



HYP BATT

Hyper powered vessel battery charging system

Document Title	Multi-MW charger validation
Document type and number	Deliverable 3.4

Primary Author(s)	Thomas Gerrits HELIOX BV Marcello Maccarini HELIOX BV
Document Version Status	2.0 final
Distribution level	SEN – SENSITIVE

Project Acronym **HYPOBATT**

Project Title	Hyper Powered vessels battery charging system
Project website	WWW.HYPOBATT.EU
Project Coordinator	Endika Bilbao IKERLAN ebilbao@ikerlan.es
Grant agreement number	101056853

Date of deliverable: [30.09.2025]

Date of submission: [03.10.2025]



**Funded by the
European Union**

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

Copyright © all rights reserved. This document or any part thereof may not be made public or disclosed, copied or otherwise reproduced or used in any form or by any means, without prior permission in writing from the HYPOBATT Consortium. Neither the HYPOBATT Consortium nor any of its members, their officers, employees, or agents shall be liable or responsible in negligence or otherwise for any loss, damage or expense whatever sustained by any person as a result of the use, in any manner or form, of any knowledge, information or data contained in this document, or due to any inaccuracy, omission or error therein contained



CONTRIBUTOR AND FORMAL REVIEWERS

	Name Organisation	Date
Document Manager	T. Gerrits Heliox	2025-09-02
Contributor 1	M. Maccarini Heliox	2025-09-12
Contributor 2	J. Gerrist Heliox	2025-09-21
Contributor 3	P. Torri Heliox	2025-09-10
Internal Reviewer 1	P. Grippi STT	2025-10-03
Internal Reviewer 2	A. Reina STT	2025-09-25
Internal Reviewer 3	C. Barron BRING	2025-10-03
External Reviewer 1	J. Zwysen Flanders Make	2025-10-03
External Reviewer 2	E. Bilbao Ikerlan	2025-09-30
External Reviewer 3	M. Pommer Frisia	2025-10-02

DOCUMENT HISTORY

Document Version	Date	Author Organization	Description
0.1	2025-09-02	T. Gerrits Heliox	Initial version
0.2	2025-09-10	T. Gerrits Heliox	Technical core sections ready in first internal release
0.3	2025-09-12	T. Gerrits Heliox	Heliox internal first version
1.0	2025-09-23	T. Gerrits Heliox	First internal released version
1.1	2025-09-25	T. Gerrits Heliox	Reviewed version
1.2	2025-09-26	T. Gerrits Heliox	Reviewed version
1.3	2025-09-27	T. Gerrits Heliox	Edited version
1.4	2025-09-30	T. Gerrits Heliox	Review – Quality assurance
1.5	2025-10-01	T. Gerrits Heliox	Edited final version
2.0	2025-10-03	T. Gerrits Heliox	Final version – Submitted to EC

Approval Status			
WP Leader Approval	Organisation Name	Checked By	Approved
	Heliox	T. Gerrits	Date: <i>03-10-2025</i> Signature: <i>Thomas Gerrits</i>



TABLE OF CONTENTS

- EXECUTIVE SUMMARY..... 13
- OBJECTIVES..... 15
- 1. INTRODUCTION..... 16
- 2. Generic Overview of the system 17
 - 2.1 Products overview composing the HYPOBATT system 17
 - 2.2 Standards plotted to HYPOBATT charging system 20
 - 2.3 Charging system related standards 21
 - 2.4 Description of the vessel-side power circuit..... 21
- 3. 3 MW charging container..... 23
 - 3.1 Electrical design of charger..... 24
 - 3.2 Mechanical design of charger..... 25
 - 3.3 Safety and protections..... 28
 - 3.3.1 Medium voltage switchgear 28
 - 3.3.2 Transformer protections..... 28
 - 3.3.3 AC insulation monitoring device..... 29
 - 3.3.4 LV over-current protections..... 29
 - 3.4 Integrated enclosure and cooling functions..... 30
 - 3.4.1 Environmental basic requirements..... 31
 - 3.4.2 Cooling station..... 32
 - 3.4.3 Dry cooler..... 33
 - 3.4.4 Internal dip tray – cooling liquids containment 34
 - 3.4.5 External dip tray – transformer oil containment 34
 - 3.4.6 Container insulation..... 34
 - 3.5 Climatic conditioner testing..... 35
 - 3.6 Electrical functional testing 36
 - 3.7 Power circulation testing 36
- 4. DC outlet dispenser design for ACD integration..... 38
 - 4.1 Electrical design of DC outlet..... 38
 - 4.1.1 Power section 39
 - 4.1.2 Communication section..... 39
 - 4.2 Safety and Protections 41
 - 4.2.1 Insulation monitoring device (IMD)..... 41



- 4.2.2 Residual current monitoring device (RCM) 42
- 4.2.3 Over-current protection relocation..... 43
- 4.3 Mechanical design of DC outlet..... 44
- 4.4 Basic signalling boards software and PLC control..... 44
- 4.1 Testing of the DC outlet with EV inlet..... 45
- 5. Island charger system composition and testing..... 47
 - 5.1 Main specifications..... 47
 - 5.2 Electrical functional diagram 48
 - 5.3 Proposed island preparation test composition 48
 - 5.4 Lab testing setup..... 49
- 6. IEC 61851-23-3 deviations and Possible violations..... 51
 - 6.1 Inductance violation 51
 - 6.2 Over-current protection 52
 - 6.3 No active voltage symmetry while above 920 V DC..... 52
 - 6.4 HYPOBATT project deviations to the MCS standard 54
 - 6.4.1 No MCS plugs used 54
 - 6.4.2 Non-symmetric loading of V_{DC} by the EV..... 54
 - 6.4.3 Y-capacitance surpasses limit of MCS standard..... 55
 - 6.4.4 IMD response time too slow due to high Y-capacitance on vessel..... 56
 - 6.4.1 Leakage and common-mode currents 56
- 7. DISSEMINATION, EXPLOITATION AND STANDARDISATION 57
- 8. RESULTS AND DISCUSSION 58
 - 8.1 Achieved results reflected to the objectives..... 58
 - 8.2 Discussion..... 58
- 9. CRITICAL RISKS..... 61
- 10. CONCLUSIONS 63
 - 10.1 Recommendation for future work..... 63
 - 10.2 Identification of contribution per partner 63
- 11. References 64
- 12. Appendices..... 65
 - 12.1 Appendix A – Factory acceptance tests – LV section 65
 - 12.2 Appendix B – Factory acceptance tests – MV section..... 65
 - 12.3 Appendix C – Installation manual..... 65
 - 12.4 Appendix D – DEMO preparations to WP5 testing..... 65



12.5	Appendix E – Product leaflet 3 MW charging station.....	66
12.6	Appendix F: Overload and short-circuit protection.....	67
12.7	Appendix G: 3 MW test plan.....	69
12.8	Appendix H: 3 MW test results.....	69



LIST OF ACRONYMS, ABBREVIATIONS AND DEFINITIONS

LIST OF ACRONYMS

Acronym	Definition
EoL	End of Life; For a battery is defined as the point when the SoH of the battery reach a definite remaining level
PLd	Performance Level d; Defined in the IEC 60204-1 / EN 60204: Safety of machinery - Electrical equipment of machines"
SoA	State of Art; The state of technological advancement at the date of publication of this report
SoC	State Of Charge; Amount of energy available in a battery at a specific point in time expressed as a percentage
SoH	State of Health; Figure of merit of the condition of a battery compared to its ideal conditions
SyS	System: this abbreviation is used to refer the overall charging system
SWG	SWitch-Gear: (dis)connection and protection device, typically used for the safety disconnection of a connection normally closed during operation

LIST OF ABBREVIATIONS

Abb.	Name	Definition
AC	Alternating Current	Current with alternating polarity as function of time
ACD	Automated Connection Device	Shore-side device for automated contacting with EV
AFE	Active Front-End	Active rectification converter used to perform an AC to DC power conversion. Main advantages over a passive diode rectifier is the ability to exchange energy in both directions (AC-DC and DC-AC) while optimizing power quality on both the AC and DC ports
AGV	Automated Guided Vehicle	Remote operated and controlled vehicle used for automated point-to-point transport
AMCS	Alarm Monitoring and Control System	Control system that handles and displays onboard alarms
BESS	Battery Energy Storage Systems	System of batteries with BMS, protections and communication interface to the EV
BMS	Battery Management System	Control system that manages the use of the batteries within the specifications set by the manufacturer
CB	Circuit Breaker	(dis)connection and protection device, typically used for the safety disconnection of a connection normally closed during operation. Common product versions are ACB (air CB), gas insulated (GICB) and VCB (vacuum CB)
CCS	Combined Charging System	Standardized plug definition (type-1 for USA/Can, type-2 for EU) which is a combination of communication and AC, DC power pins within one connector
CP	Control Pilot	Hardwired protective signal with low-level PWM communication line, it is used to signal charging level between the EV and the EVSE, and can be manipulated by EV to initiate charging as well as other information by PLC



CPO	Charge Point Operator	Company responsible for building, operating, and maintaining the growing network of EV charging stations
DC	Direct Current	Fixed current amplitude and polarity as function of time
DSO	Distribution System Operator	The entities responsible for the distribution and management of electrical energy from a generation source to a final customer
DT	Digital Twin	Representation -or a virtual model- of an either functional device or a physical system
EMC	Electro-Magnetic Compatibility	The ability of a device to be compatible with surrounding electrical equipment without loss of functionality by complying to a defined limit in immunity and emission of electric and magnetic field strength
EMS	Energy Management System	System of (EVSE) controller tools used by DSO or operator to monitor, control, and optimize the performance of energy generation, storage, and consumption
EV	Electric Vehicle (vessel)	Battery powered, self-propelled movable object with EVSE contacting interface
EVCC	EV communication controller	EV-side controller that communicates with the EVSE side SECC and the EV internal controllers, e.g. the BMS
EVSE	EV Supply Equipment	Shore-side charging system with EV contacting interface and infrastructure interface
FDIS	Final Draft International Standard	In the context of ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission) standards, an FDIS is one of the last stages in the development of an international standard.
GFD	Ground Fault Detection	Device that detects an AC phase to ground fault
HMI	Human Machine Interface	Component that allows interaction of a user with the electronic product in the form of a visualisation, button, sensor or sound.
HPC	High-Power Charging	Charging power class of 150-350 kW within CCS aimed for DC EV charging voltage range 200-920 V DC [1]
HW	Hard-Ware	Physical electric component, product or composed system
ICP	In-rush Current Protection	limits current at start-up
IP	Inverted Pantograph	ACD system where the pantograph (actor) is mounted on infrastructure side (mast-down or stationary) and actuates downwards
IP	Ingress Protection	System feature related to the capability to avoid the ingress of external object, dust, and liquids
IMD	Insulation Monitoring Device	monitors the insulation of a circuit with respect to PE and reports back a warning or fault status when occurring
ICT	Information Communication Technology	the use of any computers, storage, networking and other physical devices, infrastructure and processes to create, process, store, secure and exchange all forms of electronic data
IT	Isolated Terra	Electrical power system where the neutral is not connected to earth
LVD	Low Voltage Directive	The low voltage directive (LVD) (2014/35/EU) ensures that electrical equipment within certain voltage limits provides a high level of protection for European citizens, and benefits fully from the single market.



LVSC	Low-Voltage Shore Connection	Type of OPS AC shore voltage connection for vessels
MCS	Mega-Watt Charging System	Charging interface (CharIn) initiative MW charging plug-socket definition including communication, safety, and dimensions
MH	Must Have	The Outcome or requirement which MUST be integrated in the system
NA	Not Applicable	Not Applicable
NC	Normally-closed	Contact status in unpowered situation is closed
NO	Normally-open	Contact status in unpowered situation is open
NTH	Nice To Have	The Outcome or requirement is related to not necessary feature but good practice / potential benefits / latent improvement ...
OEM	Original Equipment Manufacturer	An organization that makes devices from component parts bought from other organizations
OCA	Open Charge Alliance	OCPP host association
OCPP	Open Charge Point Protocol	Standardized communication between the EVSE and the charge point operator
OSCP	Open Smart Charging Protocol	open communication protocol between a charge point management system and an energy management system. This protocol imparts a 24-hour forecast of the accessible capacity of an electricity grid
OVP	Over-Voltage Protection	Protection against a too high voltage
PC	Power Cabinet	Power Conversion cabinet with system control function
PCM	Power Conversion Module	Module determining minimal power conversion granularity on which the overall PC is based, <i>M</i> PCMs form PC
PE	Protected Earth	Protection point of electrical equipment by a guaranteed connection to earth with a limited and defined impedance
PLC	Power Line Communication	Technic superimposing AC signals on a DC powered line to setup the communication Physical Layer
PP	Proximity pin	Pin in the CCS type-2 connector detecting plug connection in the EV inlet socket
PSC	Pin-Socket Connection	ACD system where the pin (actor) is mounted on infrastructure side (mast-down or stationary) and actuates in a horizontal movement
PWM	Pulse-Width Modulation	Discretized electrical representation of an analogue signal with reduced average power
RCD	Residual-Current Detection	protection against an earth fault by detecting the leakage current of a circuit with respect to PE
RCM	Residual-Current Monitor	Monitoring function of leakage current at specified position
RMP	Roof-Mounted Pantograph	ACD system where the pantograph (actor) is mounted on the roof of the EV (EV-up or mobile) and actuates upwards
RPP	Reverse-Polarity Protection	protects against DC connection polarity reversal between the EVSE and the EV
SBC	Shore-Side Battery Charging	Using separate off-board equipment to charge an EV BESS
SCC	Short-Circuit Check	check for short circuit in the cabling between EVSE and EV
SECC	Supply equipment communication controller	EVSE-side controller that communicates with the EV-side EVCC and the EVSE internal controllers, e.g. the system manager



SEEC	Supply equipment environment conditioner	EVSE PC environmental conditioner that ensures the system climate is within the specified range of operation according to all components used within the system
SELV	Safety Extra-Low Voltage	As for IEC 61140: circuit isolated by a transformer and safe in all conditions, even in the event of an earth fault
SH	Should Have	The Outcome / Requirement is strongly recommended, if not applied a reasonable justification is needed
SIL	Safety Integrity Level	As for IEC 62061, Safety of machinery - Functional safety of safety-related control systems
SMI	Standard module interface	standardized interface between the different functions in the EVSE system
SSE	Shore-Side Electricity	Charging energy provided from shore-side
SW	Soft-Ware	Programmed instruction set to control a component, product or composed system
TBD	To Be Discussed	The Outcome / Requirement need to be discussed
TN-C	Terra Neutral - Combined	AC grid connection method of an EVSE where the Neutral and PE connections to the grid are combined
TN-S	Terra Neutral - Separate	AC grid connection method of an EVSE where the Neutral and PE connections to the grid are separated
TSO	Transport System Operator	Operator of the high-voltage transmission system, typically nation-wide with voltage levels 50-400 kV AC
TT	Terra-Terra	Electrical power system where the neutral is connected to earth
V2G	Vehicle to grid	Transfer of electrical energy from an EV via onboard or external stationary EVSE towards the grid, thereby effectively discharging the EV battery
WIR	Warning / Info / Reference	The Outcome / Requirement is relevant and need to be discussed and decision must be taken



LIST OF TABLES

Table 1 Environmental requirements.....	31
Table 2 climatic conditioner testing.....	35
Table 3 electrical functional testing.....	36
Table 4 power circulation testing in correspondence to Figure 18.....	37
Table 5 Island charging system main specifications	47



LIST OF FIGURES

Figure 1 Overview of the different products in the system and their mutual interfaces 18

Figure 2 overview of EVSE system and components; left: power cabinet and control, middle: ACD with DC outlet and coupler, EVSE-EV communication, and EV with batteries representation and control section. The 3 MW converter is shown here but apart from the MV input section, the island charger is equal..... 18

Figure 3 hard-wired safety control functions and mutual products interaction that trigger error-shutdown using a fast-stop sequence of contacts. In the ACD the fast-stop is considered as Emergency stop..... 19

Figure 4 EVSE system overall control block-diagram indicating the different sections and interactions. 20

Figure 5 overview of leading maritime, charging and industry standards applicable to HYPOBATT. This figure must be extended with ACD-related standards for D7.2 21

Figure 6 overview of the EVSE - EV interface as defined for MCS charging (source: Charln GmbH)..... 21

Figure 7 E-kat per side (port-side, PS and star-board, SB) charging power circuit SLD (in German)..... 22

Figure 8 ISO view 3D design of the power cabinet with on top the dry cooler 23

Figure 9 Single-line diagram of power cabinet electrical schematic as built in the container .24

Figure 10 Single-line diagram of the auxiliary 400 V AC power distribution from T2 to loads 25

Figure 11 - Container inside layout and dimensions 26

Figure 12 Container layout CAD drawing of actual implementation..... 27

Figure 13 ISO view 3D design of the power cabinet..... 27

Figure 14 container inner climatized compartment with distinctive cooling components; vortex fan-panels (below roof), the different parts of the internal cooling station; pumping station (blue frame), manifolds (in front), and air-liquid finned heat exchanger (yellow)..... 30

Figure 15 pictures of the cooling station components and placement in the container..... 32

Figure 16 dry cooler dimensions, will be placed on top of the container in the HYPOBATT demo. 34

Figure 17 gross container without doors showing inserted and to-be-inserted insulation panels..... 35

Figure 18 indication of power flows in circulation test setup..... 37

Figure 19 DC outlet dispenser cabinet composition, main components placement and dimensions..... 38

Figure 20 single-line diagram of the DC outlet power section..... 39

Figure 21 detailed single-line diagram of control and communication in the DC outlet with main controller HCB – SECC and the 2 low-level SECCs as indicated. 40

Figure 22 DC outlet dispenser cabinet mechanical design and realized prototype 44

Figure 23 low-level communication testing setup of SECC and EVCC to assure EVSE - EV interoperability 45

Figure 24 HYPOBATT communication testing validation setup..... 45

Figure 25 impression of the ISO 15118-20 high-level message exchange of the SECC with the EVCC 46

Figure 26 Combined SECC/EVCC signals interaction control testing setup..... 46



Figure 27 verification of communication stack interactions	46
Figure 28; 2x30 kW charger	47
Figure 29 Electrical functional diagram with control indications	48
Figure 30 dual 60 kW Island testing setup in power circulation mode with EV DC bus representing system	48
Figure 31 testing application interface.....	49
Figure 32 Island charger preparation measurement results control performance improvements.....	50
Figure 33 differential and absolute side B voltage definitions and symmetry requirements....	53
Figure 34 charging DC voltages on battery and DC bus sides.....	55
Figure 35 C1 limit, capacitance versus the human-body resistance	56
Figure 36 differences in IT charging network situations between EVSE and (non)insulated EVs wherein the non-insulated IT networks have an undefined earth (UE) return via a parasitic impedance, Z_p , alongside of the defined return impedance, Z_s	59



EXECUTIVE SUMMARY

Standardized charging solutions are key for further growth of the electric vessel market. Due to the diversity of ships, such standardized charging solutions must be scalable and modular. This is to be achieved both in architecture as in eventual mechanical, electrical and thermal product construction, and with a standardized communication interface for control, monitoring, safety, and administration.

In chapter 2, an overview of the different sections and components in the overall EV charging system (EVSE) is given and explained in relation to the system architecture as defined in D3.1 and D3.2. The overall control is explained to implicate the interactions. These sections are equal for both the 3 MW, MV AC supplied mainland-charger and the 120 kW, LV AC supplied island-charger.

As defined in D1.1, D3.1, and D3.2, initially the power converter (PC) was defined as a 1.25, 2.5, 5 MW modular building block. In this document, the 2.5 MW PC is upgraded to a 3 MW product as will be explained in chapter 3.

The core design aspects of the EVSE charging container are presented in the respective sections of chapter 3. Firstly, the complete electrical design is presented showcasing the vast number of components and functions that needed to be integrated to make a stand-alone EVSE system. Secondly, the mechanical solution to this complex jigsaw will be presented along with the resulting space availability of the cooling functions that had to be integrated to fit the overall enclosure. Performance tests of the climatic system and its behaviour during full-power circulation testing finalizes this chapter. The link between electrical functional behaviour and thermal performance is indicated and a comparison with the requirements from the conductive charging standard are made. Additionally, the error-shutdown circuit is presented and explained. This circuit assures a safe interlocked system situation and assures the propagation of a possible fast-stop; both when triggered by the Vessel it is passed on to the charger and vice versa.

The actual contacting and communication of the EVSE with the vessel is executed in the DC outlet dispenser, as explained in chapter 4. This part of the charging system is intended to be close to the vessel to assure a high communication signal integrity level. The design of the different dispenser aspects is explained therein; electrical power and communication sections, the required safety and protection features to assure safe operation, the mechanical design to obtain a good ACD integration fit, and lastly the testing of the communication between the DC outlet and the EV inlet sections according to the MCS charging standard. Integration of the DC outlet dispenser cabinet in the ACD is detailed in D4.3.

The island charger system is explained in chapter 5. It is based on a legacy Heliox charging solution which is not being sold commercially anymore. However, this platform provides a flying start to showcase the required low-power charging and can be limited in power. As with the mainland solution, it equally has been built and is tested in accordance with the DC outlet dispenser to prepare for full charging behaviour testing.

The MCS standard is on the verge of being finalized with the review of the FDIS version ongoing. In this chapter 6, the known deviations and possible violations of the currently



described requirements are listed and explained. On some of the items, exclusions or alternatives are presented. Functional testing with the coupling system will be done in T4.3, and full-scale testing of the whole system will be done in WP5. For the demo charger delivery, an installation manual will be composed after which the system will be prepared for shipment in WP5.

Keywords: HYPOBATT, vessel charging, modular, multi-MW charging, MCS, charger architecture, requirements, standardization, marine, safety, digital twin, 3 MW charging.

OBJECTIVES

Main objective: Implement and internally validate the full-scale charger based on the mutually requirements defined in D1.4, the development and prototype testing done in T3.2, and the development of the system enclosure with climate conditioner in T3.3. To do so, mechanical, and electrical production documentation has been made based on the requirements D1.4, the charger architecture defined in D3.1 and resulting multi-MW charger, and the climatic environment conditioner and system enclosure, as designed in D3.2 and D3.3 respectively. The hyper vessel charger device under test (DUT) is produced and functionally tested in a power circulation set-up. However, this testing is not yet finalized. The island charger is to be tested together with the DC outlet dispenser, the individual tests have been started, but not yet in combination. Functional testing with the coupling system will be done in T4.3, and full-scale testing of the whole system will be done in WP5. For the demo charger delivery, an installation manual will be composed after which the system will be prepared for shipment in WP5.

