HYPOBATT

Hyper powered vessel battery charging system

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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, *M* 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

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EXECUTIVE SUMMARY

This deliverable D5.5 marks the end of the intense period of experimental validation for the HYPOBATT project. Starting with the main achievement; successful charging sessions with up to 1.8 MW of overall power, including communication fully according to the MCS standard have been demonstrated. The strong collaboration between the project partners was a crucial factor in achieving this result together; although the testing was planned and prepared well, the eventual creativity and perseverance of the team members was essential. The testing proved to be quite a challenge due to the weather in Norden; heavy snowfall, strong winds, and perceived temperatures down to -20 °C, as can be seen in Figure 1.

Figure 1 Photo of the testing site at the Norden port

Testing the developed megawattscale (MW) charging system is essential to ensure safe, reliable, and efficient operation required for large electric vessels and heavyduty applications. Because MW-scale charging pushes components, communication protocols, and protection mechanisms to their operational limits, thorough validation is needed to confirm that the system can maintain stable power transfer, respond correctly to dynamic load changes, and handle fault conditions without risk to equipment or personnel. Such testing also verifies interoperability between the EVSE and the vessel, ensures compliance with relevant standards, and provides confidence that the system can operate consistently in realworld environments where mechanical movement, electrical noise, and harsh conditions are unavoidable. After several years of design and discussion, the results of the multi-MW system for marine application are presented herein.

This report firstly describes the three different charging system set-ups for testing using different combinations of 2 EVSE systems (EVSE 1: 3 MW main system and EVSE 2: 120 kW island system) and 2 EVs (EV 1: Frisia E-I electric catamaran and the EV 2: GMS vessel Marino). The tested combinations are EVSE 1 – EV 1, EVSE 2 – EV 1, and EVSE 1 – EV 2, according to the KPIs defined in the project proposal. Secondly, the testing outcomes of each of these combinations are detailed. Lastly, the overall results, discussion and recommendations for future work are presented.

Although the testing provided verification of the main goals and objectives, not all intended results were measured. For example, the efficiency measurements failed because the MV SWG power-meter did not function properly during the demonstration. Beyond the scope of the HYPOBATT project, further testing is needed to characterize the performance and improve towards commercial roll-out of the developed solutions.

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

OBJECTIVES

Main objective: Test and validate the full-scale multi-MW charger system on the marine environment, based on the requirements mutually defined in D1.4, the development and prototype testing done for the power cabinet in D3.4 and D3.5, and for the ACD system in D4.4 and D4.5, respectively. To do so, a masterplan containing all essential steps for the system test has been made, based on the requirements D1.4 and test plan presented in D3.4. Present results on a real marine environment of the charging system are developed. All responsibilities in achieving these objectives are a shared responsibility of Damen (vessel), STT (ACD), Frisia (port), and Heliox (PC and DC outlet in ACD).

Additional objectives are as follows:

- Present test results of successfully charging session, detailing each step of the charging sequence.
- Test of EVSE-EV communication following MCS standard.
- Show evidence of safe charging session, through protections and emergency stops.
- Present a multi-MW charging session results.
- Verify the project KPIs using the test setup (separate document).

1. INTRODUCTION

This deliverable D5.5 marks the end of the intense period of experimental validation for the HYPOBATT project. The presented validation report provides all the test results of the multi-MW charger system on a realistic operating environment. The installation of the system at Frisia site enabled comprehensive assessment and testing of the full complexity of a charge system on a marine application. The EVSE-EV system communication and charger power cabinet has been developed as described in D3.1, D3.2 and D3.3, while functional and power testing validating on lower scale setup was carried out in D3.4. The details of the site preparation for the demo, together with installation of the entire system at Frisia were shown on D5.1 and D5.2, respectively. Before the test and validation took place, the site installation was certified by a notified body, where the safety, function, non-function, and operation aspects were reviewed, and presented in D5.3.

As outlined in Deliverable D5.2, Chapter 2 provides a brief description of the three different test installations; the mainland and island system at Frisia and the Kötter Werft system. Following the certification of these installations, as documented in D5.3, the testing phase was initiated, and its results are presented in this report.

Chapter 3 presents the EVSE-EV communication test results, explained in the context of the system communication architecture defined in D3.2. The communication setup is presented along with its behaviour during connection and disconnection of the charging system, for mainland and island system. Communication robustness, reliability, and the initial parameter exchange between EVSE and EV after connection are also discussed.

The main results of the mainland charging system are presented in chapter 4. It details the performance of each charging phase, from initial connection to final disconnection, highlighting the successful demonstration of megawatt-level charging. The chapter also covers key operational scenarios, including emergency stops and system disconnections, along with an assessment of protective-earth (PE) currents. In addition, the system electromagnetic compatibility (EMC) basic behaviour is evaluated.

2. CHARGING SYSTEM OVERVIEW

Executive Summary

According to the work described in tasks 5.1, 5.2, and 5.3, the test sites was prepared and certified for the system test demonstration and docking validation. Also, the detailed description of all equipment composing the HYPOBATT system was shown. This chapter will summarize the HYPOBATT system components and shows its installation at Frisia and Kötter Werft sites for the test validation and demonstration.

2.1 Frisia mainland system test setup (EVSE 1 – EV 1)

In Figure 2, an overview of the different equipment composing the mainland installation of the HYPOBATT system test setup at Frisia site:

1. Medium voltage AC connection (**MV AC**), 20kV AC grid powering the MW Charger container (PC).
2. **3MW Charger container**, with 2 DC output connected to the DC outlet at ACD. Each output maximum capability of 1100V, 1500A and 1.5MW.
3. **DC outlet** is the power connection between EVSE and EV, also the EVSE charging control and communications (SECC – EVCC).
4. **ACD**, connects EVSE DC power and communication to the Electrical Vessel.
5. **Ship interface**, interface where the ACD will connect with the vessel.
6. **Electrical Vessel**, EV system composed of two battery packs of 900kWh each.

