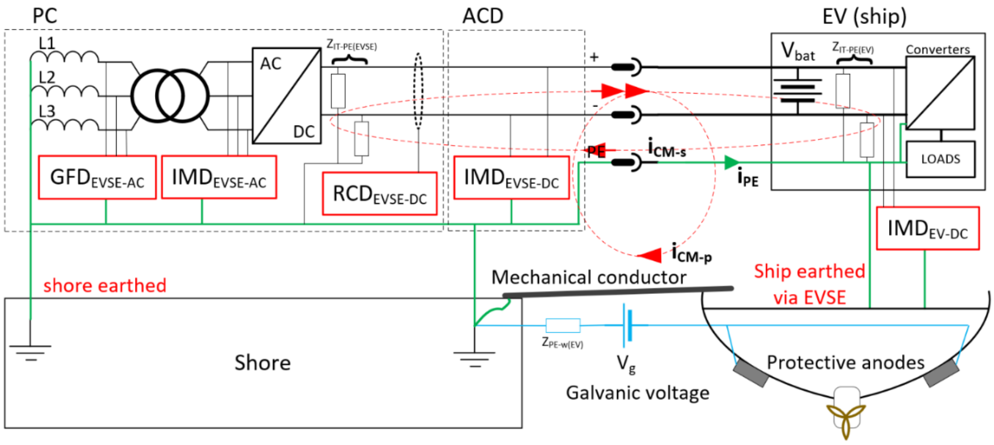

Figure 18: updated version of Figure 14 with PC, ACD separation, required GFD, RCD, and IMD measurements and indicated CM stray (i_{CM-s}) and parasitic (i_{CM-p}) current, leading to electrolytic corrosion.

Electrolytic corrosion is caused by an external electrical source which creates stray currents as explained in D1.2. Therefore, electrolytic phenomena can also occur on similar metals. Stray currents cause oxidation of anodes which is dissolution (loss) of the material which can be quantified as weight loss. Stray currents are defined as leakage currents flowing through unwanted paths created by supply system imbalances or wiring flaws. The electrolytic corrosion effect is different based on the type of metal and current frequency. According to Faraday's law of electrolysis, when a DC current leaves steel (~98% iron) through an electrolytic path such as water then there will be a metal loss of about 9.1 kg / A / year. Additional to DC electrolytic corrosion, also the AC CM stray current can cause electrolytic corrosion, however this greatly depends on the frequency (Chen, 2017). Overall, the AC corrosion is low compared with DC stray corrosion for steel (4-18%), but for e.g. aluminium AC stray currents can be an issue (up to 50%). The AC corrosion rate decreases with increasing frequency and can be neglected for frequencies above 100 Hz (Ghiran & Rampen, 2020).

9.3.2 Stray currents

9.3.2.1 Sources

As shown in Figure 18, there are 2 types of stray current; the stray current ($i_{CM\text{-}s}$) with a known return path PE, and the parasitic stray current ($i_{CM\text{-}p}$) with an unknown return path, as indicated with a mechanical conductor. The main and known stray current sources active during a charging session are shown in Figure 18, being the converters on both EVSE and EV side. Each of these sources will produce a resultant CM voltage, being $v_{IT\text{-}PE(EVSE)}$ and $v_{IT\text{-}PE(EV)}$, respectively. The resulting stray current, $i_{CM\text{-}s}$, exact path and value will depend on the physical location and RCL network values of $Z_{IT\text{-}PE}$ on EVSE ($Z_{IT\text{-}PE(EVSE)}$) and EV ($Z_{IT\text{-}PE(EV)}$) side.

To ensure interoperable and electro-magnetically compatible behaviour between the EVSE and EV, different aspects must mutually comply. From EMC perspective, both EVSE and EV must keep their emission within their respective zone as set in Figure 38 of D1.2, which is exactly the intention of strategically placed stray capacitances in $Z_{IT\text{-}PE}$ on each end; assuring that the emission generated by its own converters is contained internally. The allowed emission levels are defined in **Req_D1.4-067** for the EVSE, in IEC 61800 for the EV drives (level C4), and as a goal for the EV in IEC 61851-21-1. The latter originates from the IEC 61000, where specific levels are changed for the charging application. The parasitic stray current, $i_{CM\text{-}p}$ is minimized by effectively confining the EMC zones, minimizing the PE conductor impedance and maximizing the impedance of alternative return paths.