Additional objectives are as follows:

- Provide a report on electrical and mechanical design of charger (this report)
- Integrate enclosure, integrate cooling, and functionally test conditioner in charger (in chapter 3)
- Produce hyper vessel charger and perform functional testing and power circulation (D3.5)
- Compose installation manual of DEMO for installation in ports (in appendix C)
- Prepare DEMO (with D3.5) for shipping to perform the functional testing of the whole system composed by the modular multi-MW charger, the automated connector and the interfaces and communications in T4.3

Status fulfilment of the requirements are as follows:

- All hardware has been developed and built
- The testing of basic functional performance has been done
- The power conversion and non-functional testing is still ongoing



1. INTRODUCTION

The content presented in this deliverable D3.4 aims at providing all required information to produce, construct, install, and validate the multi-MW charger. The EVSE-EV system architecture of D3.1 has been translated towards application in the container integrated enclosure with cooling as has been designed in D3.2 and D3.3 for implementation in the container integrated demo setup of D3.5. To avoid the use of too detailed diagrams and electrical circuitry, principal diagrams and circuits are used to try and give the reader a thorough understanding of the conceptual ideas without losing herself/himself in details of certain components. The design and implementation of certain safety aspects like the IMD measurement method are detailed and aligned with the WP4 deliverables that will be presented in D4.4.

Based on the defined multi-MW charger function and interfaces, firstly in chapter 2 the generic overview of the system is given, after which the mainland charging 3 MW container product design is detailed in chapter 3. The WP3 part to be integrated in the ACD is explained and detailed in chapter 4, while the island charger details are given in chapter 5. In chapter 6, the discrepancies between the MCS standards requirements and actual HYPOBATT implementation based on the products defined in previous chapters are given. Therein some fundamental but also practical complexities are raised. In this deliverable, a suitable power conversion topology to be used has been devised that can cover all requirements of modularity and scalability for the revised insights gained through numerous discussions with potential customers and participation in standardisation taskforces on different MW-scale charging applications. The latter has been extensively done to try and align the designs in the best possible way with the currently leading draft version of the MCS standard.



2. GENERIC OVERVIEW OF THE SYSTEM

Executive Summary

In this chapter, an overview of the different sections and components in the overall EV charging system (EVSE) is given and explained in relation to the system architecture as defined in D3.1 and D3.2. The overall control is explained to implicate the interactions. These sections are equal for both the 3 MW, MV AC supplied mainland-charger and the 120 kW, LV AC supplied island-charger.

Additionally, the error-shutdown circuit is presented and explained. This circuit assures a safe interlocked system situation and assures the propagation of a possible fast-stop; both when triggered by the Vessel it is passed on to the charger and vice versa.

2.1 Products overview composing the HYPOBATT system

In Figure 1, an overview of the different products and their mutual interfaces for defining the boundaries per product are given:

1. Container, connected to:
 - 1) AC MV: **EVSE int-1**
 - 2) Control: **EVSE int-2**
 - 3) Cooler: **EVSE int-5**
 - 4) DC outlet in ACD: **EVSE int-7**
2. DC outlet, connected to:
 - 1) Container: **EVSE int-7**
 - 2) ACD: LV AC, ETH communication, 1500 V DC
3. ACD – stationary side (EVSE), connected to:
 - 1) DC outlet: LV AC, ETH communication, 1500 V DC
 - 2) ACD – mobile side (EV): **EVSE int-3** (this is exactly the MCS interface)
4. ACD – receiving side (EV), connected to:
 - 1) ACD – stationary side (EVSE): **EVSE int-3** (this is exactly the MCS interface)
5. Vessel – EV
 - 1) ACD – receiving side side (EV)

The generic EVSE system overview from Figure 1 is detailed in Figure 2, in correspondence to Figure 1 of both D3.1 and its updated version in D3.2:

- **Top-left section:** power conversion topology in the power cabinet from (in 3 MW case) MV AC to LV DC, see chapter 3.1.
- **Top-middle section:** power connection between EVSE and EV in ACD, see 4.1.1.
- **Top-right section:** simplified EV power section, for details; see Damen Frisia E-I SLD.
- **Bottom-left section:** container control composition, see Figure 4.
- **Bottom-middle section:** EVSE-side communication, see chapter 4.1.2.
- **Bottom-right section:** EV-side communication, see chapter 4.4

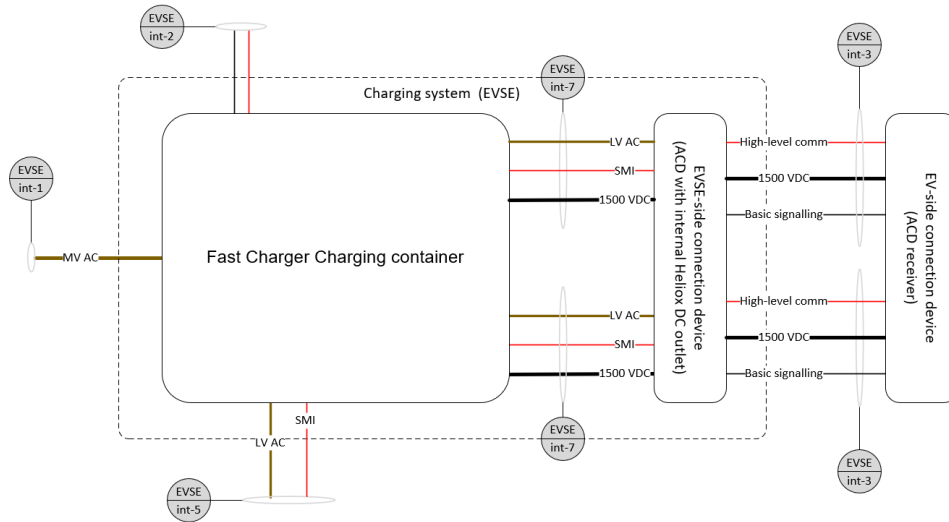


Figure 1 Overview of the different products in the system and their mutual interfaces

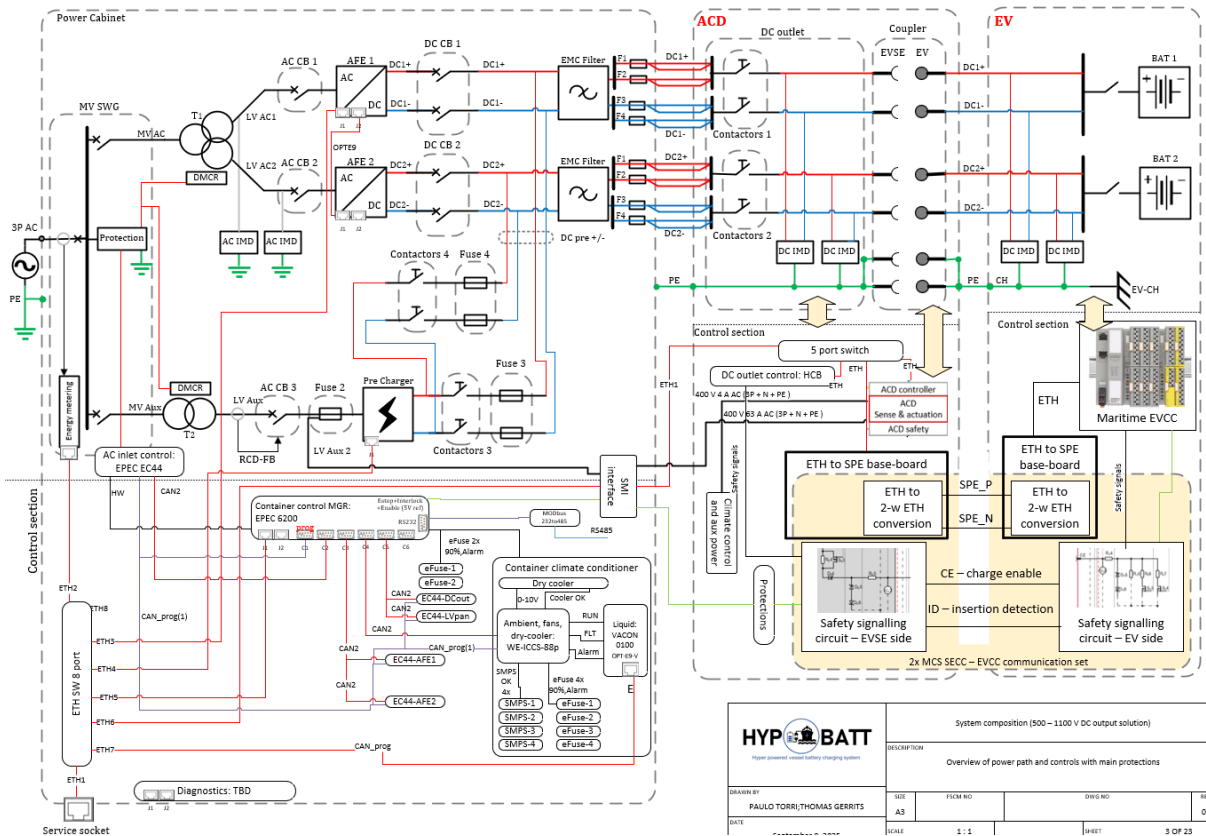


Figure 2 overview of EVSE system and components; left: power cabinet and control, middle: ACD with DC outlet and coupler, EVSE-EV communication, and EV with batteries representation and control section. The 3 MW converter is shown here but apart from the MV input section, the island charger is equal.

To ensure safe operation of the EVSE system and its interaction with the EV, the hard-wired safety circuit as depicted in Figure 3 is implemented. Therein the 2 defined safety functions interlock and fast-stop are detailed.

The interlock is a series connection of all normally-open (NO) door contacts in this implementation since no other connections such as HV DC power connections are present in

the system. The EVSE is enabled to start a charging session if the interlock chain is closed, meaning that all doors are closed. If during active operation the interlock is breached, a fast-stop is triggered to assure a safe situation.

The fast-stop safety function is a normally-closed (NC) series connected circuit of different components per indicated product. In the container, these are the safety functions of e.g. MV and LV switchgear. In the ACD this is an emergency stop function in the form of a remote control managed by the captain of the EV and optionally a public emergency-stop on shore side. In the DC outlet the fast-stop function can be triggered by 3 functions:

- 1) Excessive residual current towards the vessel detected by the residual current monitor (RCM) sensor. This triggers a full stop equal to the container, ACD and EV
- 2) Either SECC 1, OR SECC 2, OR the HCB triggers a single-channel fast-stop; this leads to the interruption of the charging session of that respective channel by triggering state E on both EVSE and EV side.
- 3) The HCB triggers a fast-stop equal to the container, ACD and EV can trigger by setting both SECC 1 AND SECC 2 in state E, leading to a fast-stop at EVSE and EV sides. This is implemented with the logic AND function of the NC contacts in the SECCs.

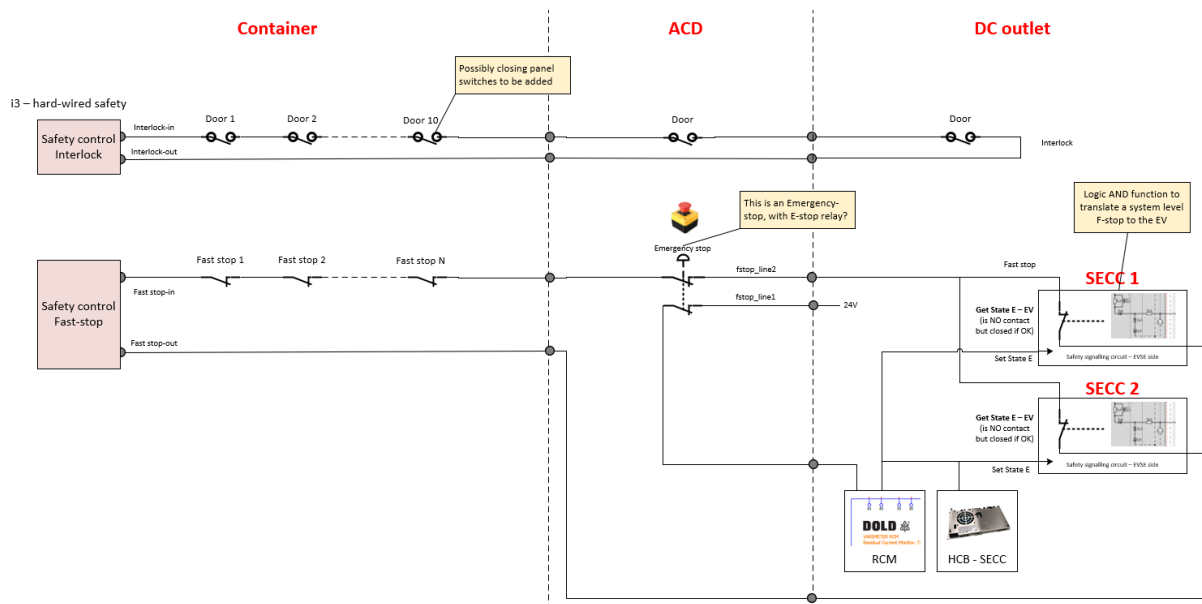


Figure 3 hard-wired safety control functions and mutual products interaction that trigger error-shutdown using a fast-stop sequence of contacts. In the ACD the fast-stop is considered as Emergency stop.

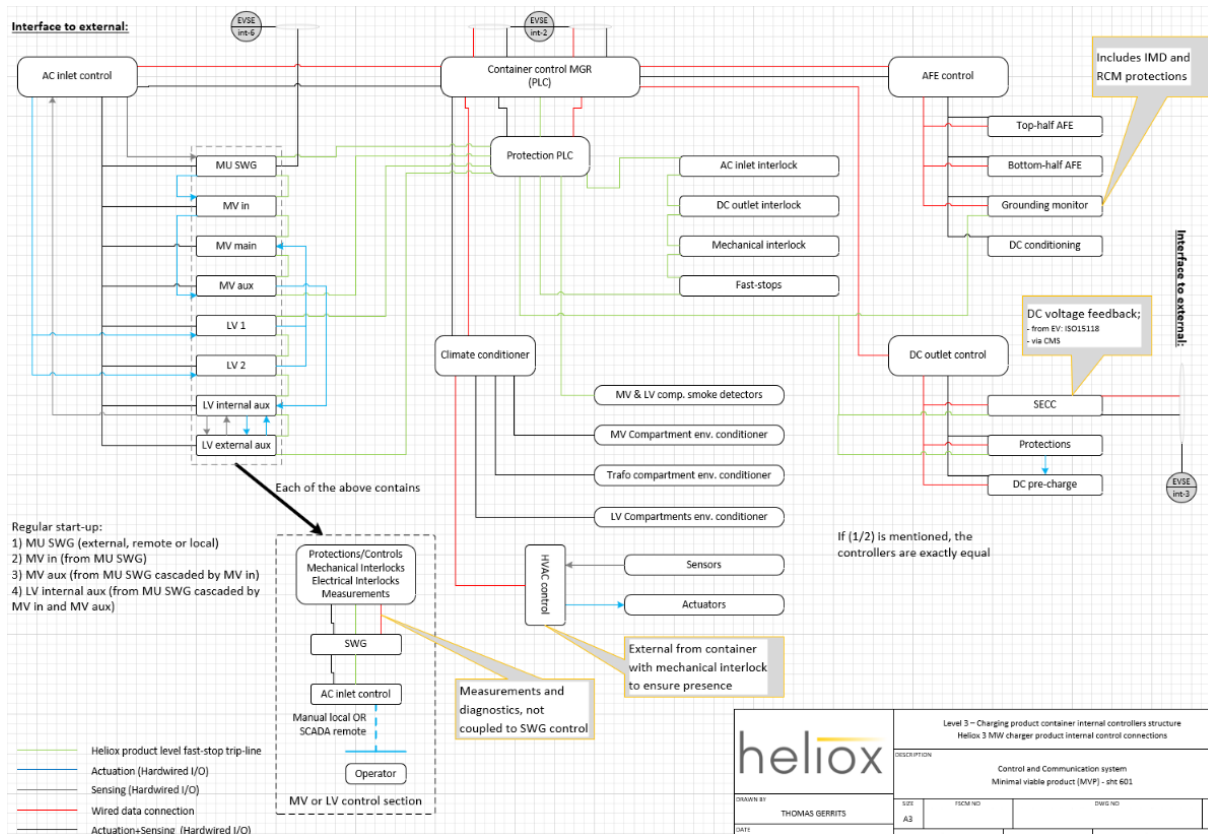


Figure 4 EVSE system overall control block-diagram indicating the different sections and interactions.

The complete EVSE is controlled with a set of control devices as indicated in the lower section of Figure 2. The functional division of these controls is given in Figure 4. Therein, the main control functions are indicated being:

- **AC inlet control:** assuring proper and safe operation of AC MV and LV sections.
- **Container control manager (MGR):** allows integration of multiple 3 MW units in a larger EVSE acting as one power conversion system. Manages the combined use of these units in relation to grid connection loading and charging sessions.
- **Climate conditioner:** controls the internal and external climate to be kept within safe operating range and reduces performance or shuts off in case these are exceeded.
- **Protection PLC:** gathers the safety feedback of all other control functions and decides the system- and per charging-session-status.
- **AFE control:** controls the power conversion active front-end (AFE) based on respective SECC defined voltage- and current-setpoints.
- **DC outlet control:** performs

Each of the above sections control all functions listed, assure and verify the intended status of each component/device, and monitor the numerous resulting parameters, i.e. voltages, currents, timings, temperatures, etc.

2.2 Standards plotted to HYPOBATT charging system

To cover the gaps in SCB-DC as presented in D1.1, the automotive standards are used. More specifically, the MCS type. Since the HYPOBATT charging system is composed of shore- and

vessel-side products, and because the maritime-, charging- and industry-related standards apply, there is quite an extensive set of standards relevant, from which the leading ones are depicted in Figure 5. All relevant standards mentioned in [2] and [3] are included.

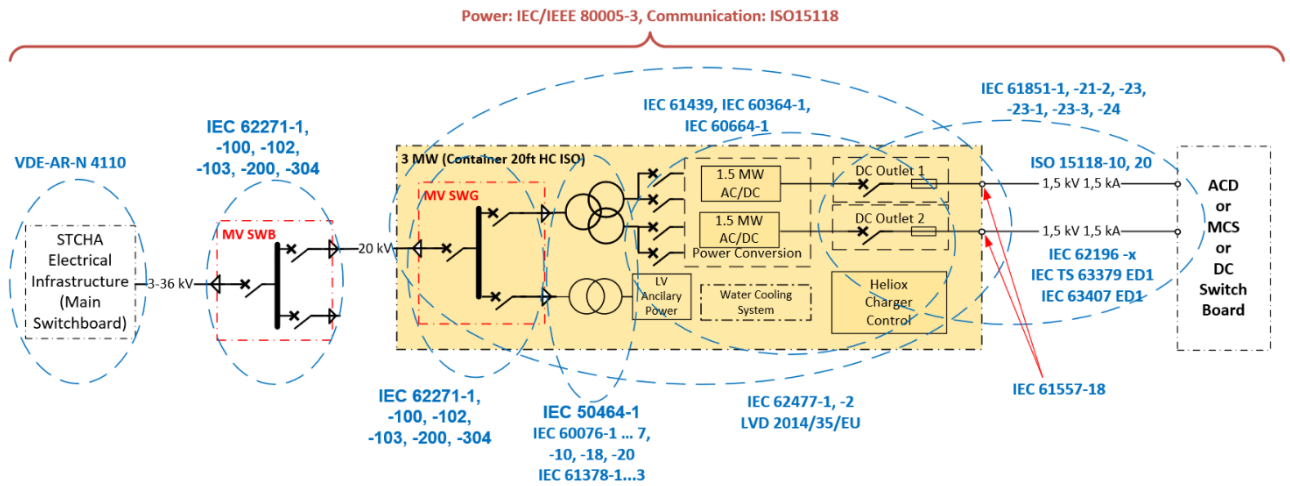


Figure 5 overview of leading maritime, charging and industry standards applicable to HYPOBATT. This figure must be extended with ACD-related standards for D7.2

2.3 Charging system related standards

The actual charging process will be performed as defined in the IEC 61851 series of which the applicable parts are listed in D1.1. Following parts are especially important in relation to MCS:

- ISO 15118-10: automotive based Ethernet as physical layer (SPE, 10base-T1S)
- ISO 15118-20: charging communication protocol (encrypted with TLS 1.3)
- IEC 61851-23-3: system and safety requirements (SAE J3271 is US/Can equivalent)
- ISO 5474-3: safety and interoperability of charging system

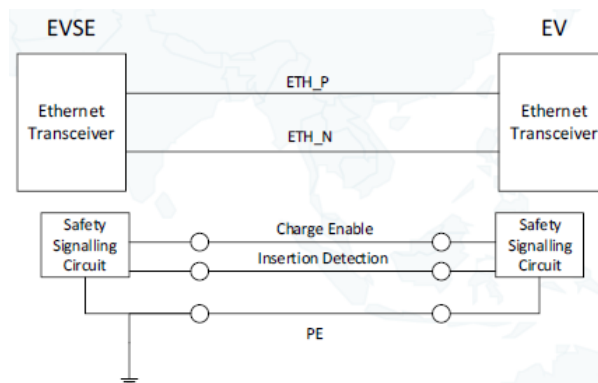


Figure 6 overview of the EVSE - EV interface as defined for MCS charging (source: CharIn GmbH)

2.4 Description of the vessel-side power circuit

The power circuit per side of the E-kat EV is shown in below Figure 7, which is equal for port-side (PS) and starboard (SB) sides. These power circuits are galvanically isolated, and each monitored with an IMD. The main components are:

- Batteries (BB) see specifications in diagram, voltage range: 672-869 V DC, nominal: 777 V

- DC/DC converters ensuring a fixed DC-BUS voltage from BB
- DC-BUS: voltage range: 950-1000 V DC, nominal 970 V
- Over- and short-circuit protection between charger and DC-BUS: 1000 A
- DC inlet to land-connection (MCS in commercial, ACD counterpart in HYPOBATT)
- Additionally, there are loads connected to the DC-BUS (not shown)

The charging system will thus be used as a constant voltage (CV) source supplying **per side**:

- voltage range: 950 – 1000 V DC, nominal 970 V, will be CV but can vary within this range
- current range: 25 – 920 A DC, unidirectional in the direction towards the vessel batteries
- power range: 24 – 900 kW

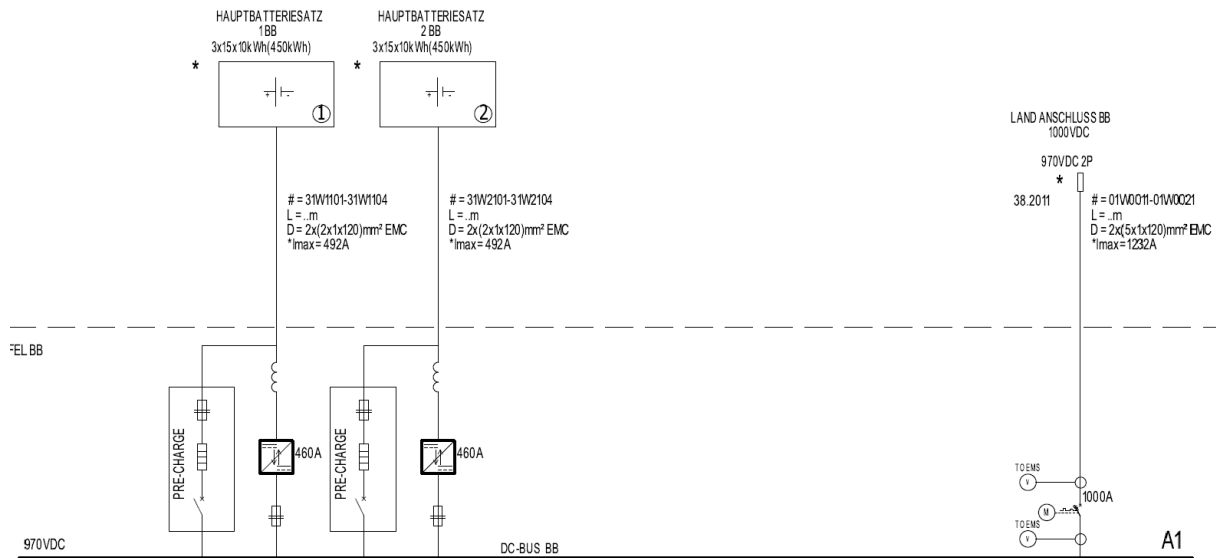


Figure 7 E-kat per side (port-side, PS and star-board, SB) charging power circuit SLD (in German).