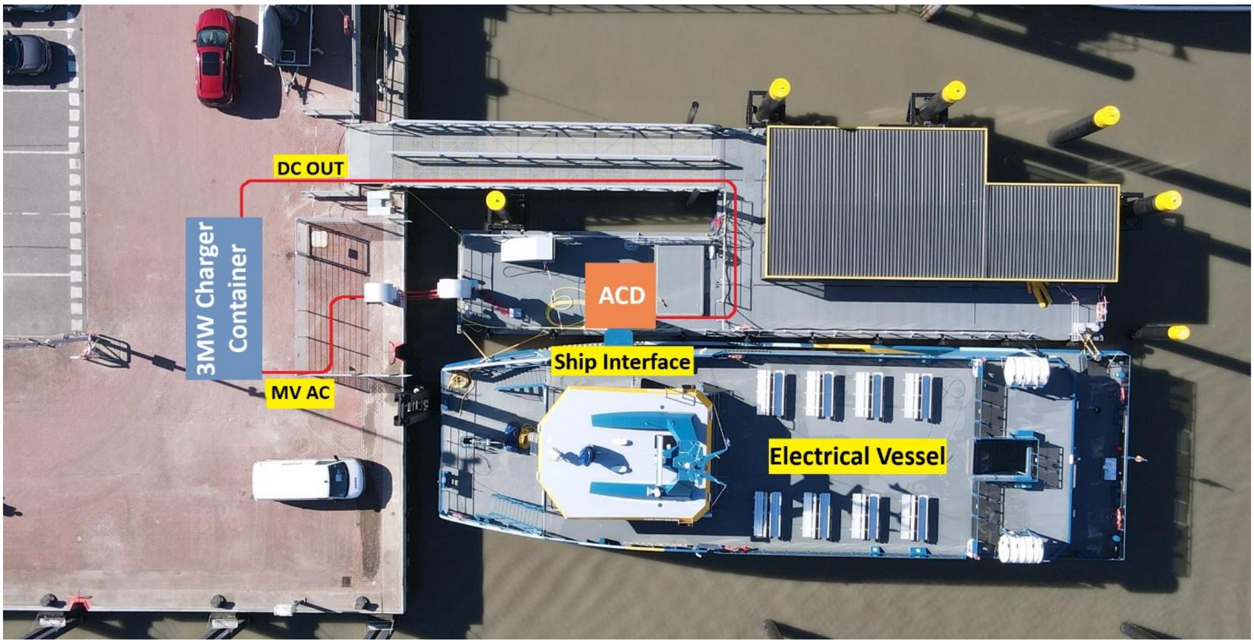


Figure 2 Overview of the test system installation at Frisia site.

Figure 3 presents the actual placement of each component of the test system on the Frisia site.

Figure 3 overview of the mainland system EVSE 1 test installation and equipment placement at Frisia site.

All equipment shown here was tested and validated individually before the complete system test took place. It started with the testing and validation of the ACD connection to the ship interface, where is detailed described on the Deliverable 5.4. After that, the communication and charging session control were tested, following the charging sequence described on the MCS standard IEC 61851-23-3. All protections mechanisms and emergency features were verified at this stage. Finally, the complete charging session test, including power transfer, was performed, and the results of these tests are presented here.

2.2 Frisia island system test setup (EVSE 2 – EV 1)

Figure 4 presents the island system test, composed by:

1. Two **2x60kW power cabinets**, supplied by 400V 63A AC mains each, connected to the DC outlet in the ACD.

2. **DC outlet** as in the mainland system, is the power connection between EVSE and EV, also the EVSE charging control and communications (SECC – EVCC).
3. **ACD**, connects EVSE DC power and communication to the Electrical Vessel.

Figure 4 Overview of the island system (EVSE 2) test installation.

The testing and validation of the island test system brought a lot of challenges to the HYPOBATT team. Adverse weather condition restricted the test on the island due the ice, which risked damaging the vessel. The decision made was to move the island system to be tested at mainland, at a different location from the mainland system but still within the Frisia site at Norddeich. This introduced another challenge, the ACD connection to the vessel only could only be made at high tide, creating substantial time constraint for testing the island system.

Due to these limitations, the island system setup was tested only with respect to the ACD connection to the ship interface, and the communication between EVSE and EV. Power transfer testing could not be performed. However, this didn't diminish the goals of the second test system, as the island system's power cabinets were similar to the mainland system's power cabinet. Moreover, neither power cabinets played a role on the communication and control of the charging sequence, they acted solely as a power supply, with a constant voltage and current demand limitation according to the system itself, delivering power when requested.

2.3 Kötter Werft system test setup (EVSE 1 – EV 2)

Figure 5 Installation of EVSE 1 connection system for EV 2

Figure 5 shows the installation of the Automatic Connecting Device (ACD) on the shore-side infrastructure and the ship interface mounted on the GMS vessel Marino at Kötter Werft. The setup reflects real shipyard conditions, ensuring proper alignment between the ACD and the vessel interface prior to operation. This installation demonstrates the adaptability of the EVSE system connection interface to practical deployment environments on the second vessel application (EV 2).

3. SECC – EVCC COMMUNICATION TEST RESULTS

Executive Summary

This section summarizes the communication testing performed on both the mainland and island charging systems, the communication architecture was defined on deliverable 3.2. The tests focused on verifying the complete communication chain between the EVSE and the vessel, from initial physical connection detection to the end of the charging session. The communication robustness and charging session parameter exchange are also presented here.

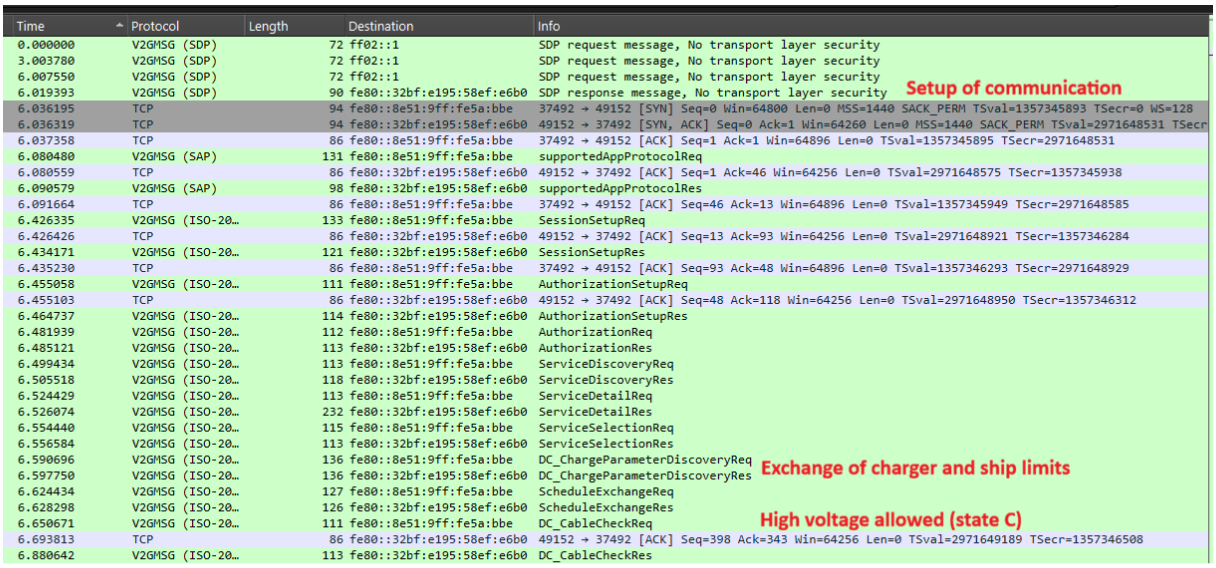
3.1Mainland system communication test

3.1.1 Communication setup

In the charging protocol, the session is setup after physical connection detected by the basic signals (CE and ID signals). During testing it was noticed that a delay of 6 seconds is required for debouncing the initial connection.

After the delay the charger responds to the charger discovery broadcast of the vessel and responds with the IPv6 address and port where the vessel can connect to.