9.3.2.2 Effects

The resulting possible effects of insufficient EMC and a lack of interoperability assurance are;

- Electrolytic corrosion
- Mutual interference of communication and equipment due to emission exceedance
- Too large C_y values required for EMC, thereby;
  - Complicating insulation measurements (too slow or not possible)
  - Shifting stray current paths outside of the intended confined area as a result of smaller stray impedance outside of the EMC zone.
- Interference of wired EVSE-EV communication, which can lead to charging interruption

9.3.2.3 Measurements

To properly counteract the stray currents, these must first be detected. Observing Figure 18, it can be noticed that the CM path in the direction from EVSE to EV is equal for both $i_{CM\text{-}s}$ and $i_{CM\text{-}p}$. Resultingly, $RCD_{EVSE\text{-}DC}$ cannot be used to detect and discriminate either one; it measures

$$i_{RCD} = i_{CM-s} + i_{CM-p}$$

Equation 7: residual current relation to CM currents

Measuring i_{CM-p} individually is not possible by definition; the path it follows is undefined and can follow e.g. conductive non-electrical paths like the mechanical conductor or water between ship and shore. Lastly, it can be observed that the return of i_{CM-s} is solely the PE, therefore $i_{PE} = -i_{CM-s}$. Measuring i_{PE} is therefore required to firstly determine i_{CM-s}. Subsequently, i_{RCD} and i_{PE} can be used to derive

$$i_{CM-p} = i_{RCD} + i_{PE}$$

Equation 8: parasitic CM current dependency of measured currents

9.3.2.4 Compensation

The stray currents that can lead to electrolytic corrosion in the EVSE-EV system must be compensated (TDK, 2023) while the ship is connected to shore, as indicated in Figure 18. Eliminating stray currents during the charging process is considered a responsibility of the EVSE converter since that initiates the ship-shore connection. Compensation can be done either directly by the EVSE AC/DC converter or by an additional CM voltage source that produces a voltage such that i_{RCD} is compensated up to 100 Hz. Effectively, in the EVSE a DC side RCD is required ($RCD_{EVSE-DC}$) that detects and provides the power converter with the measured value for compensation.

9.3.2.5 System protections

It is expected that leakage currents will be a combination of DC and AC currents in the order of hundreds of mA up to a few A, therefore it cannot be detected and compensated up to the level of personal safety (< 30 mA in EU). The intention is to make it safe for corrosion and fire prevention, thereby limiting the leakage current in the range of 0.03-5 A DC and/or AC up to 100 Hz in accordance with IEC 60947 and IEC 60755. Equivalently, this is in accordance to the ship rules for protections against earth conductor faults which states that; if the current in the earth connection (i_{PE}) exceeds 5 A, there is to be an alarm and the fault current is to be automatically interrupted or limited to a safe value (Register, 2019).

According to the MCS standards; CM currents are limited in a maximum overall system value of 25 mA in total, which is a combination of the maximum EVSE-EV system leakage current limit during charging (10 mA) and the IMD detection current (15 mA) limit. In an application with a single IT circuit alike vehicle charging, the EVSE-EV system is equal to that one IT circuit, however, on the Ekat vessel, there are 2 IT circuits in the EVSE system, simultaneously performing a charge session. Therefore, these two combined IT circuits mutually must keep their leakage below that limit. Considering the increase in power, combined with the surpassing of the vessel Y-capacitance limits and halving of the per-circuit average CM limit presents a significant complexity.

In principle, the IMDs could be operated cascaded or out-of-phase, thereby they will not mutually interfere with another, but as explained in the previous section; IMD detection times are already too slow to comply with the standard due to the exceeded Y-capacitance levels. By only allowing each IMD to be operational for, at best 50% of the operational time, the detection time in worst-case scenario further increases. Additional measures are required, therefore.