3. 3 MW CHARGING CONTAINER

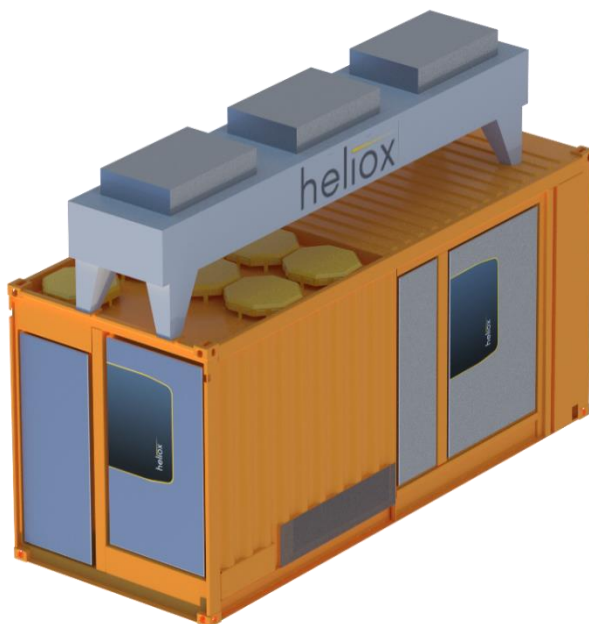
Executive Summary

The core design aspects of the EVSE charging container are presented in the respective sections of this chapter. Firstly, the complete electrical design is presented showcasing the vast number of components and functions that needed to be integrated to make a stand-alone EVSE system. Secondly, the mechanical solution to this complex jigsaw will be presented along with the resulting space availability of the cooling functions that had to be integrated to fit the overall enclosure.

Performance tests of the climatic system and its behaviour during full-power circulation testing finalizes this chapter. The link between electrical functional behaviour and thermal performance is indicated and a comparison with the requirements from the conductive charging standard are made.

The exterior initial design and resulting first prototype container are depicted in Figure 8a, and b, respectively. The main distinctive components shown are:

- **Top cooler:** C5 dry cooler suitable for Marine environment and capable of extracting 85 kW of heat from the container.
- **Transformers section** (below yellow circles in Figure 8a): direct ambient-air cooled section to extract heat generated by the 2 MV//LV transformers.
- **MV switchgear section** (front-left doors in Figure 8a): ensuring safe (dis) connection of the charging system with respect to the incoming MV grid.
- **LV power sections** (right doors in both Figure 8a&b): houses the power conversion.
- **LV control** (top-left doors in Figure 8b): houses all control and auxiliary power parts.
- **LV DC distribution** (bottom-left doors in Figure 8b): all LV connections to the field.



(a) CAD render, MV side front-left



(b) actual product, LV side front-left

Figure 8 ISO view 3D design of the power cabinet with on top the dry cooler

As defined in D1.1, D3.1, and D3.2, initially the power converter (PC) was defined as a 1.25, 2.5, 5 MW modular building block. Although 3 MW is used here to describe the maximum

continuous performance level, the 2.5 MW power level is required to be achievable irrespective of the environmental situation, as listed in Table 1.

3.1 Electrical design of charger

In Figure 9, the single-line diagram (SLD) of the container internal electrical schematic is depicted. Therein, the different sections of the system can be identified as:

- **MV switchgear (SWG) section** (left dashed): incoming and 2 outgoing fields for the protection of the grid connection, main power transformer (T1), and the auxiliary supply transformer (T2), respectively.
- **Transformer section:**
 - Main power transformer (T1): 20/0.35 kV, 3.15 MVA transformer with 2 LV windings to supply the two power conversion circuits.
 - Auxiliary supply transformer (T2): 20/0.4 kV 100 kVA transformer in TN-S grid configuration to supply all auxiliary 3P and 1P loads in the system.
- **Power conversion sections** (top): 2 identical AC/DC power conversion stages capable of transforming the 350 V AC from T1 to a variable DC voltage in the range 500-1100 V DC. The main components for protection, conversion, and filtering are indicated.
- **Auxiliary supply section:** LV distribution of AC voltage to supply the different indicated loads; ACD (63 A), Aux (32 A), HVAC/dry cooler (63 A), pumping station (16 A), pre-charge supply (32 A) and internal 3P LV control functions (16 A), and 1P control functions(2x 16 A), as indicated in both Figure 9 and Figure 10.
- **Pre-charge section:** performs the pre-charging of 3 functions:
 - **AFE drives:** the individual drives can be DC pre-charged to bring them online and assure proper power conversion behaviour afterwards.
 - **DC line pre-charge:** to pre-charge the field wiring up to the dispenser.
 - **Short-circuit check:** to assure a safe EVSE-EV system status prior to charging, the DC circuit up to the incoming contactor of the EV can be pre-charged. The EV can sense the voltage present while the EVSE limits the current.

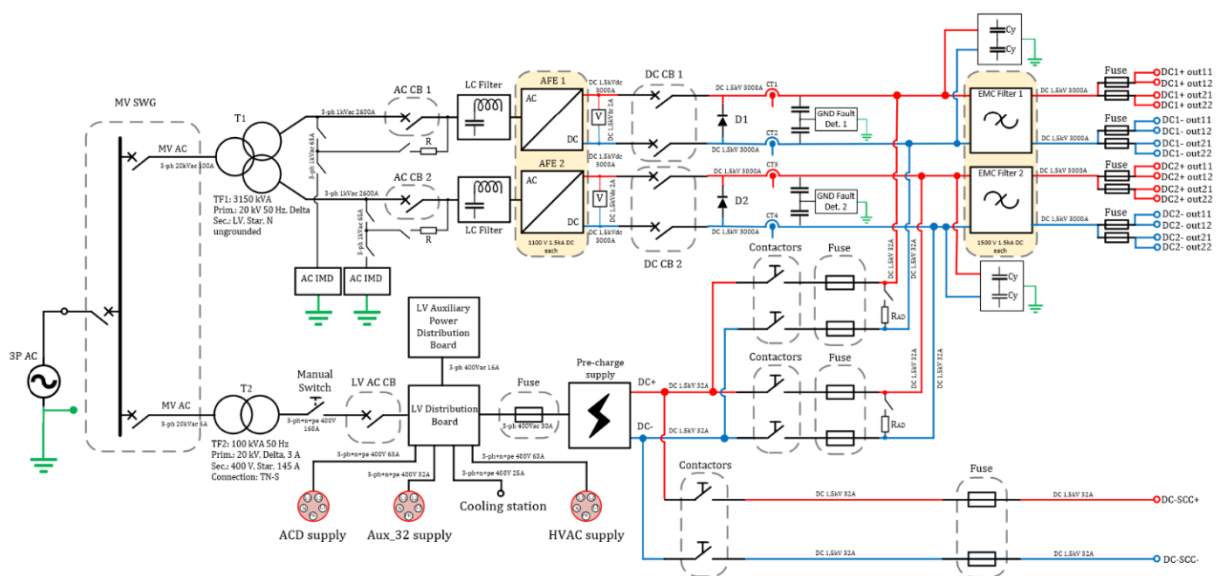


Figure 9 Single-line diagram of power cabinet electrical schematic as built in the container

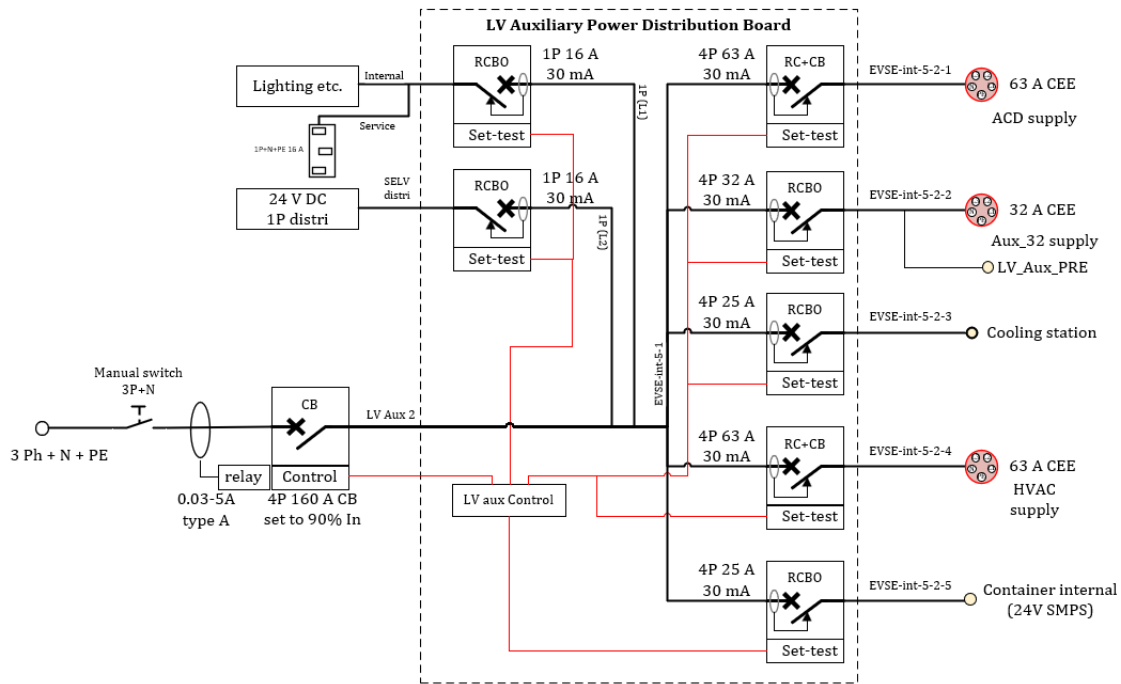


Figure 10 Single-line diagram of the auxiliary 400 V AC power distribution from T2 to loads

3.2 Mechanical design of charger

The starting point for the mechanical design of the charger was a 20 ft high-cube container. Initially, it was expected that a standard shipping container could be outfitted with the required electrical and thermal mgmt. components. However, the final outcome as shown in Figure 8b is a fully custom-made product with all parts tailored to the needs of the electrical components.

The power cabinet external and sectioned internal mechanical CAD design are based on Figure 11 and extensive discussions of which the result is shown in Figure 13a, and b, respectively. An overview of the actual internal sections is given in the container layout of Figure 12. The basic specifications to which it has been designed are:

- 20 ft High cube container (ISO 668-1CCC), vandal resistance: IK11.
 - With all corner castings, loading capabilities according to ISO 668
 - Re-certified after construction (not yet achieved)
 - Estimated gross weight: 22.000 kg (fully equipped)
- No forklift openings (only corner casting or lifting eyes hoisting allowed), see Figure 8b.
- Transformer enclosure compartments with upwards air relief direction:
 - Transformers each IP65 rated
 - Cooling air is taken into the transformers compartment via the grid-irons on the 2 longitudinal container sides by creating under-pressure with the 7 roof-mounted fans.
 - Air-circulation for T1 performed with 6 pieces of 3 phase 500 W PWM controlled fans.
 - Air-circulation for T2 performed with 1 piece of 3 phase 500 W PWM controlled fan.
- Container ingress protection: IP67. According to Req_D1.4-033 on Deliverable 1.4.
- Doors on short sides give access to; left: MV SWG, right: LV DC cabling and control.
- Doors on longitudinal sides give access to conditioned compartments (only in workshop)

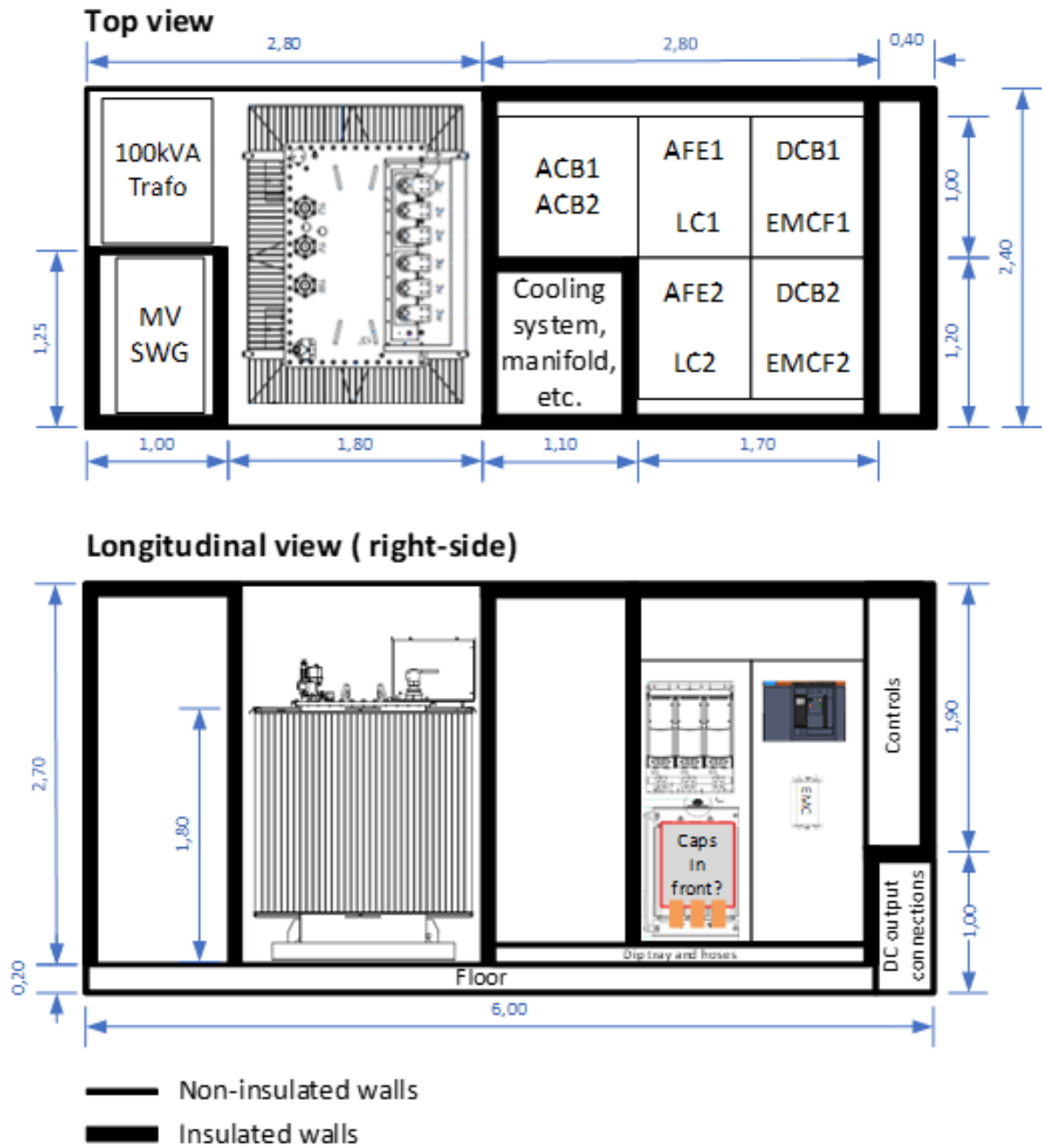


Figure 11 - Container inside layout and dimensions

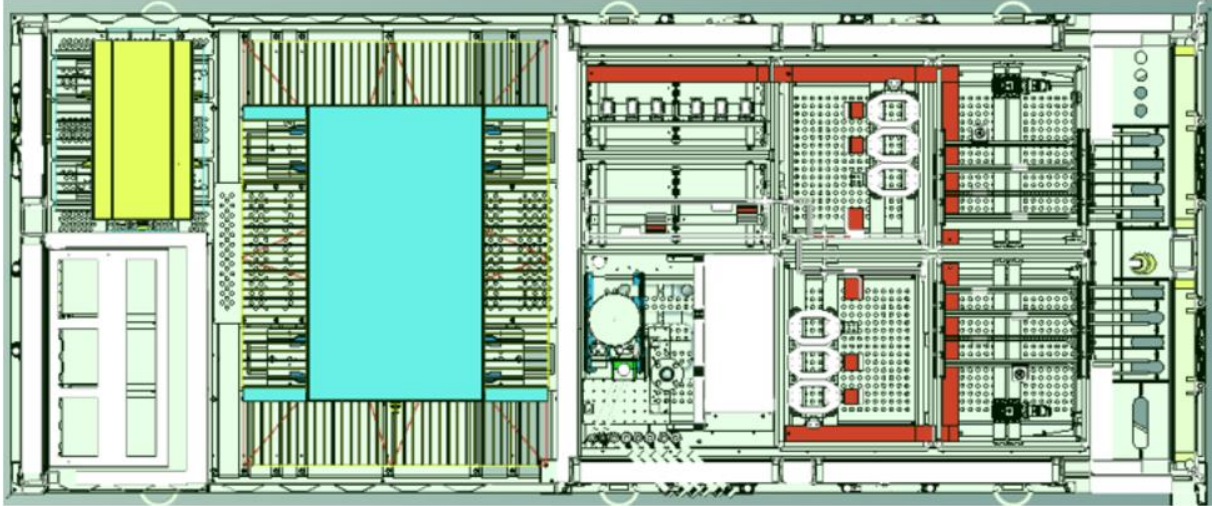


Figure 12 Container layout CAD drawing of actual implementation

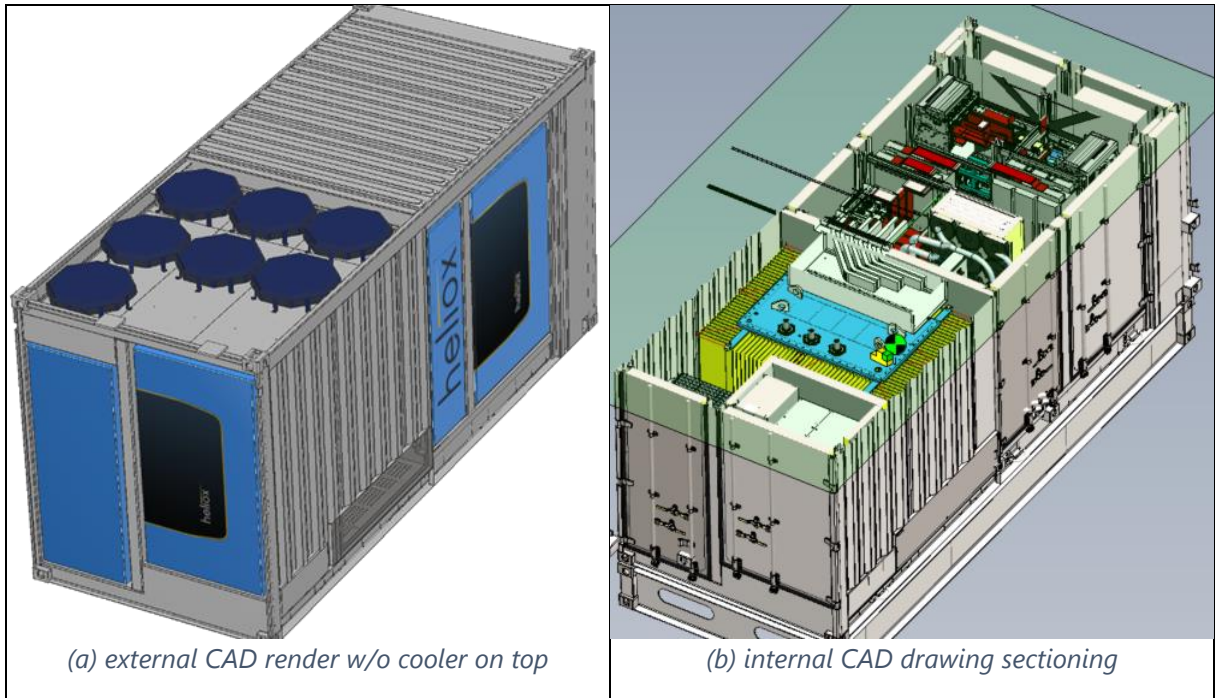


Figure 13 ISO view 3D design of the power cabinet



3.3 Safety and protections

3.3.1 Medium voltage switchgear

MV SWG: thermal over-current (OCP) and short circuit protection (SCP) of the incoming feeder and transformers

- OCP level: range of the SWG: 7.2 – 630 A
 - Incoming: 120 A
 - To T1: 100 A
 - To T2: 7.2 A
- SCP level: breaking current 20 kA
- Incoming field is equipped with voltage, current, power, cos-phi measurements

3.3.2 Transformer protections

Throughout their use, there have been numerous objections to the use of oil-cooled transformers alike the oil-natural convection air forced (ONAF) version applied in this design. To assure safe operation within its thermal specifications, the following protections are added to each transformer. With the below mentioned protections, oil transformers are used for high-temperature environments e.g. solar skids all over the world.