When the vessel connects to the charger via TCP some session setup is done to check the compatibility between charger and vessel. After the charger parameter discovery state, the vessel allows high voltage on the connection, and the charger will start with the cable check to determine if the connection is valid for charging. These steps are presented on Figure 6.



```
Time        Protocol          Length  Destination                 Info
0.000000    V2GMSG (SDP)          72 ff02::1                     SDP request message, No transport layer security
3.003780    V2GMSG (SDP)          72 ff02::1                     SDP request message, No transport layer security
6.007550    V2GMSG (SDP)          72 ff02::1                     SDP request message, No transport layer security
6.019393    V2GMSG (SDP)          90 fe80::32bf:e195:58ef:e6b0   SDP response message, No transport layer security
6.036195    TCP                   94 fe80::8e51:9ff:fe5a:bbe     37492 → 49152 [SYN] Seq=0 Win=64800 Len=0 MSS=1440 SACK_PERM TSval=1357345893 TSecr=0 WS=128
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6.037358    TCP                   86 fe80::8e51:9ff:fe5a:bbe     37492 → 49152 [ACK] Seq=1 Ack=1 Win=64896 Len=0 TSval=1357345895 TSecr=2971648531
6.080480    V2GMSG (SAP)         131 fe80::8e51:9ff:fe5a:bbe     supportedAppProtocolReq
6.080559    TCP                   86 fe80::32bf:e195:58ef:e6b0   49152 → 37492 [ACK] Seq=1 Ack=46 Win=64256 Len=0 TSval=2971648575 TSecr=1357345938
6.090579    V2GMSG (SAP)          98 fe80::32bf:e195:58ef:e6b0   supportedAppProtocolRes
6.091664    TCP                   86 fe80::8e51:9ff:fe5a:bbe     37492 → 49152 [ACK] Seq=46 Ack=13 Win=64896 Len=0 TSval=1357345949 TSecr=2971648585
6.426335    V2GMSG (ISO-20…      133 fe80::8e51:9ff:fe5a:bbe     SessionSetupReq
6.426426    TCP                   86 fe80::32bf:e195:58ef:e6b0   49152 → 37492 [ACK] Seq=13 Ack=93 Win=64256 Len=0 TSval=2971648921 TSecr=1357346284
6.434171    V2GMSG (ISO-20…      121 fe80::32bf:e195:58ef:e6b0   SessionSetupRes
6.435230    TCP                   86 fe80::8e51:9ff:fe5a:bbe     37492 → 49152 [ACK] Seq=93 Ack=48 Win=64896 Len=0 TSval=1357346293 TSecr=2971648929
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6.455103    TCP                   86 fe80::32bf:e195:58ef:e6b0   49152 → 37492 [ACK] Seq=48 Ack=118 Win=64256 Len=0 TSval=2971648950 TSecr=1357346312
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6.481939    V2GMSG (ISO-20…      112 fe80::8e51:9ff:fe5a:bbe     AuthorizationReq
6.485121    V2GMSG (ISO-20…      113 fe80::32bf:e195:58ef:e6b0   AuthorizationRes
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6.505518    V2GMSG (ISO-20…      118 fe80::32bf:e195:58ef:e6b0   ServiceDiscoveryRes
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6.526074    V2GMSG (ISO-20…      232 fe80::32bf:e195:58ef:e6b0   ServiceDetailRes
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6.556584    V2GMSG (ISO-20…      113 fe80::32bf:e195:58ef:e6b0   ServiceSelectionRes
6.590696    V2GMSG (ISO-20…      136 fe80::8e51:9ff:fe5a:bbe     DC_ChargeParameterDiscoveryReq
6.597750    V2GMSG (ISO-20…      136 fe80::32bf:e195:58ef:e6b0   DC_ChargeParameterDiscoveryRes
6.624434    V2GMSG (ISO-20…      127 fe80::8e51:9ff:fe5a:bbe     ScheduleExchangeReq
6.628298    V2GMSG (ISO-20…      126 fe80::32bf:e195:58ef:e6b0   ScheduleExchangeRes
6.650671    V2GMSG (ISO-20…      111 fe80::8e51:9ff:fe5a:bbe     DC_CableCheckReq
6.693813    TCP                   86 fe80::32bf:e195:58ef:e6b0   49152 → 37492 [ACK] Seq=398 Ack=343 Win=64256 Len=0 TSval=2971649189 TSecr=1357346508
6.880642    V2GMSG (ISO-20…      113 fe80::32bf:e195:58ef:e6b0   DC_CableCheckRes
```

Figure 6 EVSE and EV communication during connection and charging sequence initialization.

Figure 7 presented the measurement of CE and ID signals on each stage of EVSE and EV communication on the EVSE MCS board, for both charging outputs. When the ACD is not connected, the MCS board indicate state A. State B0 indicated that ACD is connected, state B is when EVSE is ready, but EV is not yet ready to charge. Finally state C indicates EV is ready to charge. After that, the vessel closed its circuit breaker if the voltage of EVSE matches the charging voltage request and start the power transfer.

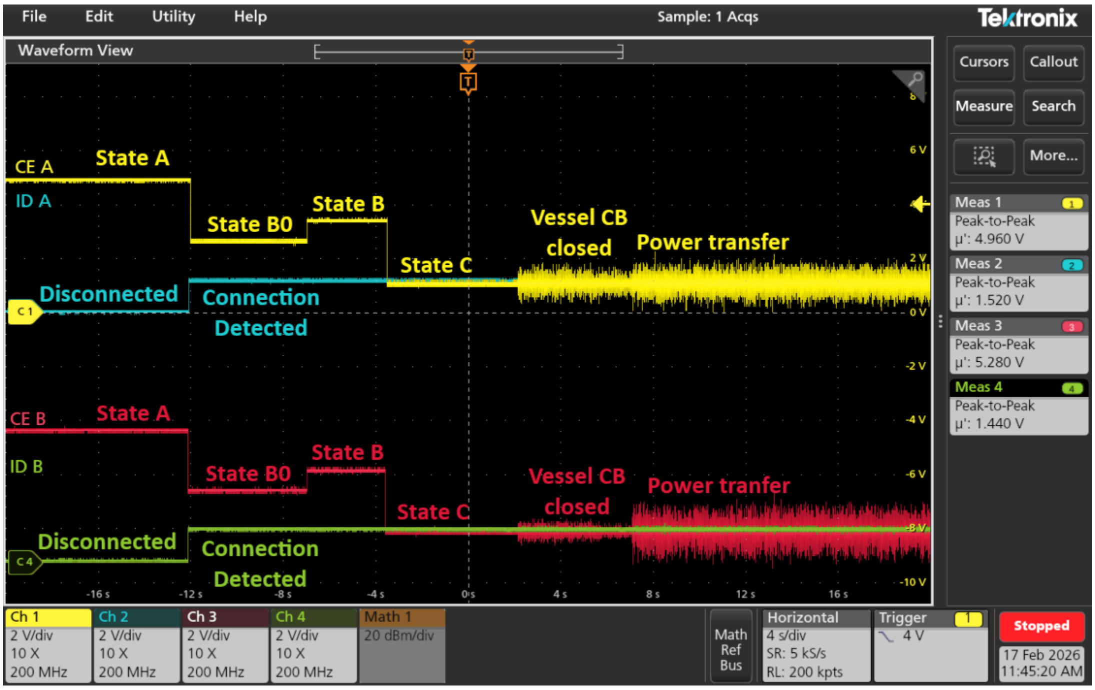


Figure 7 CE and ID communication signals during charging sequence initialization, where yellow is CE A Portside, blue is ID A (Portside), red is CE B (Starboard) and green is ID B (Starboard).

At the ending of charging sequence, the same process happens with inverted sequence, from state C to state A, when indicates the ACD is disconnected. Figure 8 presents the CE and ID signals of both outputs during the ending of the charging sequence.

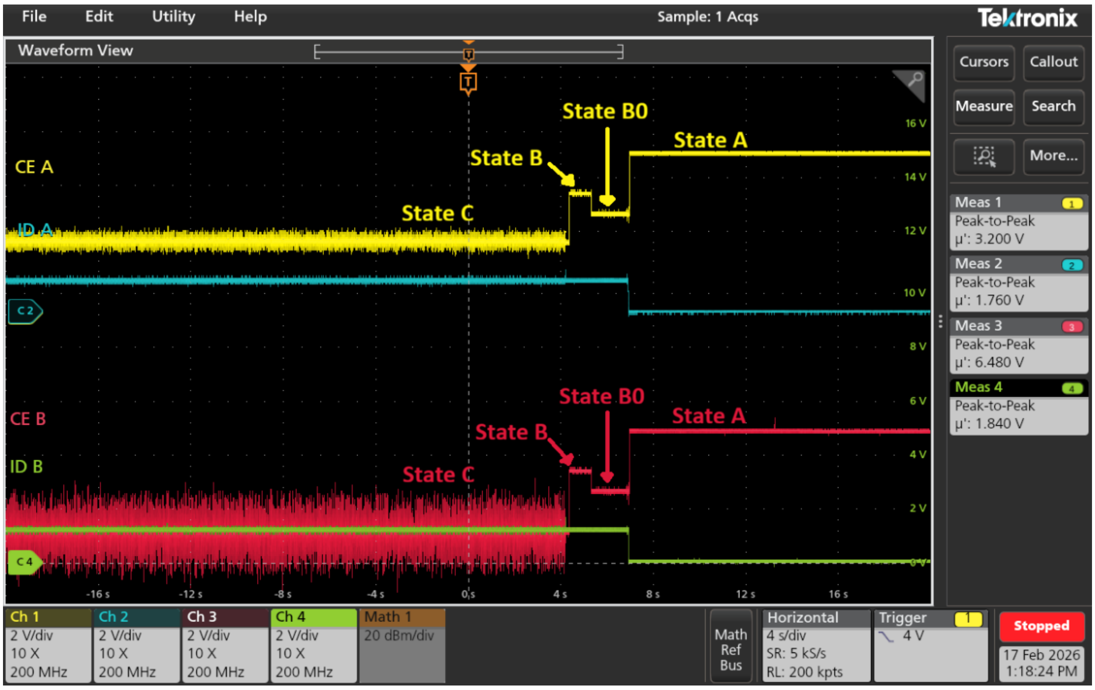
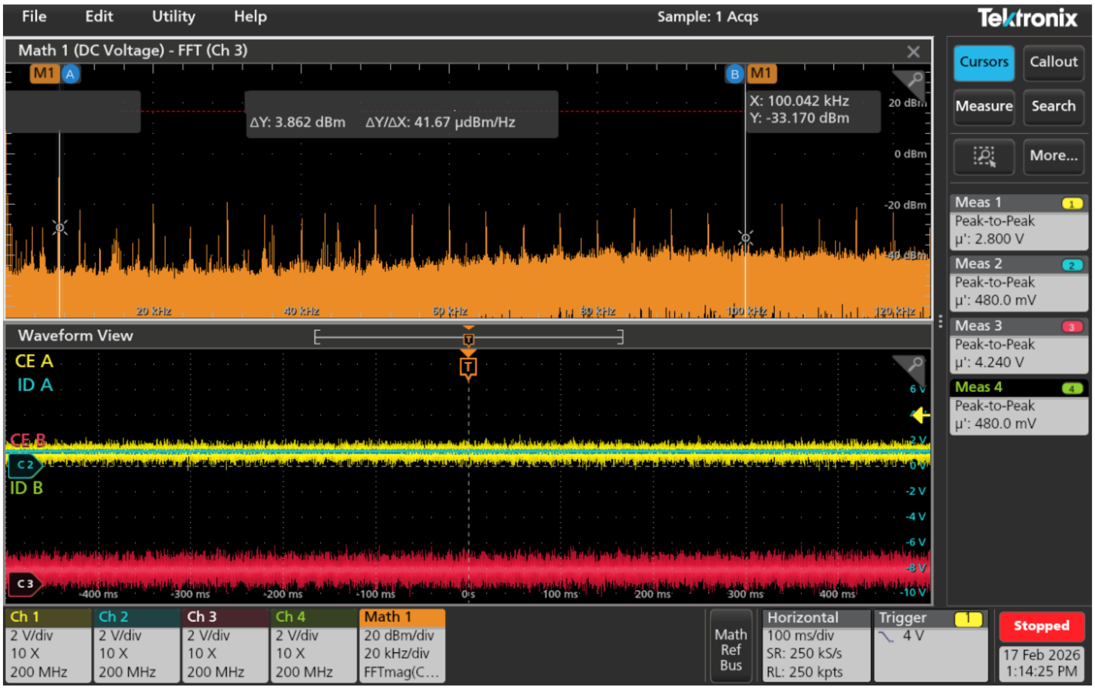


Figure 8 CE and ID communication signals during charging sequence ending, where yellow is CE A Portside, blue is ID A (Portside), red is CE B (Starboard) and green is ID B (Starboard).

As seen on Figure 7 and Figure 8, after the closing of the vessel's circuit breaker, the CE signal of both outputs get noise interference. This happens because the location of the CE signal on the ship interface is close to the power connection (DC+ and DC-). This interference doesn't cause any loss of communication during all tests done at Frisia. Figure 9 shows the FFT of the CE signal highlighting the origin of the interference is the power converter switching frequency.



ΔY: 3.862 dBm ΔY/ΔX: 41.67 μdBm/Hz
X: 100.042 kHz
Y: -33.170 dBm

Meas 1 Peak-to-Peak μ': 2.800 V
Meas 2 Peak-to-Peak μ': 480.0 mV
Meas 3 Peak-to-Peak μ': 4.240 V
Meas 4 Peak-to-Peak μ': 480.0 mV

Ch 1 2 V/div 10 X 200 MHz
Ch 2 2 V/div 10 X 200 MHz
Ch 3 2 V/div 10 X 200 MHz
Ch 4 2 V/div 10 X 200 MHz
Math 1 20 dBm/div 20 kHz/div FFTmag(C…
Math Ref Bus
Horizontal 100 ms/div SR: 250 kS/s RL: 250 kpts
Trigger 1 4 V
17 Feb 2026 1:14:25 PM

Figure 9 FFT of the CE signal.