3.3.2.1 DMCR protection relay

A DMCR (Detection, Measurement, and Control Relay) is a protection relay used in hermetically sealed oil-immersed transformers. It provides comprehensive protection by monitoring and controlling several critical parameters within the transformer. Here are the main functions and protections offered by a DMCR relay:

1. **Dielectric Fluid Level:** It monitors the level of the insulating oil (dielectric fluid) inside the transformer. If the oil level drops too low, it can indicate a leak or internal gas emission, which could lead to serious faults.
2. **Pressure Control:** The relay measures the internal pressure of the transformer tank. Excessive pressure can be a sign of overheating or other internal issues. The DMCR relay can trigger alarms or shut down the transformer to prevent damage.
3. **Temperature Monitoring:** It keeps track of the oil temperature at two different thresholds. Overheating can be caused by continuous overvoltage or insufficient cooling. The relay can activate alarms or de-energize the transformer if the temperature exceeds safe limits
4. **Gas Detection:** The relay can detect the presence of gas within the transformer, which can be a byproduct of internal faults or overheating. This helps in identifying potential issues before they become critical

By continuously monitoring these parameters, the DMCR relay ensures the safe and efficient operation of oil-immersed transformers, protecting them from internal faults, prolonged over-voltages, and fire risks associated with inflammable dielectric fluids.



3.3.2.2 Temperature control

Based on the ambient, casing, and internal oil temperatures, the cooling fans on top of the transformers are controlled such that during normal operation air-forced (AF) cooling is applied as a function of the difference between these temperatures. Basically, there are 4 operating modes:

- 1) Idle: no fan active
- 2) Normal operation: fans PWM controlled
- 3) Derating: fans on max power and charger power decreases until transformer temperature stabilizes to $< 100\text{ }^{\circ}\text{C}$
- 4) Over-temperature: once derating does not lower transformer temperature the charging is stopped.

3.3.2.3 Mechanical composition temperature transfer main transformer

Main transformer T1 is deliberately confined in the container to assure airflow in between the fins. The design is tightly made with the goals to effectively cool while preventing thermal conductive heat transfer to the container walls. This all fits but thermal performance and conductive heat transfer will be verified during test.

3.3.2.4 Over-current protection auxiliary transformer

Auxiliary transformer T2 has no thermal current limitation from the MV SWG since the thermal current limit cannot be set sufficiently low to protect it. 7.2 A/phase is the lowest SWG setting while 2.9 A is the full-load RMS current. This will be monitored and protected by:

- LV side maximum current is limited to 110% of nominal power transformer
- Thermal protections avoid overheating
- Controls will be used to reduce loading in case of overheating
- DMCR relay will switch off transformer as final protection

3.3.3 AC insulation monitoring device

The IT sections of the charger are continuously monitored by the insulation monitoring devices. The DC-side IMD installed in the DC outlet measures the impedance of the two DC conductors with respect to PE. If the impedance drops below a threshold value, a warning or an error is provided. In the event of an error message, the charging process will be stopped. Since the DC section is not connected to T1 in advance of pre-charging the AFEs, the LV AC-sided insulation is monitored with the AC-IMDs until the whole circuit is connected. These IMDs can be disconnected to allow for the DC-sided IMD to take over when power circuit is active.

3.3.4 LV over-current protections

3.3.4.1 AC

AC circuit breaker (CB, 3-pole) with parallel LC-filter pre-charge: thermal- and peak-current limiting devices. AC-CB levels:

- OCP range: $0.4 - 1 \times I_n$, $I_n = 3200\text{ A}$ (1280 – 3200)

- SCP level: 66 kA

3.3.4.2 DC

- DC CB: configurable 4-pole 750 or 2-pole 1500 V DC breaker, DC-CB levels:
 - OCP range: 0.4 – 1 x I_n , $I_n = 3200$ A (1280 – 3200)
 - SCP level: 60 kA
- DC output fuse: OCP level: 1000 A, SCP level: 250 kA, 1500 V DC used to thermally protect 2 parallel conductors towards the dispenser.

3.4 Integrated enclosure and cooling functions

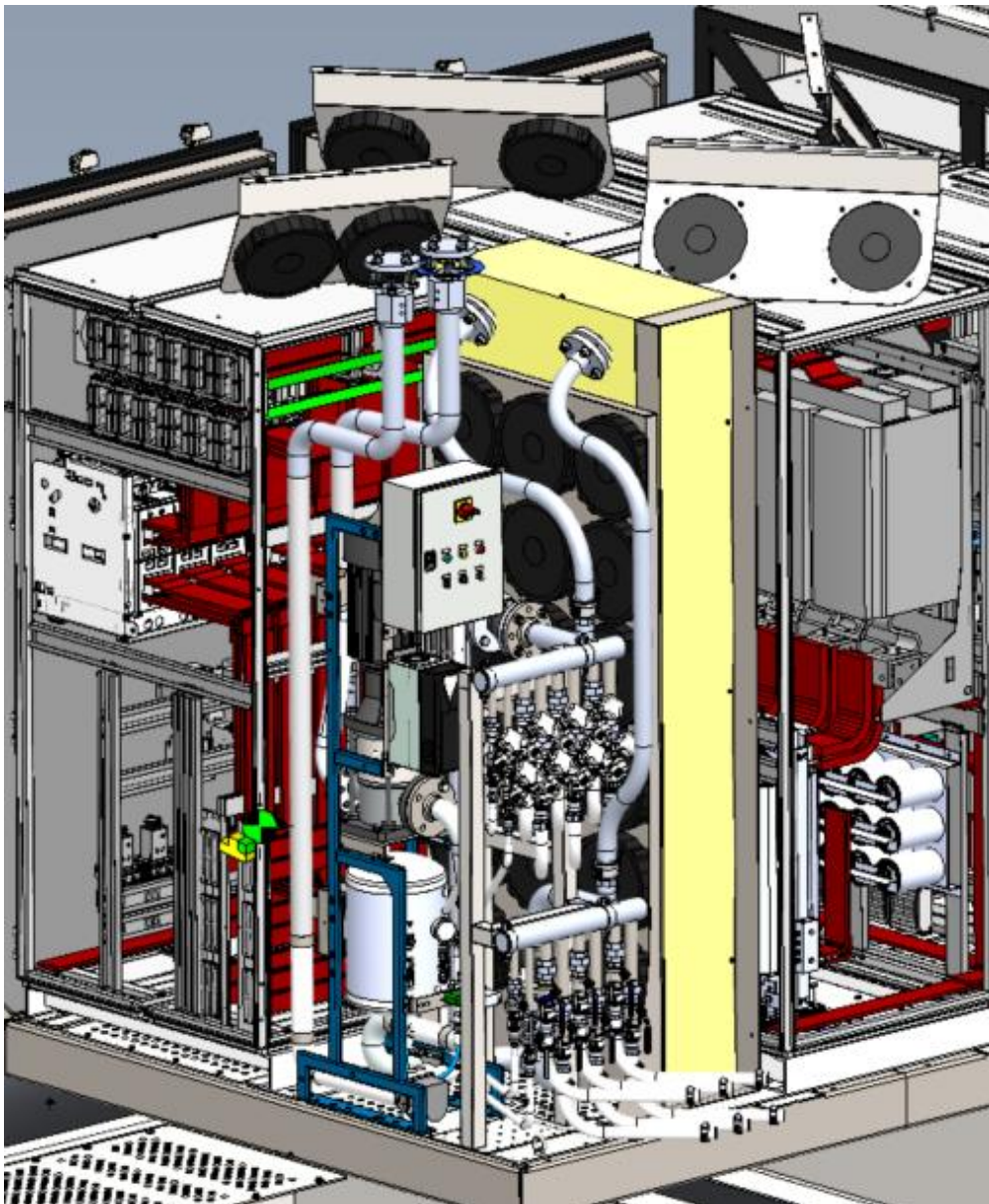


Figure 14 container inner climatized compartment with distinctive cooling components; vortex fan-panels (below roof), the different parts of the internal cooling station; pumping station (blue frame), manifolds (in front), and air-liquid finned heat exchanger (yellow).



The container must house, protect, and thermally stabilize all components needed for power conversion and control of the EVSE. The intention is to maximize mechanical rigidity and thermal performance while keeping as much space available inside for component placement.

All distinctive thermal management system (TMS) components are separately specified, designed and build in accordance with the requirements set during the container design. Individual components are further detailed in following sections. All components are installed and integrated into the container. Since it is impossible to take a picture of the complete charger-internal, a 3D view from the CAD drawing is used to show how the integrated enclosure and cooling system are composed, as depicted in Figure 14. The step-by-step transition of heat from generated in a component inside of the container towards outside ambient temperature is:

- **Forced air circulation:** closed circuit air circulation inside of the conditioned compartment, executed by 21 circulation fans and 8 vortex fans for hot spots.
- **Finned tube air plate exchanger:** extracts heat from the conditioned compartment.
- **Heat transfer:** Cooling liquid is circulated from direct liquid cooled components and plate exchanger towards the external dry cooler. Performed by manifolds and pump.
- **Finned tube air plate exchanger:** releases the heat from the hot liquid to the ambient air outside of the system (part of the dry cooler).
- **Forced air circulation:** open circuit air circulation from bottom to top, executed by 3 circulation fans (part of the dry cooler).

3.4.1 Environmental basic requirements

The different requirements related to the cooling system, allowed ambient conditions and humidity are listed below in Table 1. These are solely the requirements for a dry-cooler based climate conditioner on the charging system. The main thermal vs. performance requirement is that under all conditions in Table 1 the 2.5 MW power defined as modularity building scale from D3.1 can be achieved still. The 3 MW is under standard ambient range compliant MCS.

Table 1 Environmental requirements

	Min.	Nom	Max.	Remark
Charger standard ambient temperature range	-20 °C		40 °C	Unlimited output power
Charger extended ambient temperature range	-30 °C		50 °C	Derating outside standard 3 MW range, still assuring the modular 2.5 MW
Intake air temperature				Equal to ambient
Exhausted air temperature			60 °C	In operational mode
Storage temperature	5 °C		40 °C	If EVSE not ON
Cabinet internal temperature	0 °C	25 °C	50 °C	Operational Non-operational
Cabinet internal derating temperature	45 °C		50 °C	Derate power 20% / °C
Ambient relative average humidity			95%	Non-condensing
Ambient relative peak humidity			100%	Non-condensing
Container internal relative humidity			90%	Non-condensing

3.4.2 Cooling station

The cooling station assures that generated heat is removed in case of over-temperature, or that components are heat-conditioned when the ambient temperature is too low. Excess heat is transported to the external cooling system. If insufficient heat is produced in the container to keep the internal temperature above the specified level, the circulating liquid is heated after which this energy is used to pre-condition components and internal circulation air.

3.4.2.1 Conditioned internal compartment finned heat exchanger

The finned tube air heat exchanger transfers heat between a fluid inside the tubes and air flowing over the outside in the conditioned container compartment. The tubes are fitted with extended surfaces, or fins, which greatly increase the contact area with the air. This enhanced surface area improves heat transfer efficiency, especially since air has low thermal conductivity compared to liquids. Hot or cold fluid flows inside the tubes, while air passes across the fins, allowing efficient heating or cooling. The internal finned heat exchanger is a custom-made design that is aimed to extract a maximum of 35 kW of excess heat from the conditioned compartment. As shown in Figure 14, fans are placed on the surface area of the finned heat exchanger to increase and regulate the air speed over the fins. PWM controlled fans are used.

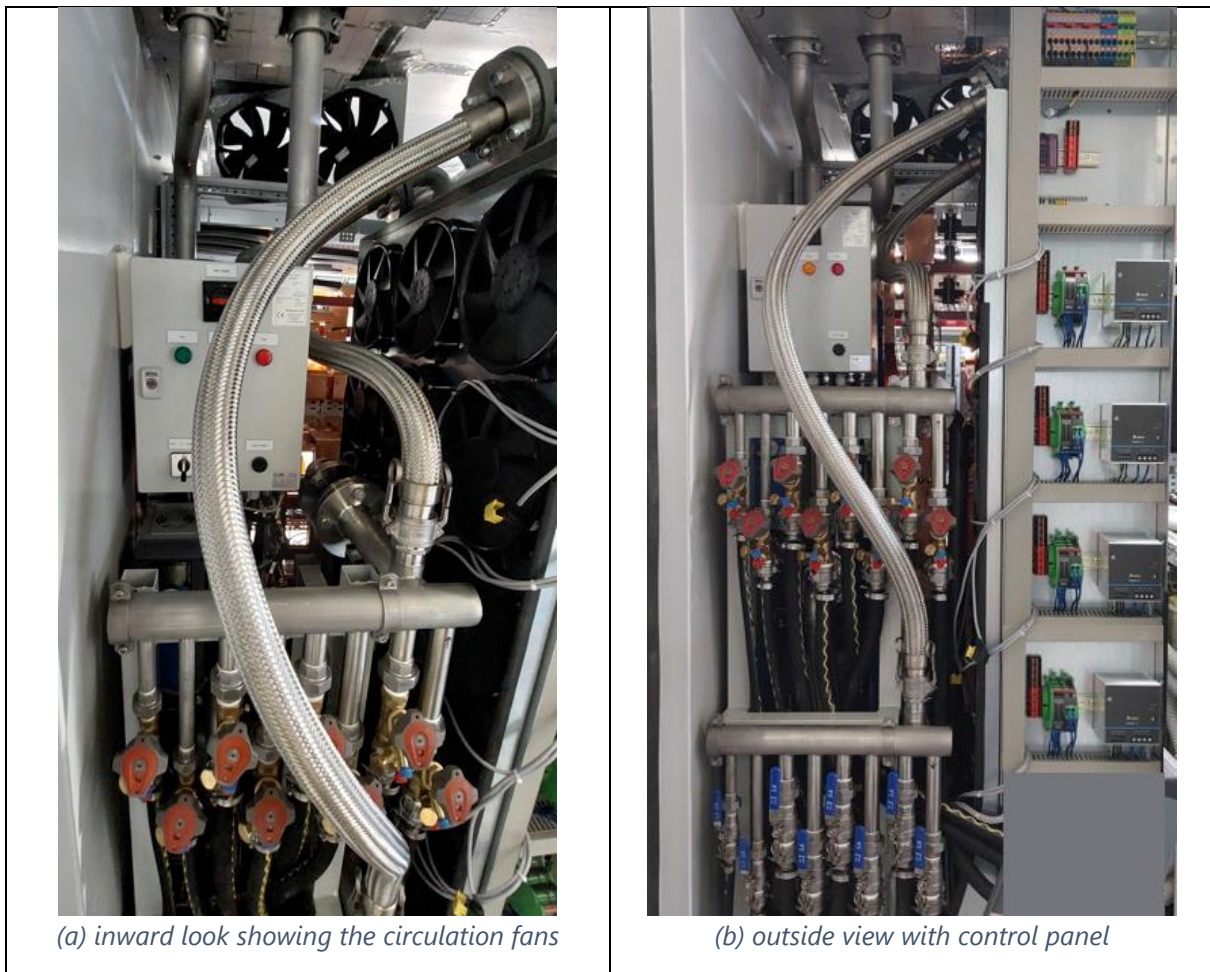


Figure 15 pictures of the cooling station components and placement in the container



3.4.2.2 Manifolds

The manifolds are placed at the designated area next to the temperature-controlled electronic cabinets area, as shown in Figure 15b. Main function of the manifolds is the distribution and flow-regulation of the cooling liquids towards the different components. Additionally, the hose connections are provided that give a flexible connection to the respective components. Each manifold output furthermore has a ball valve to stop the flow and a flow reducer. Each return hose has a drain cap, to drain the water on a component level.

3.4.2.3 Pumping station

The pumping station primarily ensures sufficient overall flow based on liquid temperatures in the system. The pumping station is a custom designed product to assure sufficient flow while complying to the stringent dimensional width requirement of 300 mm, the main features are:

- Single pump version (no redundancy) that is powered by an inverter running at 60 Hz. This significantly increases the pressure and flow capacity (max. power @50 Hz = 3 kW, @60 Hz = 4 kW).
- A buffer vessel is added instead of pressure vessel to ensure sufficient liquid in the system, needed because we have a dry cooler not directly connected to the station.
- Cooling is performed by passing through external cooler and release heat to ambient.
- Heating is performed by a resistive element in the buffer vessel; this is distributed to the electronics via the liquid hoses and via the internal heat exchanger.
- Since the pump is frequency controlled, a bypass valve is not included. Instead, the function of not passing the cooling liquid through the external cooler is achieved by reducing or even completely stalling the flow. Downside of this is that to pre-heat the system, liquid must be passed through the external circuit (with fans off).
- In this compact configuration, the inclusion of the by-pass valve was not possible.

3.4.3 Dry cooler

The dry cooler consists of a finned tube air heat exchanger and a set of fans to assure forced circulation. The fans are PWM controlled for speed regulation, thereby the noise of the fans can be limited if the TMS allows for this. The main specifications of the dry cooler are:

- Cooling capacity: 85 kW
- Max. air flow: 59056 m³/h
- Max. electric power needed: 3.9 kW (3 fans of 1.3 kW each)
- Environmental rating: C5 (marine or industrial)

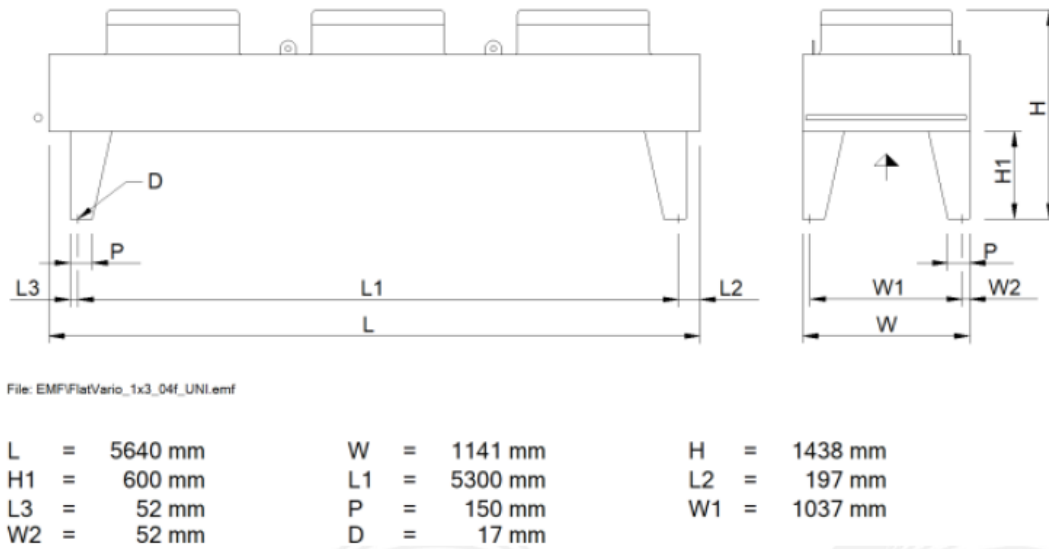


Figure 16 dry cooler dimensions, will be placed on top of the container in the HYPOBATT demo.

3.4.4 Internal dip tray – cooling liquids containment

The container climatised compartment holds an internal dip tray for the containment of cooling liquids that could leak from any of the TMS components or connections between them. Schematically indicated as **dip tray** in *Figure 11*, the longitudinal view. No hazardous liquids are used within the TMS, however, still this containment solution has been included in the design. A submersible pump can be used to drain the tray during maintenance. The volume is sufficient to hold all liquid cooling present in the system. A level sensor is placed to detect presence of fluids.

3.4.5 External dip tray – transformer oil containment

Container base structure integrated dip tray running completely below transformers, MV SWG and internal dip tray as schematically indicated as **Floor** in *Figure 11*, the longitudinal view. For the containment of oil that could leak from one of the MV//LV transformers. No hazardous oil is used (ester oil), however, still this containment solution has been included in the design. A submersible pump can be used to drain the tray during maintenance. The volume is sufficient to hold all transformer oil present in the system. The roof-structure over the transformers is designed such, that no rainwater will fall into the external drip tray. This is drained via the walls of the container. A level sensor is placed to detect presence of fluids.

3.4.6 Container insulation

To achieve the climatic requirements listed in Table 1, it was a prerequisite to fully insulate the container; a non-insulated container in sunlight can reach temperatures of up to 70 °C. The insulation requirements to the container are indicated in *Figure 11*, and the implementation of insulating the container is shown in *Figure 17*. The doors of the conditioned compartments are also internally insulated. In all cases a 10 cm thick polyurethane insulation is used with a Lambda λ : 0.022 W/mK and protected with aluminium laminated paper.



Figure 17 gross container without doors showing inserted and to-be-inserted insulation panels.

3.5 Climatic conditioner testing

Tests of the basic functions and communication of the cooling station with the power cabinet main controllers have been conducted successfully. Listed in below Table 2 are the main functions of the climatic conditioner and each corresponding status.

Table 2 climatic conditioner testing

Test	Description	Status
IO control	Read-back status of all IO to the climatic condition controller, i.e. logic, PWM and analogue FB	All tested individually and working (100%)
Communication control	Communication of climatic controller with PC main control to assure proper overall functioning	Basic communication working, signalling to be extended still (50%)
Fan control	PWM speed control and FB for different fan groups: <ul style="list-style-type: none"> Heat exchanger (18x) Vortex circulation (8x) Main T1 cooling (6x) Aux T2 cooling (1x) Dry cooler release (3x) 	Each respective: <ul style="list-style-type: none"> 100% 100% 100% 100% 0%
Pumping station start	Pressure buildup, air relief from liquids circuit and start of controlled flow of cooling aid.	Attempted but not yet successful (50%)
Pumping station run	Temperature controlled flow adaption to assure intended behaviour, heating and cooling	0%



Flow tuning and verification	Assuring intended flow per individual cooling loop in the system as a function of combined total flow	30%
Thermal control perf.	Total cooling system working and controlled based on internal vs. ambient temperature	30%

3.6 Electrical functional testing

Tests of the basic electrical functions and communication of the local controls with the power cabinet main controllers have been conducted successfully. Listed in below Table 3 are the main electrical functions and each corresponding status.

Table 3 electrical functional testing

Test	Description	Status
MV SWG	Switching and control feeder field	100%
	Switching and control main load field (T1)	100%
	Switching and control aux load field (T2)	75% - malfunction of under-voltage lockout coil detected. Awaiting support supplier
Transformer FB and control	DMCR and thermal protections FB Thermal measurements and fan control	100% and integrated in prot. 50%
AC pre-charge	Pre-charging the AFE drive from T1 AC field	0% (depends on T2 MV SWG)
DC pre-charge	Pre-charging the AFE drive from DC supply	100% working
Line pre-charge	Pre-charging the DC output from DC supply	100% working
AC/DC PC	Perform actual power conversion based on DC voltage and current setpoints	30% Control SW working, full AFE conversion depends on AC pre-charge functioning
Aux functions	400 V AC 3P+N internal supply	100%
	230 V AC 1P+N internal supply	100%
	400 V AC 3P+N internal supply	100%
	24 V control supply and protections	100%
Protections	MV GND fault detection	100% included in MV SWG
	Auxiliary internal protections	100%
	DC over-current and over-voltage	100%
	AC under- and over-voltage lockouts	100%
	Test setup E-stop and Lock-out-tag-out	100%
	System fast-stop circuit Figure 3	Functional 100% , to be tested
IO FB & control	Interactions from control to electrical circuit functions and FB to control	80% , some parts to be tested still
Communication	Mutual communication between the main and local controllers and remote control in DC outl.	Main – local: 40% Main – DC outlet: 25%

3.7 Power circulation testing

Tests of the power cabinets AC/DC conversion stages in circulation setup according to Figure 18 to verify electrical behaviour and thermal loading is to be performed as preparation to actual charging sessions. Listed in below Table 4 are the main functions therein and each corresponding status. Power circulation is achieved by connecting the respective DC1+/- and DC2+/- together as indicated in Figure 18.

Table 4 power circulation testing in correspondence to Figure 18

Test	Description	Status
Building infeed of 400 V power	Assure sufficient and stable infeed of building supplied power to the test setup shown in Figure 18	100%
Aux-main MV	Provide an MV connection between T1 and T2	75% MV T2 SWG malfunctioning
Main LV-AFE	AC pre-charging and stable AFEs starting	50%
DC AFE1-AFE2	Connect and achieve stable LV DC power circulation	0%
V-set variation	Control AFEs to stable voltage setpoints	60% (tested low power)
I-set variation	Control AFEs to stable current circulation	60% (tested low power)
P-set variation	Control AFEs to stable power allowance per direction	60% (tested low power)
Thermal stable	Control AFEs to stable components temperature	0%

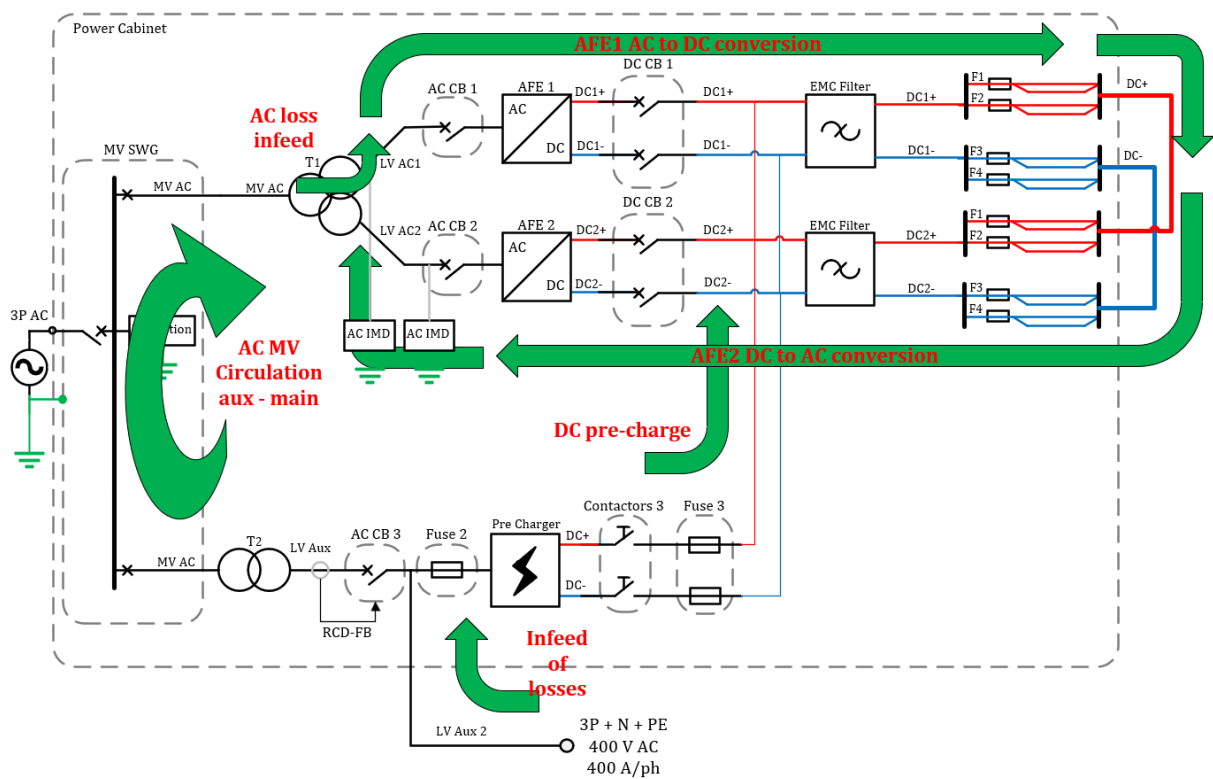


Figure 18 indication of power flows in circulation test setup

4. DC OUTLET DISPENSER DESIGN FOR ACD INTEGRATION

Executive Summary

The actual contacting and communication of the EVSE with the vessel is executed in the DC outlet dispenser. This part of the charging system is intended to be close to the vessel to assure a high communication signal integrity level.

The design of the different dispenser aspects is explained in this section; electrical power and communication sections, the required safety and protection features to assure safe operation, the mechanical design to obtain a good ACD integration fit, and lastly the testing of the communication between the DC outlet and the EV inlet sections according to the MCS charging standard. Integration of the DC outlet dispenser cabinet in the ACD is detailed in D4.4 & D4.5.

4.1 Electrical design of DC outlet

The electrical design of the DC outlet is split into the power section, that is housed in the main compartment of the dispenser cabinet, the control and communication section is placed on the inside of the door, as indicated in below Figure 19. From this sketch, the translation has been made to the eventual design as will be explained in the following.

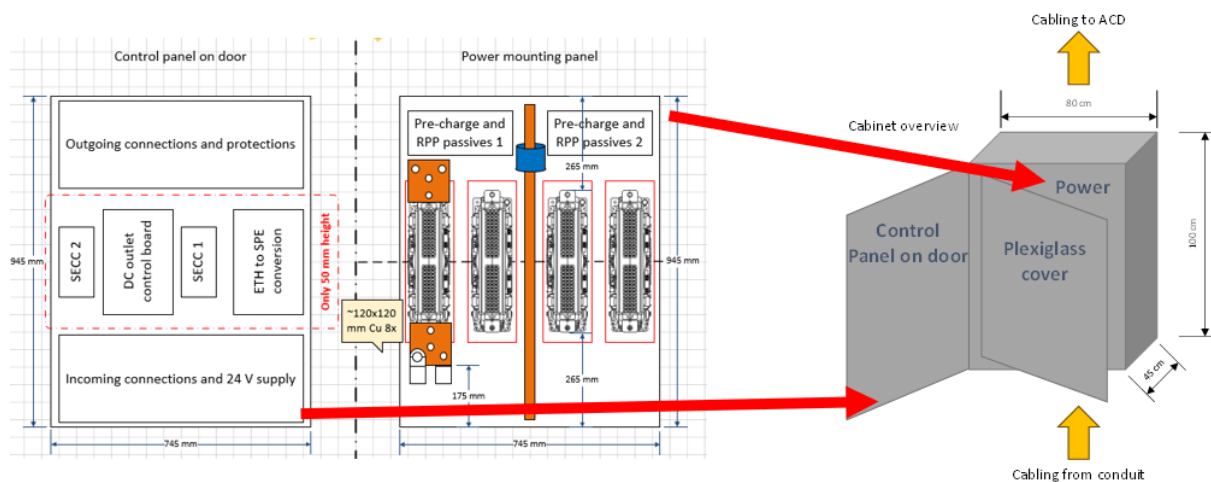


Figure 19 DC outlet dispenser cabinet composition, main components placement and dimensions.

The DC outlet dispenser cabinet design turned out to be a very tight solution to house all components needed therein. This, however, was crucial since the ACD lacked additional internal space. To this end, the DC cable protective fuses were re-located to the power cabinet.

4.1.1 Power section

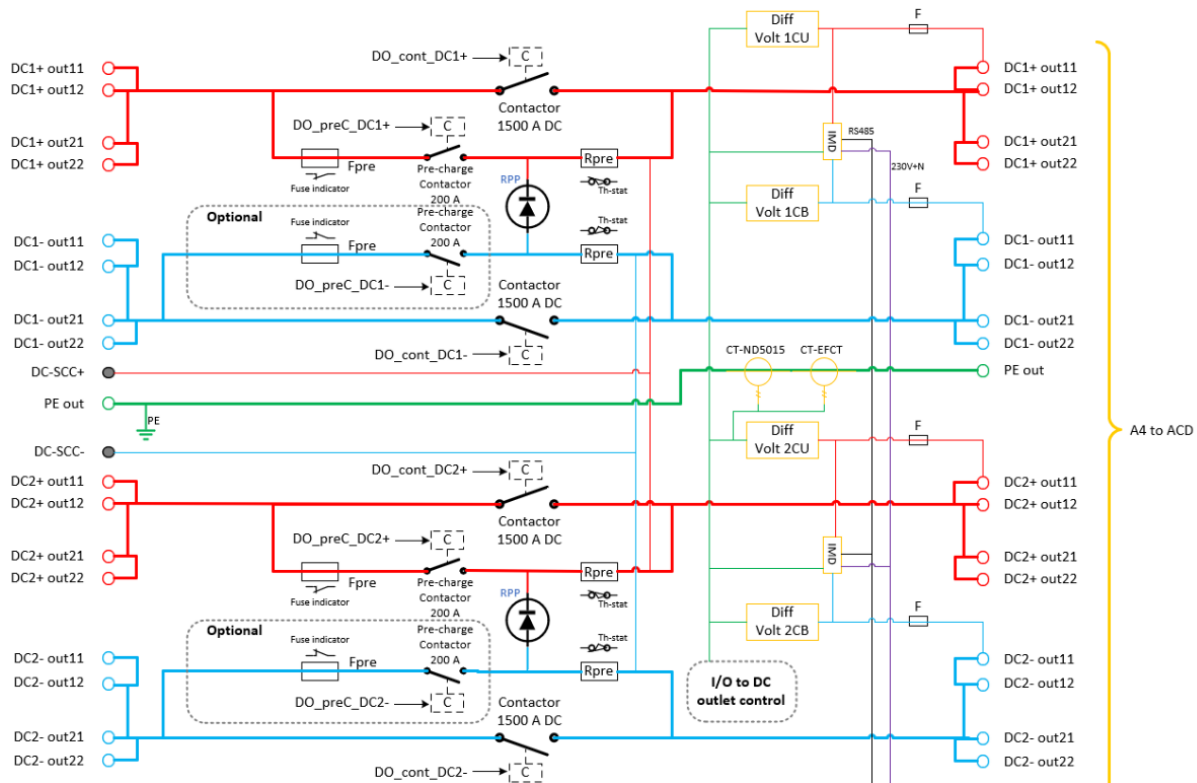


Figure 20 single-line diagram of the DC outlet power section

The 2 core functions of the DC outlet power section are:

- 1) **Pre-charging the EVSE system** outside of the power cabinet, that is the ACD and cabling running between them. Basically, only a pre-charge function in the DC+ or DC- is needed, however, it is decided to implement this function in both DC paths. This is mainly done for additional safety; during the pre-charge the added resistance (R_{pre}) reduces a potential fault current.
- 2) **Connecting the EVSE and EV** to start the charging process. As indicated in both Figure 19 and Figure 20, there are 4 pieces of 1500 A DC contactors, that perform this function. These components are quite bulky, especially due to the large arc-discharge chambers.

The other functions performed are related to the safety and protection features as will be explained in the following.

4.1.2 Communication section

As described in chapter 7 of D3.2, the supply equipment communication controller (SECC) and EV communication controller (EVCC) are based on the committee draft (CD) version of the MCS standard and have been designed and tested. The EVSE – EV communication circuits as defined in the system architecture are shown in Figure 21. Therein, the main components are shown which will be detailed in the subsections.

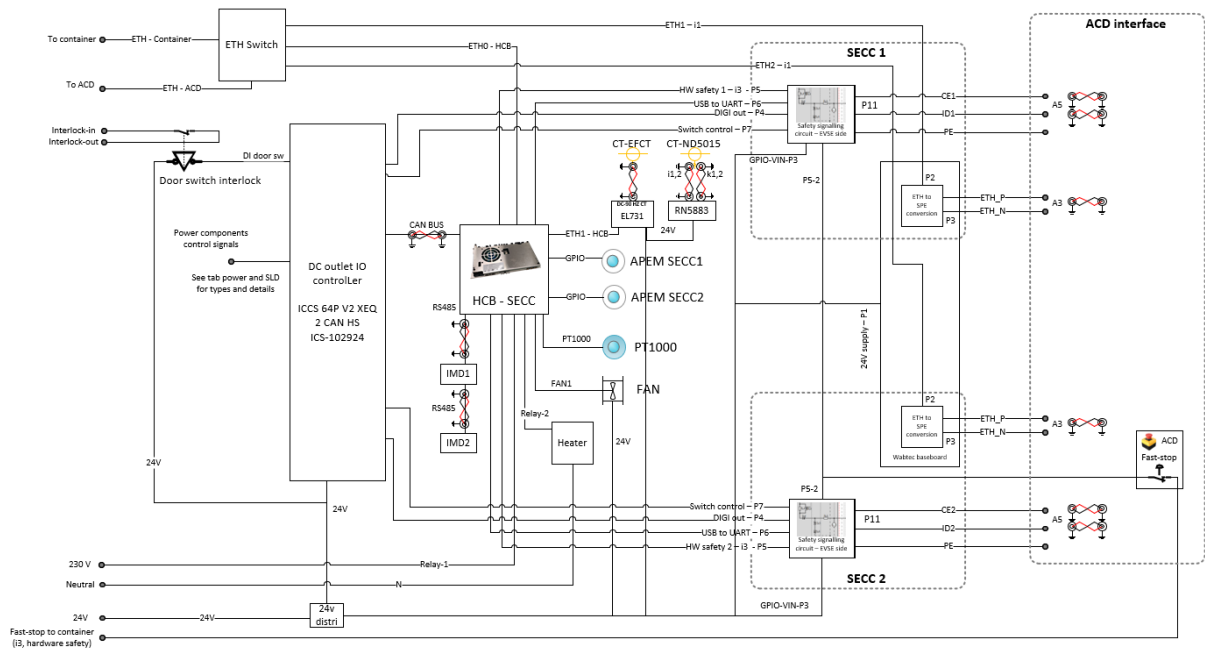


Figure 21 detailed single-line diagram of control and communication in the DC outlet with main controller HCB – SECC and the 2 low-level SECCs as indicated.

4.1.2.1 SECC

The SECC is a Heliox designed control board (HCB) that includes a Linux based controller, 4 ETH ports (2x copper, 2x SFP) and sufficient IO to control most of the standard charging station interfaces like CCS. It is used to interact with the EVSE internal communication channel (i1), manage the charging process according to a state machine flow based on the charging process states in IEC 61851-23-3, communicate with the EV according to the ISO 15118 SW stack and interact with the safety signalling circuit. Additionally, the HCB communicates with the RCM relays, IMDs, and IO controller used to control the power components.

4.1.2.1 EVCC

The Maritime EVCC is a Damen designed controller based on a programmable logic controller, to manage the EV-side of the charging process. It is used to interact with the EV internal communication channel (EV2), manage the charging process according to a state machine flow based on the charging process states in IEC 61851-23-3, communicate with the EVSE according to the ISO 15118 SW stack and interact with the safety signalling circuit. Because the ferry used for the demonstrator and the safety signal circuit are under development, the programmable logic controller enables flexibility in interface implementation.

4.1.2.2 ETH to SPE conversion

The high-level communication (A3) is defined in the MCS communication (IEC 61851-23-3) as being IEEE 802.3cg – 10BASE-T1S SPE communication as defined in IEC 63171-1. It originates from the automotive sector as a short distance (up to 25 m) 2-wire bidirectional peer-2-peer (P2P or alternatively P2multiP) communication protocol with a limited bandwidth (10 Mbit/s). The high-level 2-wire, single pair Ethernet (SPE) communication is used for all parameter value



exchange between the SECC and the EVCC according to the ISO 15118-10 physical and data link layers (1 and 2) using interface A3.

To minimize the impact of development for the SECC and EVCC, a separate add-on module will be used to convert to regular Ethernet (IEEE 802.3bw – 10/100BASE-T1 or IEEE 802.3bp – 1000BASE-T1) at both the EVSE- and EV-sides. Subsequently, the regular Ethernet interacts with the SECC and EVCC to allow for the use of industry standard controllers. Since the distance between the SECC and EVCC in the demo is likely to be larger than 25 m, the SPE conversion boards are also made capable of communicating using 10BASE-T1L SPE capable of working up to 1000 m. This is not considered in the communication standard but included as a fall-back scenario to allow for continued testing.

4.1.2.3 Safety signalling circuit

The EVSE- & EV-side safety signalling circuits are designed according to the IEC 61851-23-3 CD standard and the therein mentioned values and tolerances for the charge enable (CE) and insertion detection (ID) signal generation to define charging-state and plug-detection, respectively as indicated in Figure 6.

The main task of the CE-section of the safety signalling circuit is to define the state of the charging process, which can be altered from both the EVSE- and EV-side by changing the functional circuit voltage dividing network. The CE signal will be used to indicate and mutually alter the state of the charging process as a DC voltage in the range of 0.53 – 5.5 V DC. Main considerations in choosing this range are that aside also the detection of a fault to the auxiliary supply battery (7-32 V DC), wrong polarity faults (negative voltage), and shorted- (0 V) or open-wires (> 5.5 V DC) must be detectable. The safety state IO signals ensure that the CE state is defined and read by the respective communication controller, while the emergency stop state EC can also be triggered in HW by a manual and/or hard-wired controlled emergency stop trigger. The safety signalling circuit at both SECC and EVCC side must contain a SIL2-level direct HW trigger of the emergency stop in case state EC is triggered. By ensuring this property, a fault leading to an emergency stop at the EV will also trigger this at the EVSE side, and vice versa.

The main task of the ID-section of the safety signalling circuit is to detect whether a connection is made between the two mating parts of a plug-socket connector (insertion) or ACD (mating). Additionally, the ID supply voltage of 24 V DC can assist in waking up and powering the controllers of the unpowered side, i.e. the EVSE can black-start the EV and vice-versa.

4.2 Safety and Protections

4.2.1 Insulation monitoring device (IMD)

The required insulation measurement method for MCS is described in the draft standard, IEC CD 61557-18 [4]. An IMD in accordance with IEC 61557-8 is used for monitoring for the first fault condition in an IT system but does not incorporate the additional features that enable the monitoring of insulation resistance, as required for DC EVSE applications, for example the possibility to separately monitor the positive and negative external DC conductors as required



in MCS charging. Therefore, in the case of EVSE applications, DC-EVSE-IMD according to IEC 61557-18 replace the use of general purpose IMD in accordance with IEC 61557-8. It specifies the requirements for DC electric vehicle supply equipment insulation monitoring devices that provide insulation monitoring in DC EVSE in accordance with the requirements of IEC 61851-23, IEC 61851-23-1 and IEC 61851-23-3 for EV supply equipment with a rated maximum voltage at side B up to 1500V DC.

Availability of a fully functional, safe, and certified IMD becomes impossible since the standard is not yet finalized. Therefore, the 3 main functions of an IEC 61557-18 compliant IMD are independently achieved with other components:

- 1) The insulation monitoring function and related estimation of R_y and C_y (as defined in chapter 5 of D3.1) are executed using an IEC 61557-8 compliant IMD (IM-04PV)
- 2) The voltage balance as required by the IEC-61851-23-3 is achieved passively or actively by the power conversion stage.
- 3) The criteria for voltage balance are measured by separate voltage transducers (VTs) per pole with respect to PE in the DC outlet to verify that each absolute voltage stays within the limits set as depicted in Figure 33a.

4.2.2 Residual current monitoring device (RCM)

According to IEC 60479-1 section DC-2 of Figure 22, the limit of the total body current I_B is 25 mA. The total body current is defined as the maximum leakage current of the DC-EV charger I_{CM-s} (1000 V / 100 k Ω) plus the peak value of the IMD measuring current I_m (15 mA). To verify these limits, an RCM device is installed in the DC outlet.

To ensure proper earthing of the system to protective earth (PE), a few aspects are important:

- The DC section of the EVSE is an IT-circuit and must therefore be floating w.r.t. PE.
- Preventing galvanic corrosion, see IEC 80005-3, appendix C for the draft guidelines being formed
- Ensuring equipotential of all PE referenced conductive elements, requiring PE conductor. For this, the earthing arrangements in Annex E of IEC 62271-202 are leading.
- Assure a PE conductive path as reference for protections alike an IMD
- The different sections of the system that require operational interaction from an operator must have the ability to be connected to PE. These are:
 - a. MV switchgear (bi-directional input port)
 - b. DC power connections (bi-directional output port)
 - c. Auxiliary supply (unidirectional auxiliary and service output port) This is important to assure touch safety and fully discharged equipment during transport and installation.
 - d. Specific HV interlocking requirement - To have the installation isolated before it is earthed, the circuit-breaker, disconnecter and earthing switch shall be interlocked in accordance with IEC 62271200 (IEC/IEEE 80005-1, 6.2.1).
- The total resistance of the protective earthing must be dimensioned in such a way that protective systems are in operation all the time and can act upon an earth-fault.
- The cross section of the earthing connections must comply with the regulations and onsite conditions and must be always maintained also during repair and maintenance operations.