3.1.2 Communication robustness

During the charge session some TCP retransmissions are observed indicating that T1S frames get lost. This is mainly observed during movement of the ship. When the connection interruption is short enough the TCP mechanism will retransmit the lost frame and continue the session, as presented on Figure 10.

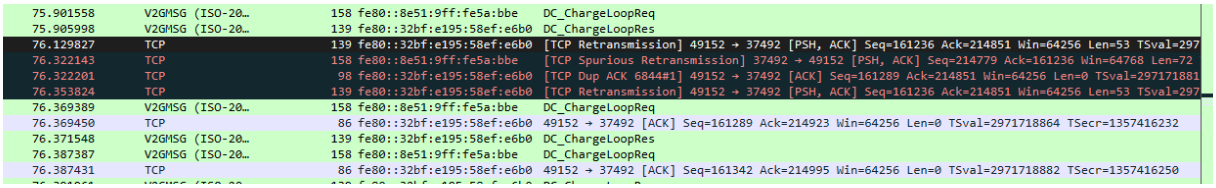

```
   75.901558      V2GMSG (ISO-20…             158 fe80::8e51:9ff:fe5a:bbe    DC_ChargeLoopReq
   75.905998      V2GMSG (ISO-20…             139 fe80::32bf:e195:58ef:e6b0  DC_ChargeLoopRes
   76.129827      TCP                         139 fe80::32bf:e195:58ef:e6b0  [TCP Retransmission] 49152 → 37492 [PSH, ACK] Seq=161236 Ack=214851 Win=64256 Len=53 TSval=297
   76.322143      TCP                         158 fe80::8e51:9ff:fe5a:bbe    [TCP Spurious Retransmission] 37492 → 49152 [PSH, ACK] Seq=214779 Ack=161236 Win=64768 Len=72
   76.322201      TCP                          98 fe80::32bf:e195:58ef:e6b0  [TCP Dup ACK 6844#1] 49152 → 37492 [ACK] Seq=161289 Ack=214851 Win=64256 Len=0 TSval=297171881
   76.353824      TCP                         139 fe80::32bf:e195:58ef:e6b0  [TCP Retransmission] 49152 → 37492 [PSH, ACK] Seq=161236 Ack=214851 Win=64256 Len=53 TSval=297
   76.369389      V2GMSG (ISO-20…             158 fe80::8e51:9ff:fe5a:bbe    DC_ChargeLoopReq
   76.369450      TCP                          86 fe80::32bf:e195:58ef:e6b0  49152 → 37492 [ACK] Seq=161289 Ack=214923 Win=64256 Len=0 TSval=2971718864 TSecr=1357416232
   76.371548      V2GMSG (ISO-20…             139 fe80::32bf:e195:58ef:e6b0  DC_ChargeLoopRes
   76.387387      V2GMSG (ISO-20…             158 fe80::8e51:9ff:fe5a:bbe    DC_ChargeLoopReq
   76.387431      TCP                          86 fe80::32bf:e195:58ef:e6b0  49152 → 37492 [ACK] Seq=161342 Ack=214995 Win=64256 Len=0 TSval=2971718882 TSecr=1357416250
```

Figure 10 TCP retransmission

3.1.3 Communication power transfer

During the charge session the voltage and currents are continuously shared between charger and vessel. Figure 11 shows the different stages in the power transfer visualized.

During the start of power transfer the charger outputs constant voltage (equal to charger voltage setpoint) while the vessel DC/DC converters do not charge the battery.

After 40 seconds the vessel starts to ramp up the power flow to the battery. When the current starts increasing the DC voltage will drop slightly to get in a constant power transfer stage by the droop control. When the battery is almost full the onboard DC/DC converters will reduce the power flow to the battery resulting in a slight increase of the DC voltage. At the end of the session when the stop button is pressed the vessel will stop the power transfer to the batteries resulting in zero DC current between charger and vessel, as presented in Figure 11

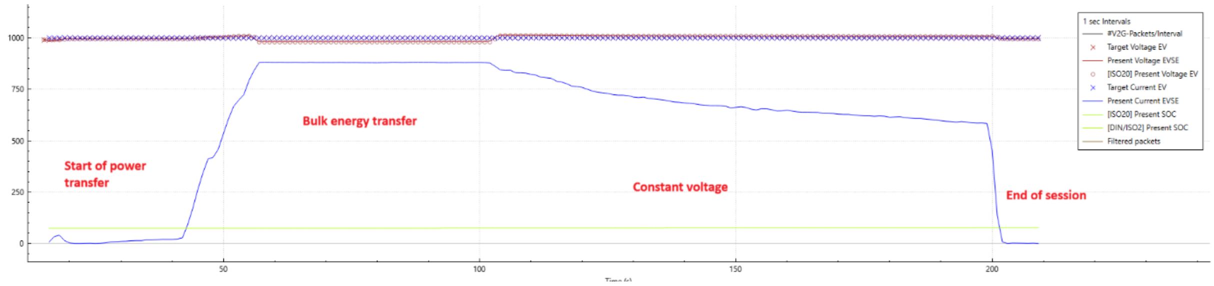
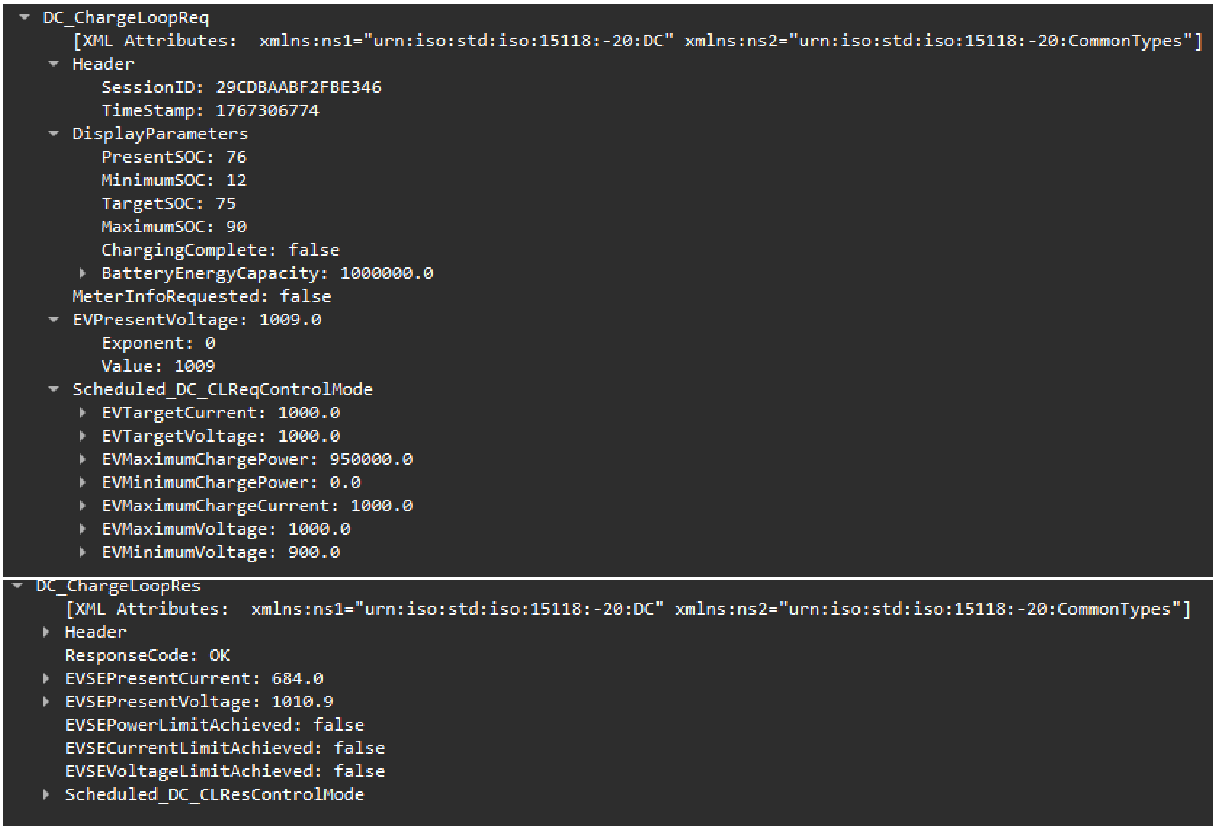