4.2.2.1 IEC 80005 substation related earthing requirements

Since the EVSE MV/LV section is considered as a substation, the following EMSA guidance is applicable [2]. 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.

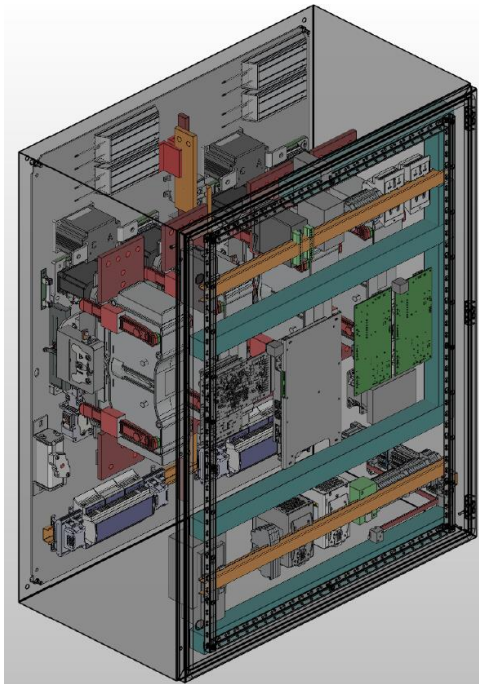
4.2.3 Over-current protection relocation

In contrary to the Heliox general architecture, no over-current protection is applied in the dispenser for different reasons:

- 1) DC outlet as small as possible; relocating fuses to container saves significant space.
- 2) IP65 requirement of the dispenser cabinet does not allow for direct air circulation between the in- and outside of the cabinet, since that would harm the sensitive parts. Fuses produce significant heat, so relocating them to the container eases the thermal design of the dispenser.
- 3) Wiring thermal protection per parallel bundle of 2 wires from container to DC outlet as indicated in Figure 9. By placing the fuses in the container this is possible, whereas this would not be when located in the dispenser.

As a result of relocating the fuses to the container, the contactors and wiring must be capable of coping with the potential short-circuit current in case of a fault. The DC contactors (Schaltbau CP1115/12) have a Rated short-time withstand current I_{cw} (@ $T < 100$ ms) of 15 kA each. Although the contactor is not required to survive a short-circuit, it has a resulting I^2t of 22,5 MA²s. Both the fuses and the DC ACB in the container are capable of switching-off a prospective short-circuit current within the contactor specified 100 ms.

4.3 Mechanical design of DC outlet



(a) ISO-view of the mechanical 3D design



(b) picture of the implemented power section

Figure 22 DC outlet dispenser cabinet mechanical design and realized prototype

The mechanical composition of the DC outlet is given in Figure 22. Therein it can be seen that the integration of all required components in the enclosure has been achieved. The enclosure is a custom-made stainless-steel type with:

- Dimensions (HxWxD): 1000 x 800 x 450 mm
- Material: stainless-steel, 316L
- Colour: RAL 7035 DRYLAC
- Protection: C5-MH
- Wall fixing lugs, cable glands and door locks all included

4.4 Basic signalling boards software and PLC control

This section describes the software implementation of the STM32 CE ID MCU. The STM32 CE ID MCU is placed on an EV or EVSE board and handles the low-level communication between charger and vehicle for megawatt charging according to IEC 61851-23-3. It drives and monitors the CE and ID lines. Also, it performs temperature measurements for two external PT1000 sensors and one internal sensor on the MCU. The MCU communicates with the main CPU via UART communication. Driving the CE and ID line is demanding some time critical generation and measurements. The scope of the MCU is that it can handle these critical things, so that the main CPU running Linux can handle less time critical things. The USS message communication is based on the existing communication protocol on the I2SE-EVCharge-SE board and extended to serve the functionality and requirements of the actual hardware implementation of the MCS basic signalling boards. The LSB is send first over UART. In case a number consists of multiple bytes, then the data is sent with the least significant byte first.

The basic signaling circuits are connected to a PLC with standard I/O. The I/O that the PLC supports is:

- Digital input with pull down
- Digital output of type push-pull, low side switch with pull-up or high side switch with pull-down.

The PLC controller is intended to use with a voltage of 12 or 24 V DC. The basic signalling boards (Figure 23) have a supply input for the digital outputs. Via this input the PLC controller determines the voltage level of the digital inputs and outputs.

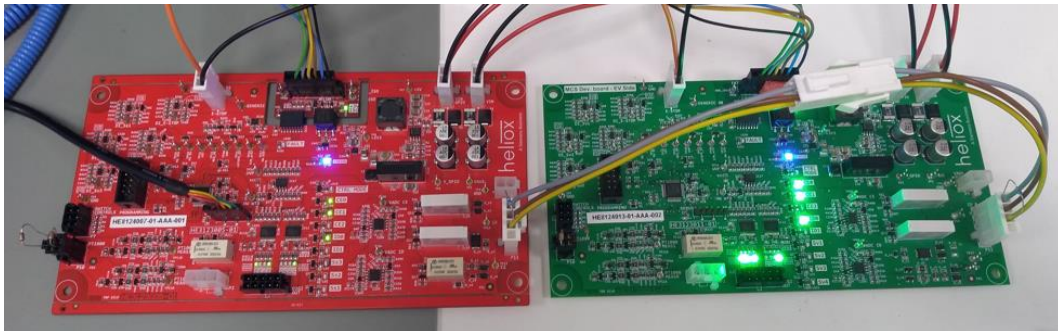


Figure 23 low-level communication testing setup of SECC and EVCC to assure EVSE - EV interoperability

4.1 Testing of the DC outlet with EV inlet

To check if the ship and charger V2G implementation of the ISO 15118-20 protocol are interoperable a validation setup has been built, see Figure 24. The charger communication stack has been implemented on a portable device that has been transported to Damen. The MCS protocol requires two independent communication parts. The first part is based on ethernet and is used for sharing of data between ship and charger. The second path consists of low-level signals that are used to verify if power transfer is allowed. For the MCS low level signalling communication two PCBs (ship and charger side) have been developed that are controlled by the communication stack.

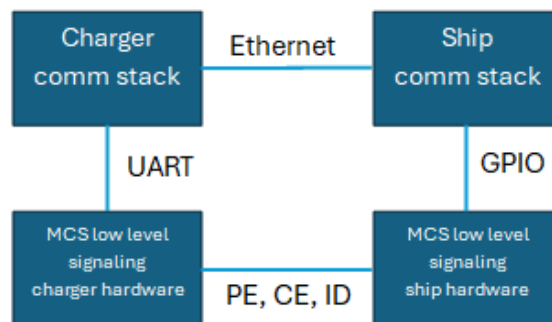


Figure 24 HYPOBATT communication testing validation setup

The ethernet side is the most challenging part as it implements the ISO 15118-20 protocol. With use of Wireshark it is possible to validate the communication sequence, from which an impression is shown in Figure 25.

587	2025-07-04	09:20:42,099589	61.342889	fe80::ca3e:a7ff:fe11:e512	fe80::60e:3cff:fe96:5056	V2GMSG (ISO-20...	128 UL_ChargeLoopReq
588	2025-07-04	09:20:42,009577	61.351877	fe80::60e:3cff:fe96:5056	fe80::ca3e:a7ff:fe11:e512	V2GMSG (ISO-20...	138 DC_ChargeLoopRes
589	2025-07-04	09:20:42,010220	61.352520	fe80::ca3e:a7ff:fe11:e512	fe80::60e:3cff:fe96:5056	TCP	86 47454 → 49152 [ACK] Seq=8238 Ack=6280
590	2025-07-04	09:20:42,023117	61.365417	fe80::ca3e:a7ff:fe11:e512	fe80::60e:3cff:fe96:5056	V2GMSG (ISO-20...	113 PowerDeliveryReq
591	2025-07-04	09:20:42,030700	61.373000	fe80::60e:3cff:fe96:5056	fe80::ca3e:a7ff:fe11:e512	V2GMSG (ISO-20...	113 PowerDeliveryReq
592	2025-07-04	09:20:42,041521	61.383511	fe80::ca3e:a7ff:fe11:e512	fe80::60e:3cff:fe96:5056	V2GMSG (ISO-20...	113 DC_ChargeLoopDetectionReq
593	2025-07-04	09:20:42,085004	61.428804	fe80::60e:3cff:fe96:5056	fe80::ca3e:a7ff:fe11:e512	TCP	86 49152 → 47454 [ACK] Seq=6307 Ack=8291
594	2025-07-04	09:20:42,432885	61.775185	AbbbSaceDi_00:3f:c6	Broadcast	ARP	60 ARP Announcement for 192.168.2.22
595	2025-07-04	09:20:42,517042	61.859342	KUNBUS_11:e5:12	Broadcast	ARP	60 Who has 192.168.1.1? Tell 192.168.1.7:
596	2025-07-04	09:20:42,644671	61.986971	AbbbSaceDi_00:3f:c8	Broadcast	ARP	60 ARP Announcement for 192.168.2.23
597	2025-07-04	09:20:42,910108	62.250108	PHOENIXCOMTA_9d:02:91	PROFIDUSNutz_00:00:00	PH-DCP	64 Ident Req, Xid:b9e710e8a, NameOfStati
598	2025-07-04	09:20:42,966985	62.309285	TexasInstrum_76:ef:3f	Broadcast	ARP	60 Gratuitous ARP for 192.168.2.1 (Reque
599	2025-07-04	09:20:43,557728	62.900028	KUNBUS_11:e5:12	Broadcast	ARP	60 Who has 192.168.1.1? Tell 192.168.1.7:
600	2025-07-04	09:20:43,611941	62.954241	fe80::60e:3cff:fe96:5056	fe80::ca3e:a7ff:fe11:e512	TCP	86 49152 → 47454 [FIN, ACK] Seq=6307 Ack
601	2025-07-04	09:20:43,657674	62.999974	fe80::ca3e:a7ff:fe11:e512	fe80::60e:3cff:fe96:5056	TCP	86 47454 → 49152 [ACK] Seq=8291 Ack=6308
602	2025-07-04	09:20:44,061644	63.403944	AbbbSaceDi_00:3f:c3	Broadcast	ARP	60 ARP Announcement for 192.168.2.24
603	2025-07-04	09:20:44,250337	63.592637	fe80::ca3e:a7ff:fe11:e512	fe80::60e:3cff:fe96:5056	TCP	86 47454 → 49152 [FIN, ACK] Seq=8291 Ack
604	2025-07-04	09:20:44,250391	63.592691	fe80::60e:3cff:fe96:5056	fe80::ca3e:a7ff:fe11:e512	TCP	86 49152 → 47454 [ACK] Seq=6308 Ack=8292
605	2025-07-04	09:20:44,351761	63.704061	PHOENIXCOMTA_9d:02:91	PROFIDUSNutz_00:00:00	PH-DCP	64 Ident Req, Xid:b9e720e8b, NameOfStati
606	2025-07-04	09:20:44,456252	63.798552	AbbbSaceDi_00:3f:c7	Broadcast	ARP	60 ARP Announcement for 192.168.2.25
607	2025-07-04	09:20:44,573544	63.915844	AbbbSaceDi_00:3f:cd	Broadcast	ARP	60 ARP Announcement for 192.168.2.26

Figure 25 impression of the ISO 15118-20 high-level message exchange of the SECC with the EVCC

The charger side communication stack (Figure 26) implements a virtual power converter and isolation monitor to verify the interaction between the communication stack and the rest of the system (Figure 27).

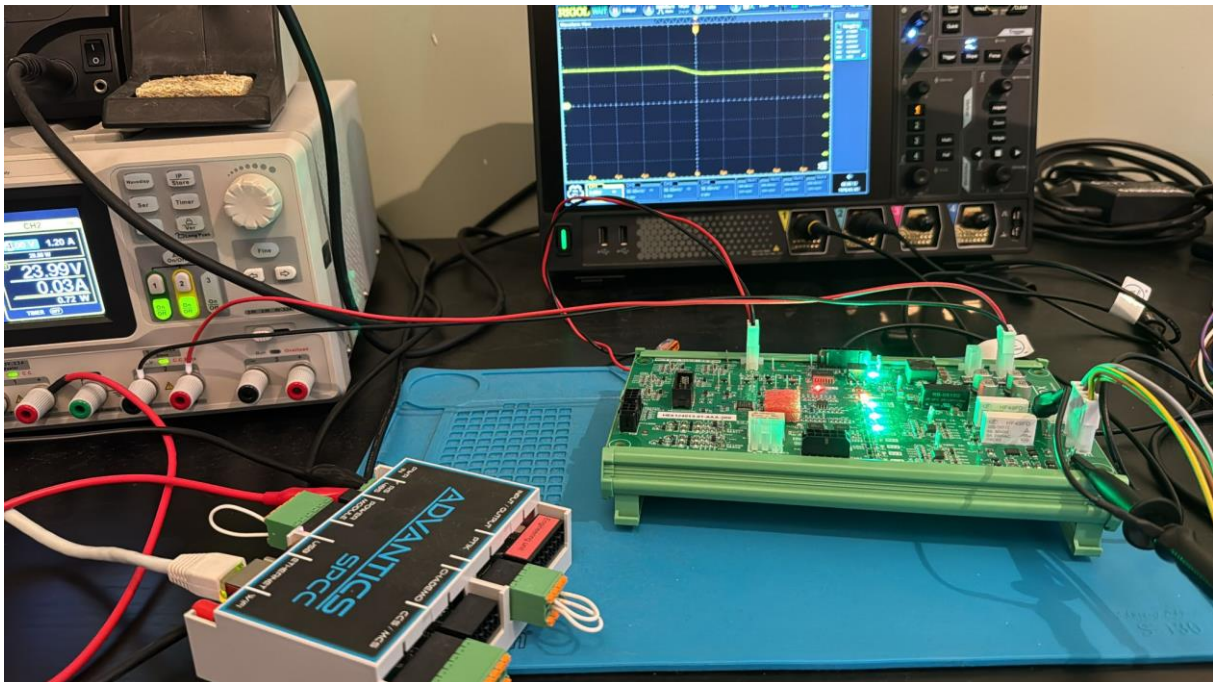


Figure 26 Combined SECC/EVCC signals interaction control testing setup

```
[INFO] Service selection by EV: DC charging with parameter set: 0
[INFO] VSECCLIB_SST_ISO20_ServiceSelection
[INFO] EV requested: VSECCLIB_SST_ISO20_DC_ChargeParameterDiscovery
[INFO] Power converter enabled
[INFO] EV maximum current limit: 900
[INFO] EV maximum voltage limit: 1040
[INFO] EV maximum power limit: 900000
[INFO] EV minimal limits: 990 V, 6000 M, 50 A
[INFO] IndSetResParam_ISO20_CPD_PowerRampLimit 0
[INFO] VSECCLIB_SST_ISO20_DC_ChargeParameterDiscovery
[INFO] EV requested: VSECCLIB_SST_ISO20_ScheduleExchange
[INFO] IndSetResParam_EVSEProcessing: 40
[INFO] VSECCLIB_SST_ISO20_ScheduleExchange
[INFO] EV requested: VSECCLIB_SST_ISO20_DC_CableCheck
[INFO] Power converter voltage set to: 2
[INFO] Power converter voltage set to: 1040
[INFO] VSECCLIB_INFO_WaitingForCPStateChange in VSECCLIB_SST_ISO20_DC_CableCheck
[ERROR] VSECCLIB_ERROR_TIMEOUT_PerformanceTimeout in VSECCLIB_SST_ISO20_DC_CableCheck
[INFO] IndCallout_DropLink_Reinitializing...
[INFO] EVSE initiated close of V2G TCP connection
[INFO] Power converter disabled
[INFO] Basic signaling opening SS3 switch to set CE to available
[INFO] V2G session connection closed
[INFO] EV connected and EVSE available
[INFO] Basic signaling opening SS3 switch to signal setup of communication to EV
[INFO] EV ready to charge
```

Figure 27 verification of communication stack interactions

5. ISLAND CHARGER SYSTEM COMPOSITION AND TESTING

Executive Summary

The island charger system is explained in this chapter. It is based on a legacy Heliox charging solution which is not being sold commercially anymore. However, this platform provides a flying start to showcase the required low-power charging and can be limited in power. As with the mainland solution it equally has been built and is tested in accordance with the DC outlet dispenser to prepare for full charging behaviour testing.

Functional testing with the coupling system will be done in T4.3, and full-scale testing of the whole system will be done in WP5. For the demo charger delivery, an installation manual will be composed after which the system will be prepared for shipment in WP5.

5.1 Main specifications

The island charger will be based on a dual 60 kW power conversion stage capable of creating up to 1500 V DC. Each 60 kW is composed of 2x30 kW, 800 V DC stages (Figure 28) that are connected in series to achieve up to 1500 V DC. The main specifications of the system are listed in Table 5. The island charger has been used previously for power conversion topology concept- and modularity-effects-testing as documented in chapter 6 of D3.2.

The DC outlet dispenser integration is based on equal control behaviour with respect to the charging container, minimizing the discrepancies between the setups.

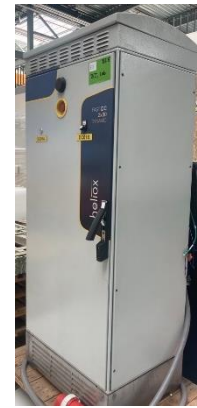


Figure 28; 2x30 kW charger

Table 5 Island charging system main specifications

Function	Specification
Environment operating	Indoor/Outdoor
Temperature	-20 to 40 °C
Charging standard	IEC61851-1/23/23-3/24 / ISO15118-10/-20
Compliance and safety	CE / EN 55011 / IEC61000-6-2
Output DC voltage range	920 - 1500 V
Rated DC output power	2 outputs; each 60 kW
Rated DC output current	2 outputs; each 0 - 60 A, bidirectional
Input connections	3P + PE + N (63 A CEE plugs if power limited)
Input power rating; full load / idle / limited	130 kVA / 100 VA / 2 x 43 kVA
Input AC line-line voltage range	2x 400 V +/-10%
Input AC phase current; maximum / fused	180 / 200 A, inrush current limited
Power factor, THD	> 0.99, < 3%
Peak efficiency	97%
Dielectric withstand	3000 V
System weight	1500 kg
Dimensions (HxWxD)	2000 x 1600 x 600 mm
Protection	IP54 / IK10 / C3 environmental
Operational noise level	<55 dB(A) @ 1 m

5.2 Electrical functional diagram

Figure 29 shows the combined electrical functional diagram of the 2 legacy chargers, power sources 1 & 2), respectively. As indicated, the Heliox high-level PLC controller sends set-points to both power sources. The 2 converters per power source are connected in series and configured as master (M) and follower (F) drives. By connecting the DC sides of the two power sources in parallel, power circulation between them is achieved.

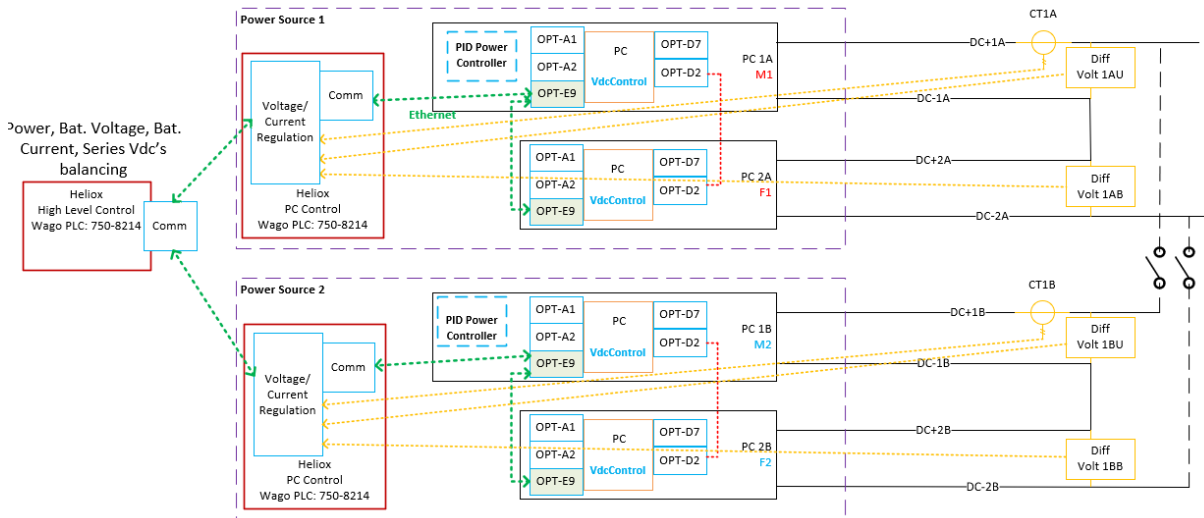


Figure 29 Electrical functional diagram with control indications

5.3 Proposed island preparation test composition

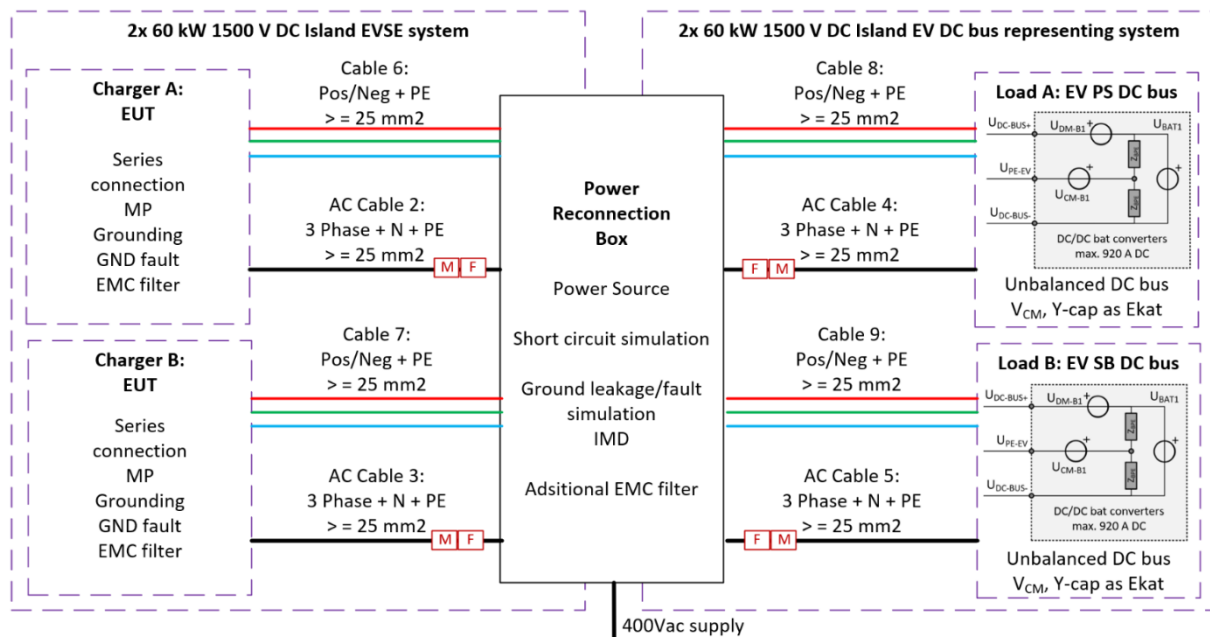


Figure 30 dual 60 kW Island testing setup in power circulation mode with EV DC bus representing system

The intention of the island testing setup is primarily to represent the developed charger and existing vessel such that charger behaviour can be pre-verified on low-power scale. Secondly,

the island chargers are capable of performing additional compensation behaviour in comparison to the 3 MW mainland charger in the form of active voltage symmetry and voltage-balance with respect to PE as indicated in Figure 33. As indicated in Figure 30, the vessel representing DC bus system can emulate deliberate imbalances and a-symmetries to measure the resulting effects of vessel on-board systems in the charging process. By enabling these possibilities, undesirable behaviour can be observed and possibly compensated by the island chargers which have an additional degree of freedom due to the 3-level conversion topology.

5.4 Lab testing setup

To perform testing of the dual power sources setup, a testing application control interface has been composed to steer and monitor the most important parameters of the high-level PLC controller. This interface is shown in Figure 31; it visualises with buttons the IO functions that need to be set for testing, e.g. relays, DC contactors and pre-charge circuits to interconnect.

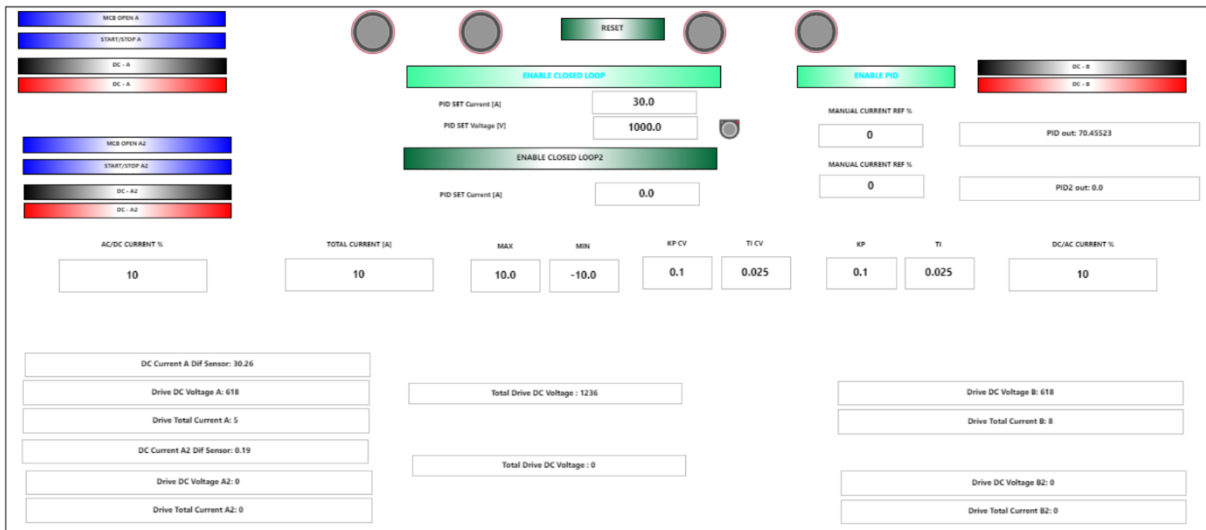
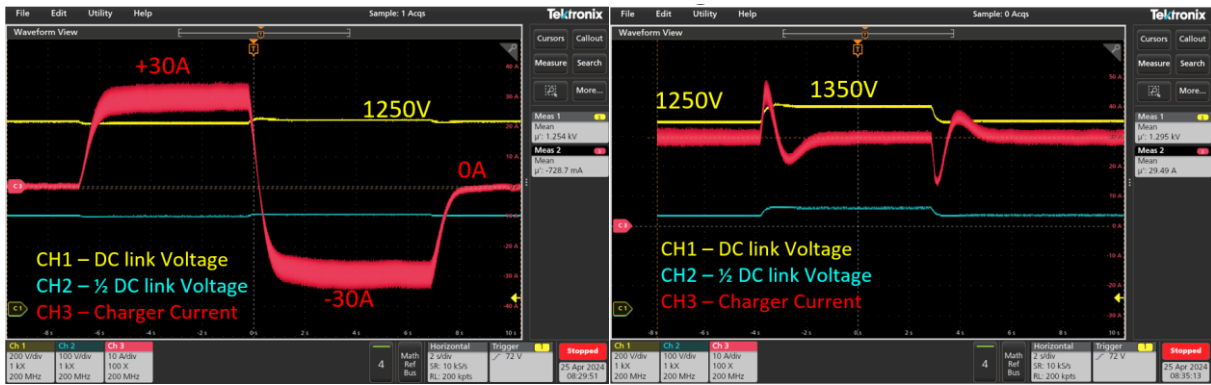


Figure 31 testing application interface

PID control parameters and voltage/current setpoints can be varied in the application interface, whereas the resulting output is witnessed on the oscilloscope (Figure 32). Therein, an example is shown of the behaviour during a current step (a), and a voltage step. The behaviour is not yet optimal, but the core principles of what we intend on testing are demonstrated. Further optimizations investigated are:

- **Current ripple peak-to-peak reduction:** as shown in Figure 32a, the ripple around 0 A is sufficiently good, but the ripple around +/-30 A DC can be improved still.
- **Current dynamics:** as shown in Figure 32b, the current overshoot to achieve a 100 V DC transition is too impulsive.
- **CM current compensation with DC-link balance:** the CM voltage and current can be influenced with the (un)balance between the DC1 and DC2 voltage-halves.
- **Vessel load charging:** surely, there will be differences in behaviour between the test shown for the situation in Figure 31 resulting in Figure 32, and the behaviour when each power source is connected to the respective vessel DC busses.



(a) Current Step (+30A to -30A)

(b) Voltage Step (1250V to 1350V)

Figure 32 Island charger preparation measurement results control performance improvements



6. IEC 61851-23-3 DEVIATIONS AND POSSIBLE VIOLATIONS

Executive Summary

The MCS standard is on the verge of being finalized with the review of the FDIS version ongoing. In this chapter, the known deviations and possible violations of the currently described requirements are listed and explained. On some of the items, exclusions or alternatives are presented.

The intention with the EVSE system developed and described in this report is to, eventually, comply to the IEC 61851-23-3 MCS conductive charging standard. At this point in time, however, this is not yet possible since:

- The standard is not yet finalized, so requirements can change still
- Some requirements still require additional research to be properly understood and complied to
- Some requirements require component functionalities that are not yet (fully) available
- A lot of engineering still needs to be done to develop the product fully accordingly
- All requirements must be tested still to verify compliance

In this chapter, the already known complexities in complying with the standard are addressed and a way forward is presented.

6.1 Inductance violation

Cited in the standard: *The side B inductance of the EV supply equipment shall be < 100 μH. The side B inductance of the EV supply equipment should be limited to reduce the effects imposed on the EV and the EV supply equipment during a load dump scenario, as well as during a short-circuit scenario.*

This comes down to $L_{DM} = L_{DC+} + L_{DC-} < 100 \mu H$ (at max, $L_{DC+} = L_{DC-} = 50 \mu H$), $L_{CM} = L_{PE} + L_{DC+} // L_{DC-} < 100 \mu H$ (at max, $L_{PE} = 75 \mu H$) The actual inductance in the DEMO situation will be measured, however, it is expected that it will not comply to this since:

- Physical size of the site resulting in large distances and with that, the inductances
- No possibility to position the container on the pontoon and with that close to the vessel
- The vessel is expected to have too high inductance values because of distances onboard

Measures that will be taken to prevent issues with resultingly increasing peak currents during a load dump or short-circuit scenario:

- Measuring the DM loop inductance, this will have the largest influence on current levels
- Calculating potential failure effects based on that inductance and assuring installation compliance
- EVSE and EV designed for higher peak current (65 kA) and I^2t values – to be verified with Damen based on vessel protections in preparation to testing
- Ensuring minimized distance between the DC+ and DC- conductors, thereby minimizing the loop inductance ($L_{loop-DM}$)



6.2 Over-current protection

As defined in IEC 61851-23-3 CDV:2024 and copied in Appendix F, there are specific overload and short-circuit protection requirements for MCS EVSE systems. The EVSE related most stringent requirements are:

- limit the peak current to ≤ 30 kA, this can be achieved in 3 ways;
 - 1) settings of the DC ACB such that system complies to this
 - 2) calculate the combined fuse ratings in combination with the installation cabling impedance (not likely to match this requirement)
 - 3) with an alternative protection circuit to be designed
- limit the I^2t value to $\leq 1\ 000\ 000$ A²s, this can be achieved in 2 ways;
 - 1) settings of the DC ACB such that system complies to this
 - 2) calculate the combined fuse ratings in combination with the installation cabling impedance (not likely to match this requirement)
- switch off the supply to the vehicle within 4 ms after start of the short circuit condition
 - 1) this can be achieved in 2 ways;
 - 1-1) settings of the DC ACB such that system complies to this. However, it is already known for the component specifications that it is too slow for this. The fastest turn-off that can be achieved is ~ 30 ms by the DC ACB, or ~ 20 ms by the DC contactors. DC OVP is required at the output of the system (in ACD) to effectively avoid a too high voltage peak by interrupting the over-current.
 - 1-2) calculate the combined fuse ratings in combination with the installation cabling impedance (not likely to match this requirement)
 - 2) Resultingly, it is not possible to comply to this requirement, three alternative solutions to be investigated:
 - 2-1) whether the vessel can cope with a longer short-circuit current, considering 30 ms
 - 2-2) adding other disconnection devices alike a pyro element or a solid-state circuit breaker (SSCB). Both have been investigated but no suitable products are available within reasonable time and at reasonable cost. Additionally, the most favourable being the SSCB has high losses which are not accounted for in the system design.
 - 2-3) diverting the over-current. If this solution would be needed this must be further investigated.

The approach will be to first investigate option 2-1, if this is not possible from vessel side, option 2-3 will be implemented.

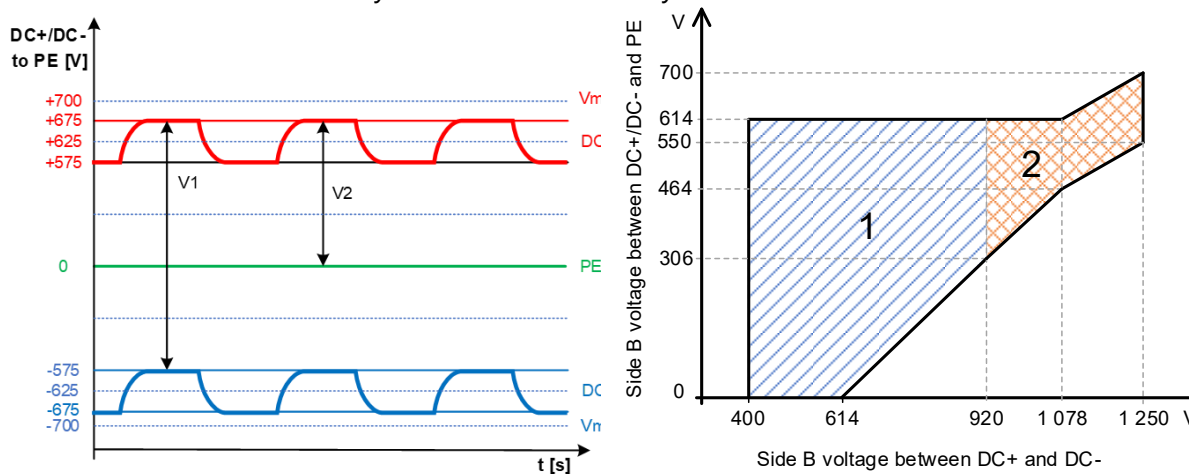
6.3 No active voltage symmetry while above 920 V DC

The standard dictates that for $V_{DC} > 920$ V DC active symmetry of the DC bus must be applied, as shown in Figure 33. The EV DC voltages $V_{EV-BUS1}$ and $V_{EV-BUS2}$ are around 995 V DC confirming that need. However, the DC outputs of the EVSE (V_{EVSE1} and V_{EVSE2} , respectively) are designed as non-symmetrical in the case of the mainland 3 MW charger. This leads to a lack of conformance, mainly due to the lack of full E-kat specifications known at the time the definitive

charger topology needed to be made. Since changing topology is a station passed for the DEMO charger, one of the following solutions could be applied to assure safe vessel charging testing at Frisia, and avoid a hazardous risk in case of touch current;

1. **Mechanical barrier:** prevent ability to touch life parts by assuring there is an additional mechanical barrier in between of the life parts and the user. This is a method also discussed in composing the MCS standard but was highly unfavoured due to the large costs resulting from it. However, for testing purposes, this is a viable option.
2. **Reduce DC bus voltage:** depending on V_{batt} and the required voltage drop of the EV DC/DC converter, it could be investigated together with Damen whether it is possible to reduce $V_{EV-BUS1}$ and $V_{EV-BUS2}$ to 920 V DC or less, thereby avoiding the active symmetry requirement from the standard.
3. **Add active balancing converter to EVSE:** in contrary to the previous option, adding a stand-alone active balancer that assures symmetry ($|V_{DC+}| = |V_{DC-}|$) is an option. The required power capabilities to this end need to be defined still. A bi-polar 2x30 kW charger connected to the DC output of the 3 MW EVSE could perform this since it can produce a DC output voltage of 920-1600 V DC.
4. **Create and monitor passive balance:** by choosing the passive components in the IT circuit such that the balance around PE is created naturally and monitoring this with a voltage sensor of DC+ and DC- to PE symmetry might be kept. However, this is unlikely due to V_{CM} caused by the EV DC/DC converter.
5. **Shift to balanced conversion:** For the island tests, a bi-polar charger composed of 2x (460 - 800 V, 30 kW, 60 A DC) for each V_{EVSE1} and V_{EVSE2} will be used for testing that will assure the active symmetry and thereby will provide the required results in terms of difference in CM currents in that test.

In the 3 MW EVSE testing, it is proposed that option 1 is used to ensure a safe testing environment. If possible and allowed by Damen and Frisia, option 2 can be additionally done to comply to the MCS standard in this regard. If this is not the case, option 3 could solve the unbalanced situation if the CM current resulting from V_{CM} is not too high. This will depend on the application. Option 4 will not work since it only helps in unbalanced situations within the boundaries of the MCS standard ($V_{CM} < 75$ V DC) which is not the case as calculated in the example. In applications where an actively controlled (conversion) voltage is created that violates the symmetry requirement, a passive circuit cannot compensate. Option 5 is not feasible for the DEMO tests anymore but will certainly be considered for future situations.



(a) differential (V1) and absolute (V2) voltage def. (b) passive (1) and active (2) V1 symmetry areas

Figure 33 differential and absolute side B voltage definitions and symmetry requirements

6.4 HYPOBATT project deviations to the MCS standard

As mentioned, the Frisia E-kat vessel is not part of the HYPOBATT project. Therefore, the specifications are aligned with the Damen charger, not with the one developed by Heliox in the project. The Damen charger-vessel system does not comply with the MCS standard, partly because this was not finalized at the time of the implementation, partly because certain MCS requirements are not aligned with marine design choices.

6.4.1 No MCS plugs used

In the HYPOBATT project, an ACD will be used which is not (yet) an allowed solution according to the MCS standard, wherein a MCS plug type is the only acceptable solution to date, as described in the IEC TS 63379. The Stemmann Technik FerryCharge ACD as alternative solution will be proposed as the automated connection solution for MCS standardization, however this process is not yet completed at the moment of testing.

6.4.2 Non-symmetric loading of V_{DC} by the EV

The MCS standard dictates that, to assure balance and avoid CM currents, the EV presents a symmetrical loading to the EVSE during charging (note 2 of section 6.3.1.112.1 in IEC 61851-23-3 CDV:2024). This means that any converter or other load on the EV-side of the DC bus must act symmetrically between DC+/- at the one end, and chassis or hull at the other end. This EV reference potential is defined as PE-EV (Figure 36) while connected to the EVSE and considered equal to EVSE-PE. In the aforementioned draft-version of the standard, no limit values to the CM current are given, however, Heliox has asked for these values to be defined before finalizing it. This should be done in absolute terms or relative to the DM overall current. In maritime applications, it is common to compose a fixed DC bus voltage for the complete vessel, or alternatively, per vessel-side. In the Damen E-kat, the latter is the case with a DC bus voltage range as indicated in section 2.4. Therein indicated, the converter used for this is a non-isolated DC/DC converter composed of a three-phase inverter with an LC-filter. The converter and DC bus voltage ($V_{EV-BUS1}$ and $V_{EV-BUS2}$ for port and starboard sides, respectively) are kept around 995 V DC while their corresponding battery voltages vary in the range 672-869 V DC. Therefore, the DC/DC converter operates in buck-mode in the direction from V_{EV-BUS} to V_{batt} , typically using interleaved PWM switching. This interleaved inverter-based DC/DC converter is non-symmetrical and can create significant CM currents. The absence of symmetry is a violation of the MCS specifications. The converter itself does not produce a CM current since it is solely connected in a DM-path (DC+/-). The CM voltage is caused by the difference in potential with respect to chassis (hull), as also indicated with the EV representing load in Figure 30;

- In the **DC+ path**; the voltage is converted from V_{EV-BUS} to V_{batt} ($V_{diff+} = V_{EV-BUS} - V_{batt}$)
- In the **DC- path**; the DC link on both sides of the converter is hard-coupled ($V_{diff-} = 0$)
- The resulting CM voltage generated by the DC/DC converter is: $V_{CM} = \frac{1}{2}(V_{diff+} + V_{diff-})$
- For the case $V_{batt} = 695$ V DC, this would result in: $V_{CM} = \frac{1}{2}(995 - 695) = 150$ V
- The resulting CM current is a result of the connected impedances on both EV and EVSE sides.

It needs to be investigated what the typical CM current levels of the DC/DC converter are; however, these are expected to be factors higher than the MCS derived limit values.

As shown in Figure 34, the absolute voltages of V_{DC+} , V_{DC-} and V_{batt+} only slightly vary during charging. The measured V_{CM} (Figure 34b) at an average value of 200 V is higher than calculated. There might be an error in the calculation; based on the differential values in Figure 34a, V_{CM} is expected to be ~ 90 V DC ($\frac{1}{2} (995 - 815)$). This shows that Y-capacitors connected at those potentials will result in a CM current flowing. Exact effects are to be further investigated during the trial testing.

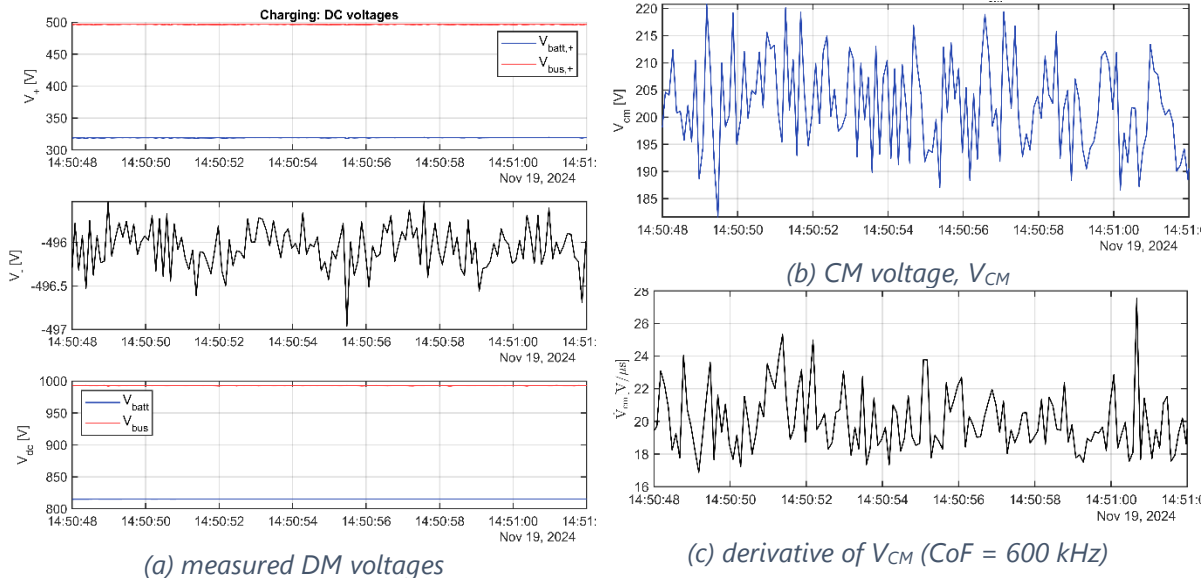


Figure 34 charging DC voltages on battery and DC bus sides

6.4.3 Y-capacitance surpasses limit of MCS standard

Since a vessel is composed of numerous converters and loads connected the DC-bus, it is complex to assure it complies with the applicable EMC standards (D1.4 **Req_D1.4-034**; IEC 61851-21, EN 61000 series and US FCC). To improve EMC behaviour, Y-capacitance is added at strategic positions in the vessel DC grid. According to measurements with the vessel IMDs, the overall amount of Y-capacitance per DC bus is smaller than 100 μ F, i.e. 44 μ F (both on PS and SB), resultingly, the overall vessel Y-capacitance is 88 μ F. The MCS standard and related EV-side leading safety standard (ISO 5474-3 on touch safety) allows for a maximum Y-capacitance depending on the DC line voltage (V_{EV-bus}) as indicated in Figure 35. For $V_{EV-bus} < 1004$ V DC, this is 30 μ F for the whole system, evenly distributed between EVSE and EV. Resultingly, the EV-side Y-capacitance per DC-bus is allowed to be 15 μ F. Therefore, the E-kat vessel Y-capacitance per IT circuit is approximately 29 μ F too high according to the MCS standard.