Figure 11 Different stages during power transfer.

3.1.4 Communication charge loop

During communication the vessel cyclic requests a target current and target voltage towards the charger. The charger replies with the actual current and actual voltage. Both situations are shown on Figure 12.



```
▾ DC_ChargeLoopReq
    [XML Attributes:  xmlns:ns1="urn:iso:std:iso:15118:-20:DC" xmlns:ns2="urn:iso:std:iso:15118:-20:CommonTypes"]
  ▾ Header
      SessionID: 29CDBAABF2FBE346
      TimeStamp: 1767306774
  ▾ DisplayParameters
      PresentSOC: 76
      MinimumSOC: 12
      TargetSOC: 75
      MaximumSOC: 90
      ChargingComplete: false
    ▸ BatteryEnergyCapacity: 1000000.0
    MeterInfoRequested: false
  ▾ EVPresentVoltage: 1009.0
      Exponent: 0
      Value: 1009
  ▾ Scheduled_DC_CLReqControlMode
    ▸ EVTargetCurrent: 1000.0
    ▸ EVTargetVoltage: 1000.0
    ▸ EVMaximumChargePower: 950000.0
    ▸ EVMinimumChargePower: 0.0
    ▸ EVMaximumChargeCurrent: 1000.0
    ▸ EVMaximumVoltage: 1000.0
    ▸ EVMinimumVoltage: 900.0
```

```
▾ DC_ChargeLoopRes
    [XML Attributes:  xmlns:ns1="urn:iso:std:iso:15118:-20:DC" xmlns:ns2="urn:iso:std:iso:15118:-20:CommonTypes"]
  ▸ Header
    ResponseCode: OK
  ▸ EVSEPresentCurrent: 684.0
  ▸ EVSEPresentVoltage: 1010.9
    EVSEPowerLimitAchieved: false
    EVSECurrentLimitAchieved: false
    EVSEVoltageLimitAchieved: false
  ▸ Scheduled_DC_CLResControlMode
```

Figure 12 Parameters communication between charger and vessel.

3.2 Island system communication test

Figure 13 presents a log of a charge session without power transfer and only the communication between EVSE-EV was established. The actual current remains zero while the requested current is around 100A. The setup of communication is equal to the mainland setup.

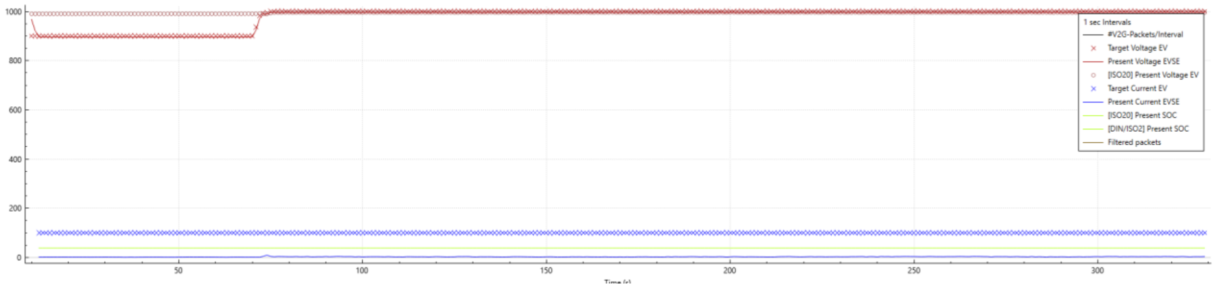


Figure 13 Log of a charging session on the island test communication.

4. MAINLAND SYSTEM CHARGING TEST RESULTS

Executive Summary

This chapter presents the test results of the mainland charging system, following the masterplan outlined in Deliverable D5.2. The overall system architecture is described in Deliverable 3.4. The complete charging sequence is detailed here, covering every step from the ACD connection to the vessel, the initiation of EVSE–EV communication, power transfer, termination of the charging session, and final disconnection.

Evidence of multimegawatt charging is provided, including the simultaneous charging of both vessel's battery packs. System behaviour during an emergency-stop event is also documented, demonstrating proper safety shutdown procedures and ACD disconnection.

Measurements of protective earth (PE) current at different power levels are included. Electromagnetic compatibility (EMC) results are also presented in this chapter.