The resulting safety issues for testing with a too high Y-capacitance value are:

- A hazardous and, if-touched while charged, potentially life-threatening discharge human body current. A solution to greatly reduce this risk is the use of high-impedance insulating mats by the testing personnel assuring a much higher fault situation impedance than the values shown in Figure 35.
- Too much delayed detection of an insulation breach. The allowed detection time for this is 60 seconds, however, this cannot be achieved if the overall system Y-capacitance surpasses 30 μ F.

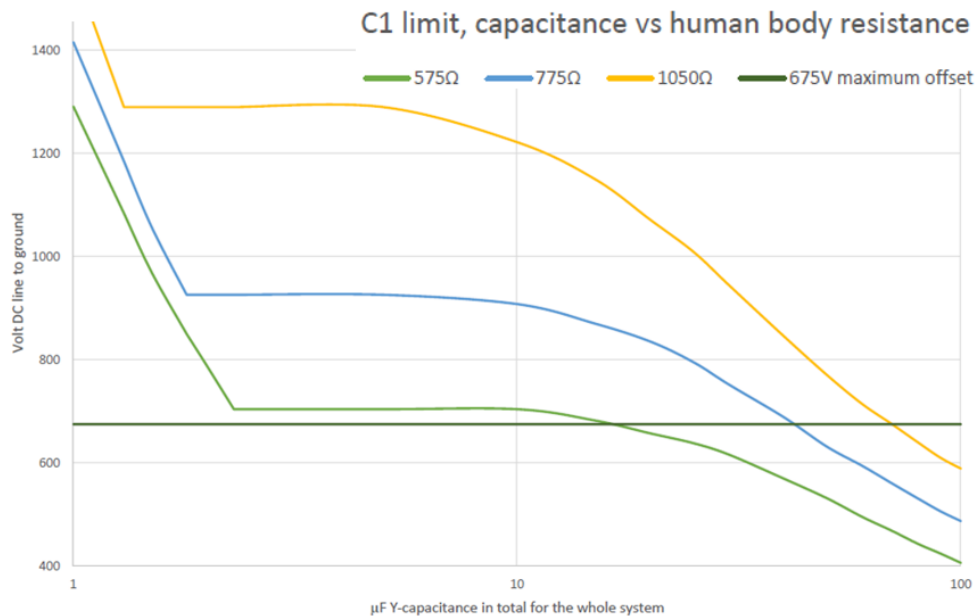


Figure 35 C1 limit, capacitance versus the human-body resistance

6.4.4 IMD response time too slow due to high Y-capacitance on vessel

Since the Y-capacitance per charging IT circuit will be too high according to the limitations as shown in Figure 35, it is expected that the IMD measuring this will be too slow to detect a failure in the system within the MCS standard allowed time of 60 seconds. The allowed Y-capacitance per IT circuit under 1000 V DC is 30 µF overall, evenly distributed between EVSE and EV and evenly between DC+ and DC-. The EVSE complies to this requirement of $\leq 15 \mu\text{F}$, however, the EV will not comply to this. The actual response time of the EV and EVSE IMD will be tested to verify response times. Voltage balance measurement is being performed, not by the IMD but with separate voltage transducers (VTs). Detection times: acc. to IEC61557-8, IEC61010-1:2010-3 (should eventually be an IMD complying to IEC61557-18).

6.4.1 Leakage and common-mode currents

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.



7. DISSEMINATION, EXPLOITATION AND STANDARDISATION

The work from this D3.4 is a sensitive document. Sensitive deliverables will never be openly publicized and only the sections not protected, as long as it has been formally confirmed by the data owner, will be potentially available to be communicated or disseminated outside the consortium.

Within WP3 (EVSE development), WP4 (ACD and infrastructure development), and WP5 (Demonstration and validation) this work will be used as DEMO products of the respective system components and their mutual interfaces for real-life validation. The proposed EVSE-EV communication platform as designed and tested here will be used in WP5.

The pictures of the realized DEMO products have already been used in a dissemination post on LinkedIn and the HYPOBATT website.

Since the verification of the multi-MW charger is not finalized and future work is needed still, an appendix is proposed to be added to this document after finalization of the tests. The full test plan and execution based results are to be added in appendices G and H, respectively. To allow finalization of this D3.4, it has been chosen not to update the complete document.

The MCS related requirements that are expected to be not achievable have been discussed as such in the respective CharIn taskforces. Further solutions need to be investigated in the Marine (M-MCS) taskforce being formed to follow-up on the HYPOBATT learnings after the project. The introduced DC power modularity levels can be used for an update of the proposal for standardized shore charging solutions to harmonize the supply and demand sides per port implementation, aligned with the MCS and R-MCS standardisation efforts.

The IMD limitations in relation to Y-capacitance aspects as marked as a risk in this report need to be further discussed outside of the HYPOBATT consortium in an attempt to standardize them. That is, next to the continued search for a solution to protect the EVSE – EV charging system as a whole during the demo.



8. RESULTS AND DISCUSSION

8.1 Achieved results reflected to the objectives

- **Main objective:** Implement and internally validate the full-scale charger based on the mutually requirements defined in D1.4, the development and prototype testing done in T3.2, and the development of the system enclosure with climate conditioner in T3.3.
 - Implementation: **done**
 - Internal validation:
 - Basic functions: **90% done**
 - Non-functional requirements, e.g. climate conditioning: **30% done**
 - Functional requirements, e.g. starting power conversion and power circulation: **20% done**
 - Charging session execution based on interaction with DC outlet: **0%**
- **Additional objectives are as follows:**
 - Provide a report on electrical and mechanical design of charger: **done**
 - Integrate enclosure, integrate cooling, and functionally test conditioner in charger: **done**
 - Produce hyper vessel charger: **done**
 - Perform functional testing and power circulation: **see main objective**
 - Compose installation manual DEMO for installation in ports: **first version done**
 - Prepare DEMO (with D3.5) for shipping to perform the functional testing of the whole system composed by the modular multi-MW charger, the automated connector and the interfaces and communications in T4.3: **0% → mutual plan made with Damen and STT to achieve this before going to Frisia.**

8.2 Discussion

The **realization of the 3 MW DEMO charger** has taken a lot of time and energy from both Heliox internal and all external engineers and builders. Although we are not as far as planned, the cooperation and discussions proved to be very meaningful. Interactions with numerous people, however, proved to require more time and attention than expected. The result is very much to our satisfaction, but there is no guarantee yet that it performs fully according to expectations.

The **fundamental functional performance** will work as intended, but there have been, and are still, practical complexities in ramping up our testing efforts. Initial testing at our Eindhoven location proved to be a too weak grid connection (63 A AC/phase) leading to a power outage of part of the building. Subsequently, we relocated testing to our Veldhoven site, where we are now still in the process of ramping up. The DUT is now connected to a 400 A AC/phase grid connection, it is however still doubtful whether we can fully exploit that power. To anticipate to these practical issues, a MV grid connection has been requested for implementation in our lab, this however will take some more time to be realized and is therefore not ready for HYPOBATT testing.

The **different subjects in chapter 6** provide sufficient inducement for discussion, especially in the M-MCS taskforce that should lead to an additional part in the conductive charging standard. Discussion in this document on the crucial aspects from chapter 6:

- Inductance violation vs. over-current protection:** the posed limitation on the allowed inductance is there to ensure a limited short-circuit current, especially on vehicle side. This is defined relatively conservative to prevent the need for expensive components on-board of the EV. It must still be verified with Damen whether a potential short-circuit during charging would be safely decimated.
- Touch current prevention:** the subjects of active voltage symmetry, Y-capacitance limitation and symmetric loading all are aimed at limiting a potentially lethal touch current. Therefore, all known precautions in the design have been taken to still detect imbalances and other effects that direct to an unsafe situation. Additionally, in the installation, the required measures will be taken to provide all mechanical barriers further derisking the possibility of a potential touch current. The required measures to achieve this will be described in the installation manual.
- Leakage current:** as indicated in Figure 36, there are differences between the insulated EV IT circuit as described in the MCS standard for automotive applications (top-left), and the marine related IT circuit options, i.e.; in a marine application there is an alternative return-path through the hull of the vessel, the water and soil back to the charger earth connection point. Resultantly, the path of CM currents is less defined, which can result in corrosion issues and elevated voltage levels. Naturally, the MCS standard does not prescribe precautions to this phenomenon. A strong effort has been made to identify I_{CM-S} and I_{CM-P} during testing and to interrupt charging if the 10 mA limit of the charger is surpassed. Whether this limitation will be feasible to use during testing is to be determined still.

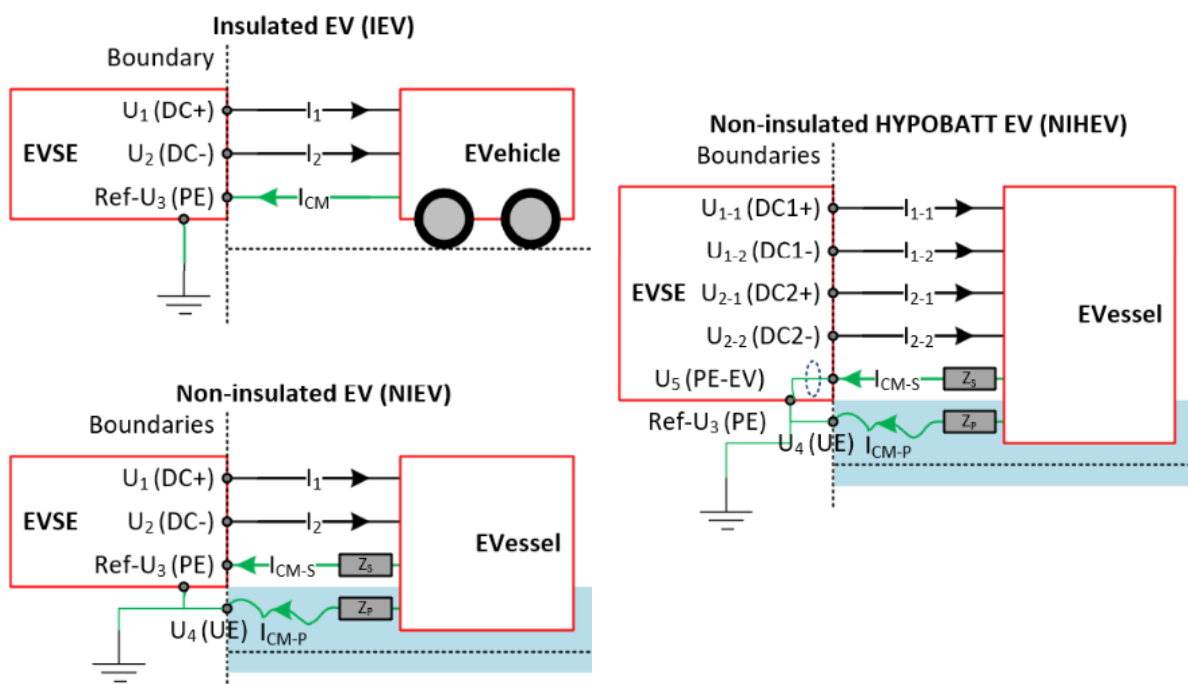


Figure 36 differences in IT charging network situations between EVSE and (non)insulated EVs wherein the non-insulated IT networks have an undefined earth (UE) return via a parasitic impedance, Z_P , alongside of the defined return impedance, Z_S .



To assure **clearance for testing**, an analysis and field auditing of the complete system must be performed still. Conversations with TUV Nord did not result in a practical approach in achieving this, therefore further investigation is ongoing. The outcomes of an analysis by another third-party should give the confidence to commence the testing, however, if unexpected issues are identified, this gives a risk in achieving the measurements in time.

.



9. CRITICAL RISKS

ID	WP/Task	Risk item	Effect	Probability ¹	Severity ²	Counter measures	Owner
1	WP3/WP4	MCS based 10base-T1S with integrated CE/ID functionality is standardized not fully tested yet, especially in combination with ACD movement.	This is to be tested at Stemmann as part of WP5 in preparation to the actual testing at Frisia.	Medium	minor	Detailed discussion of the required components to be developed by STT, Damen and Heliox conducted. Clear plan devised on what and how to approach and mutually test before the demo.	Damen, STT and Heliox
2	WP3/WP5	IMD limitations in relation to Y-cap needs to assure proper EMC behaviour and practical complexities of IMD distribution	Measuring insulation takes too long and the Y-capacitance of the vessel is too high. This is both a touch safety risk as well as a detection/measurement risk	small	high	1) Ensure that only educated test engineers are on-site and assure there is a double isolation to avoid touch hazards 2) Use of slower but higher capacitance IMD function.	Heliox, Damen

¹ Severity / Contribution to the failure of the project: Negligible, minor, serious, critical, catastrophic

² Probability of occurrence: improbable, remote probable, medium, probable, definite



3	WP3/WP5	Possible unidentified issues that would influence testing on site	Allowance to commence testing at Frisia might not be given	Small	Significant	<p>1) pre-testing and third-party witnessing of test setup at Heliox in advance of testing at Frisia</p> <p>2) optionally reducing the scope of testing at safety-critical items</p> <p>3) optionally altering the system to allow testing within MCS limit</p>	Heliox
---	---------	---	--	-------	-------------	---	--------



10. CONCLUSIONS

The core work done to achieve the required efforts have been described in this document. The main conclusion that can be drawn is that a lot of work has been done and all prototypes are realized, but the proof is in the pudding; only basic functional testing has been done yet and the real learning and improvements based on extensive testing still need to be commenced.

10.1 Recommendation for future work

Surely the power circulation full load testing of the 3 MW charger is the first goal ahead of us as Heliox. The required prerequisites to achieve this were underestimated and limited by practicalities but the path towards this is now paved.

Secondly, the power converter (2x60 kW or 3 MW) to DC outlet integration and testing needs to be finalized. Functional cooperation and assurance of the proper sequencing for charge sessions need to be discussed, implemented and verified.

Thirdly, the EVSE – EV ISO15118-10/-20 communications testing which is working must be transferred from laptop-to-laptop interaction towards controllers and combined with the low-level signalling. Since this already has been demonstrated in another application we are convinced that this is merely work to be done.

Finally, in advance of work in WP5, the ACD of Stemmann needs to be tested at manoeuvring while safety signalling and communication are active. Signal integrity and robustness are to be assured to maximize successful charge sessions when testing at Frisia.

10.2 Identification of contribution per partner

HELIOX

- Has led this task, composed and edited this report.
- Has managed, supervised and executed the development of the realized prototypes.
- Has designed the compact split-cooling solution of internal and external heat exchange making the system independent of the cooling solution.
- Designed the system modularity, conversion topology and resulting EVSE solutions.
- Tested the conversion principle on 2x 120 kW prototype system
- Defined the updated interfaces and layered communication platform and tested this.
- Co-defined the EVSE – EV communication based on MCS standardization.

STT and **DAMEN** participated in discussions leading to the definition in the EVSE–EV communication and assisted in testing this in a vessel representative situation with a hardware in the loop setup. **DAMEN** furthermore provided the measurement results of the Ekaterin vessel.

IMECAR and **BRING** supported the partners in getting to the final design of the container and related cooling solution.



11. REFERENCES

- [1] CharIn, 2023. [Online]. Available: <https://www.charin.global/technology/>.
- [2] EMSA (European Maritime Safety Agency), "SSE - Guidance to Port Authorities and Administrations - Part 1 - Equipment and Technology," EMSA, 2022.
- [3] EMSA (European Maritime Safety Agency), "SSE - Guidance to Port Authorities and Administrations - Part 2 - Planning, Operations and Safety," EMSA, 2022.
- [4] IEC TC85 (CD IEC 61557-18 ED1), *Electrical safety in low voltage distribution systems up to 1 000 V AC and 1 500 V DC - equipment for testing, measuring or monitoring of protective measures*, IEC, 2024.



12. APPENDICES

12.1 Appendix A – Factory acceptance tests – LV section

See D3.5, added therein

12.2 Appendix B – Factory acceptance tests – MV section

See D3.5, added therein

12.3 Appendix C – Installation manual

12.4 Appendix D – DEMO preparations to WP5 testing

12.5 Appendix E – Product leaflet 3 MW charging station

heliox

Heavy-duty MCS charging system 3 MW 3 kA (2x 1.5 kA)



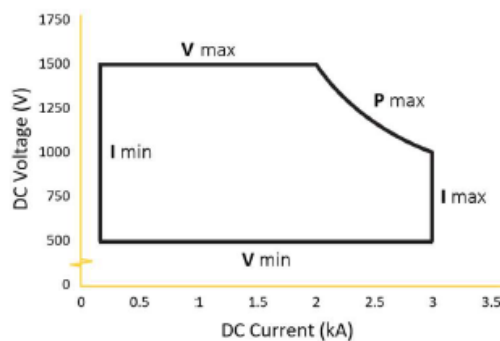
Version with dry-cooler on top shown



Charge any ACD/MCS compatible heavy-duty off-road EV, maritime electric vessel or electric truck with up to 3 MW. This ruggedized product is designed for opportunity charging of heavy-duty off-road electrified EVs in harsh environments, but can also be used for class 6, 7, 8 commercial vehicles or other large battery electric vehicles equipped with a megawatt charging system (MCS) inlet. A fast and highly-efficient charging solution for a single vehicle or vessel.

Industries highest component reliability and system redundancy keeps your fleets' battery charged-at-all-times. The charger is designed according to the IEC 61851 (parts 23-1 & 23-3 still in development) and able to interface with a single 3 kA or dual 1.5 kA MCS dispenser column or auto-connect device (ACD) using the Heliox standard remote connection interface. In this way, a wide variety of EVSE systems can be composed of the same products.

Power Curve 3 MW



Specifications

General	Charger
Charging standard	IEC61851-1/23/23-1/23-3
Communication standard	IEC61851-24 / DIN70121 / ISO15118-1/2/10/20
Optional additions	ISO15118-6 ISO15118-8 Wi-Fi (OppCharge)
Compliance and safety	CE / IEC 61851-21-2 / IEC 61439
Output DC voltage range	500 - 1500 V
Rated DC output power	3 MW
DC output current range	0.1 - 3 kA (dual 0.05 – 1.5 kA)
Input connections, Frequency	3P + PE (G), 49 - 51 Hz
Full load / idle input power	3.15 MVA / 50 kVA
Input line-line voltage range	6-24 kV AC +/- 2.5 %
Power factor above 50 % rated	> 0.99
Peak efficiency	97% (MV AC in - LV DC out)
Dielectric withstand	40/75/125 kV (depending on V _U)
Network cellular back office	4G modem, LAN OCPP 1.6J/2.0, Chargesight
Temperature range cooling options	- 40 to 50 °C, derating may apply Dry-cooler, HVAC or technical water
Operational noise level	< 80 dB(A) @ 5 m
System weight	22.000 kg
Dimensions	20 ft high-cube container ISO 668:2020 - 1CCC
Protection	IP65 / IK11
Environment operating	ISO 12944: C5-I and C5-M

Specifications subject to change without notice, under development

97% Efficiency

Highest up time

Back office systems

Zero Emissions

Support services

Industry's quietest

Global HQ
Heliox Automotive B.V.
Veldhoven, The Netherlands
+31 88 5016 300

North America
Heliox Technology Inc.
Atlanta (GA), USA

www.heliox-energy.com
info@heliox-energy.com

The copyright of the (registered) trademarks are the property of the respective owners.



12.6 Appendix F: Overload and short-circuit protection

IEC 61851-23-3 CDV © IEC 2024 (69/1025/CDV) – Section 13

IEC 61851-23:2023, Clause 13 is applicable, except as follows:

13.101 Short-circuit protection of the DC connection during energy transfer

Replacement:

The EV supply equipment shall fulfil all the requirements a) to c) below, for a short-circuit current supplied by the EV supply equipment due to any of the following fault conditions:

- fault condition 1: a short-circuit between side B live parts (DC+ and DC-);
- fault condition 2: a failure in the PEC, for example, a permanently fully conductive switching element in a buck converter.

The DC EV supply equipment shall fulfil all the following requirements:

- a) at side B live parts (DC+ and DC-) at the vehicle connector:
 - limit the peak current to ≤ 30 kA, and
 - limit the I_2t value to $\leq 1\,000\,000$ A²s,
 - switch off the supply to the vehicle within 4 ms after start of the short circuit condition.

If the short-circuit current supplied by the EV supply equipment is not sufficient to trip a fuse, if any, within the required time to limit the I_2t value, the EV supply equipment shall provide an alternative means to interrupt the short-circuit current.

- b) trigger an emergency shutdown within 1 s after the start of the short-circuit condition as specified in the respective test.

For fault condition 1, the compliance with requirements a) and b) is tested according to CC.7.5.17. For fault condition 2, the compliance with requirements a) and b) is demonstrated through design review.

- c) The protective conductor of the EV supply equipment at side B shall have the following characteristics:
 - withstand a maximum short circuit peak current of 55 kA, and
 - withstand a maximum I_2t value of 11 000 000 A²s.

These values are based on the following assumptions:

- Simultaneous short circuit in the EV supply equipment (max. 30 kA) and in the EV (max. 70 kA) including a minimum impedance of the cable assembly (minimum cable length of 2 m),



- a fault resistance of $R_{\text{fault}} = 5 \text{ m}\Omega$ for each fault,
- a fault inductance of $L_{\text{fault}} = 2 \text{ }\mu\text{H}$ for each fault, and
- both, the EV supply equipment and the EV, switch off the supply within 4 ms after start of the short circuit condition.

NOTE 1 The current peak is a result of the discharge of the capacitance of the EV supply equipment. The capacitive discharge is a transient phenomenon in the range of milliseconds.

NOTE 2 Requirements for short-circuit check before charging are given in 6.3.1.109.

For a short-circuit current supplied by the EV, the requirements in d) or e) shall be fulfilled.

- d) At the vehicle connector, the EV supply equipment shall have a 793 short-circuit current withstand rating (I_{2t}) and shall withstand a peak current according to the values as specified in ISO 5474-3 specified for system MCS. The minimum cross-sectional area of the line conductors shall be calculated according to IEC 60364-4-43:2008, Equation (3).
- e) For sections of the side B which are not designed according to the withstand rating (I_{2t}) and the peak current according to d), an overcurrent protection device shall be provided. The section of the side B which is protected by this protection device shall be designed according to the characteristics of this overcurrent protection device.

Compliance for requirements c), d) and e) is checked by inspection.



Future extensions after testing finalization:

12.7 Appendix G: 3 MW test plan

12.8 Appendix H: 3 MW test results