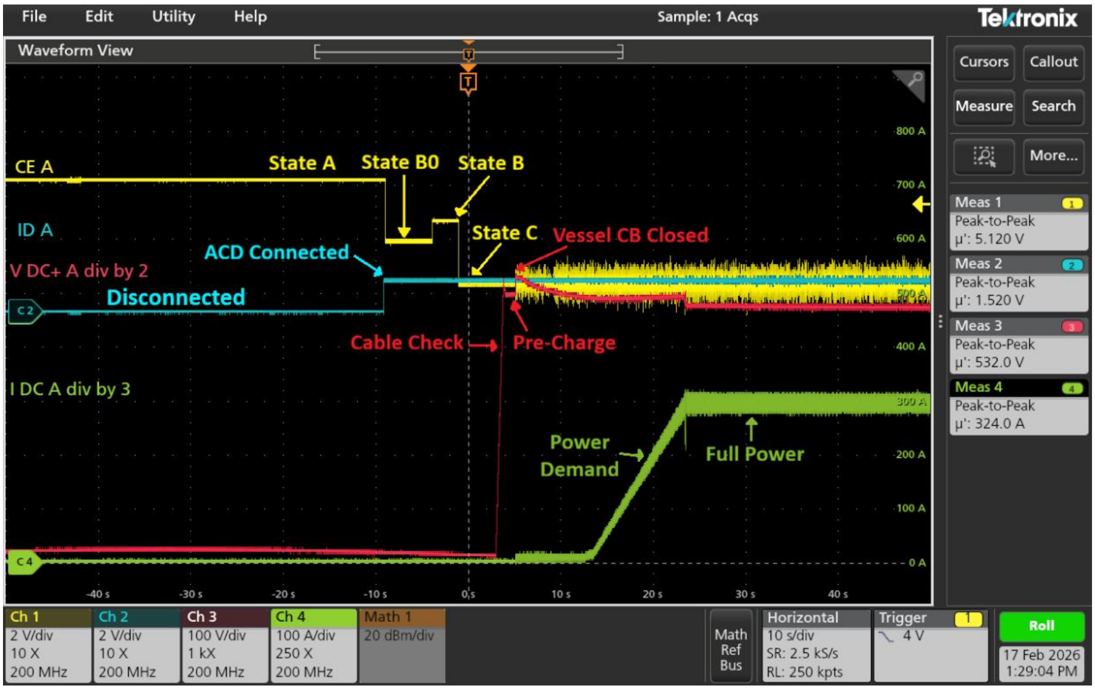
4.1 Charging session sequence test

After completing the docking test and the SECC–EVCC communication test, the charging-sequence test was performed. The results presented here refer to a single EV battery pack (portside) of the vessel (EV), charged at up to 900 kW. The results of charging of both EV battery packs (Portside and Starboard) demonstrating the system's megawatt-level charging capability, are provided at the end of this section.

Once the communication between EVSE and EV is stabilised and the charging has been requested, the sequence begins with a cable check. In this step, the EVSE verifies that there are no short circuits or insulation leaks in the connection between the EVSE and the EV. Next step is the pre charge phase, during which the EVSE charges the cable connection to match the voltage of the power cabinet. After this voltage alignment, the main EVSE contactors close, indicating that the EVSE is ready to charge.

In the HYPOBATT system, the vessel (EV) will only close its own circuit breaker (CB) once the EVSE is fully ready and the EVSE output voltage is within ±10 V of the EV's requested value. The final step is the power demand phase, where the EV specifies the charging current required for its batteries. The EVSE then supplies the requested current, limited only by the maximum current capability of the power cabinet previously communicated between the EVSE and EV.

In Figure 14 the full initialization sequence, from ACD connection to full power charging demand, is shown. Where, CE signal (yellow), ID signal (blue), charging voltage (red) scaled by a factor of 2 and charging current (green) scaled by a factor of 3.

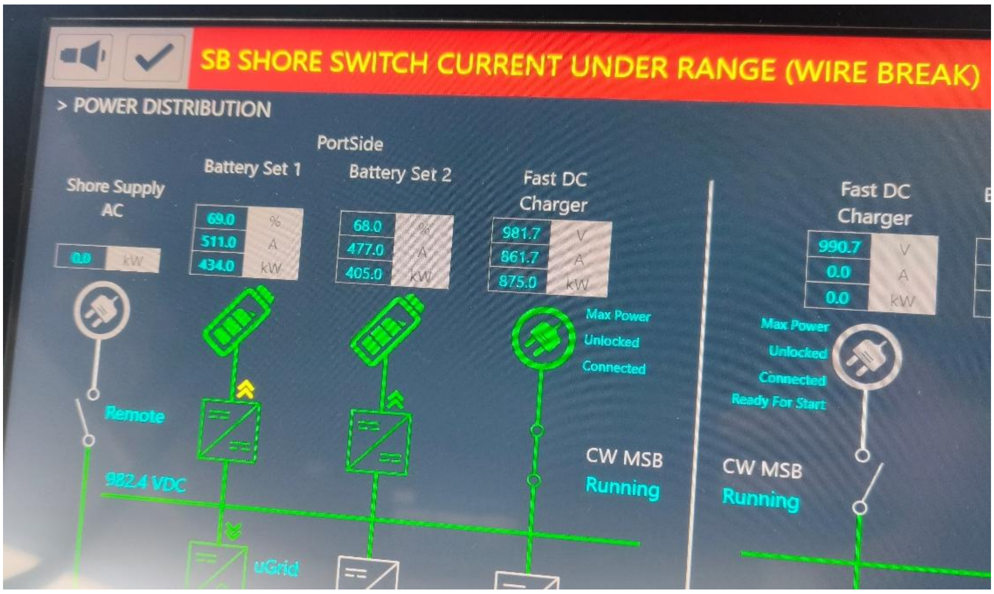


Meas 1 Peak-to-Peak μ': 5.120 V
Meas 2 Peak-to-Peak μ': 1.520 V
Meas 3 Peak-to-Peak μ': 532.0 V
Meas 4 Peak-to-Peak μ': 324.0 A

Ch 1 2 V/div 10 X 200 MHz
Ch 2 2 V/div 10 X 200 MHz
Ch 3 100 V/div 1 kX 200 MHz
Ch 4 100 A/div 250 X 200 MHz
Math 1 20 dBm/div
Horizontal 10 s/div SR: 2.5 kS/s RL: 250 kpts
Trigger 1 4 V
17 Feb 2026 1:29:04 PM

Figure 14 Overview of the ID and CE signals, charging voltage and current during connection and initialization of a charging session. Yellow signal is CE, blue signal ID, red signal charging voltage scaled by a factor of 2 and green signal is the charging current scaled by a factor of 3.

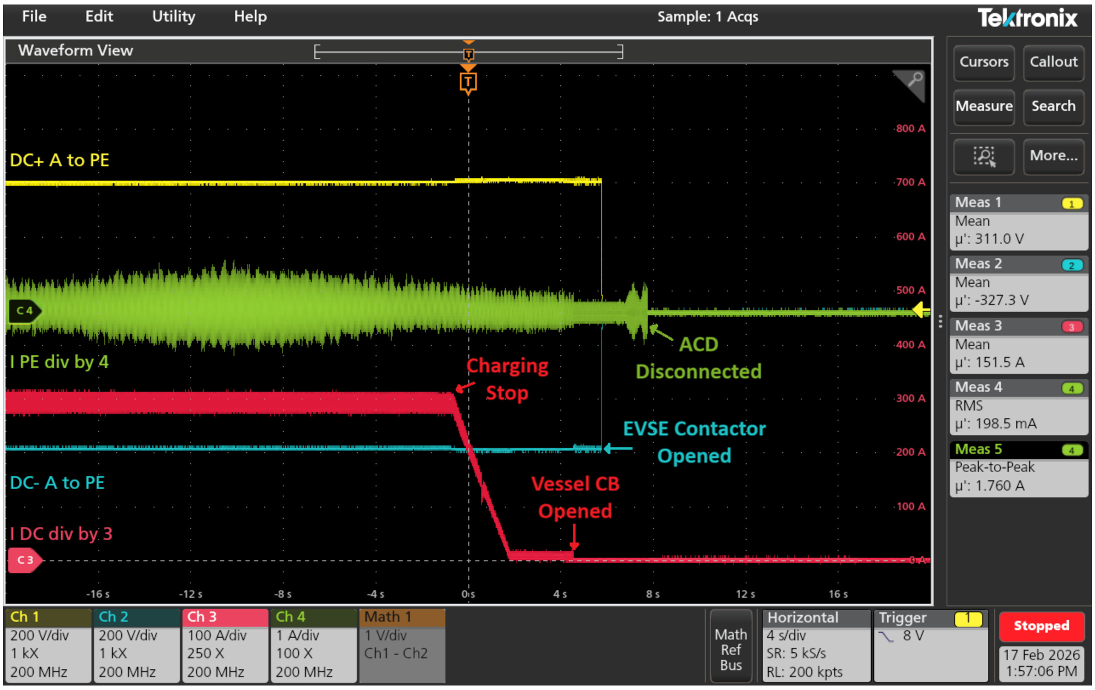
The charging voltage was set to 981 V and the current to 861.7 A, resulting in a charging power of 875 kW, as shown on the vessel dashboard in Figure 15.


SB SHORE SWITCH CURRENT UNDER RANGE (WIRE BREAK)

Shore Supply AC: 0.0 kW
Battery Set 1: 69.0 % 511.0 A 434.0 kW
Battery Set 2: 68.0 % 477.0 A 405.0 kW
Fast DC Charger: 981.7 V 861.7 A 875.0 kW
Fast DC Charger: 990.7 V 0.0 A 0.0 kW
982.4 VDC

Figure 15 Voltage, current and power during a charging session, vessel dashboard.

During the normal charging-session shutdown sequence, the EV first requests to stop charging and begins reducing the current. Once the current reaches zero, the EV opens its circuit breaker. The next step is the opening of the EVSE contactor, followed by the disconnection of the ACD from the EV. Figure 16 shows the stopping sequence, DC+ (yellow) referenced to PE, DC- (blue) referenced to PE, charging current (red) scaled by a factor of 3 and PE current (green) scaled by a factor of 4.



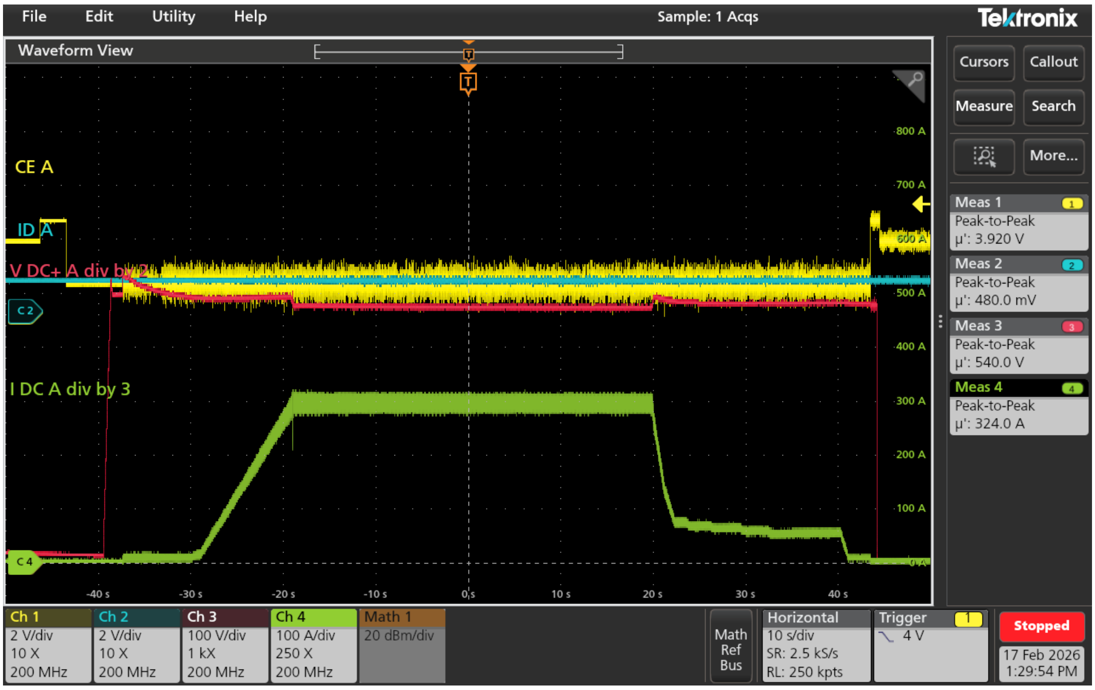
Sample: 1 Acqs

Meas 1 Mean μ': 311.0 V
Meas 2 Mean μ': -327.3 V
Meas 3 Mean μ': 151.5 A
Meas 4 RMS μ': 198.5 mA
Meas 5 Peak-to-Peak μ': 1.760 A

Ch 1 200 V/div 1 kX 200 MHz
Ch 2 200 V/div 1 kX 200 MHz
Ch 3 100 A/div 250 X 200 MHz
Ch 4 1 A/div 100 X 200 MHz
Math 1 1 V/div Ch1 - Ch2
Horizontal 4 s/div SR: 5 kS/s RL: 200 kpts
Trigger 1 8 V
Stopped
17 Feb 2026 1:57:06 PM

Figure 16 Overview of the stopping normal charging session. DC+ (yellow) referenced to PE, DC- (blue) referenced to PE, charging current (red) scaled by a factor of 3 and PE current (green) scaled by factor of 4.

Figure 17 presents a complete charging session, from the initial cable check, through full power charging, to the end of the session when the EVSE contactors open. The figure shows the CE signal (yellow), ID signal (blue), charging voltage (red) scaled by a factor of 2 and charging current (green) scaled by a factor of 3.



Sample: 1 Acqs

Meas 1 Peak-to-Peak μ': 3.920 V
Meas 2 Peak-to-Peak μ': 480.0 mV
Meas 3 Peak-to-Peak μ': 540.0 V
Meas 4 Peak-to-Peak μ': 324.0 A

Ch 1 2 V/div 10 X 200 MHz
Ch 2 2 V/div 10 X 200 MHz
Ch 3 100 V/div 1 kX 200 MHz
Ch 4 100 A/div 250 X 200 MHz
Math 1 20 dBm/div
Horizontal 10 s/div SR: 2.5 kS/s RL: 250 kpts
Trigger 1 4 V
Stopped
17 Feb 2026 1:29:54 PM

Figure 17 Overview of a full charging session. CE signal (yellow), ID signal (blue), charging voltage (red) scaled by a factor of 2 and charging current (green) scaled by a factor of 3.

Figure 18 shows the system charging both battery pack of the vessel simultaneously, 864kW on portside battery pack and 858kW on the starboard side, for a total of 1.722MW of charging power. Second shows another charging session delivering 1.736MW in total, 866kW on portside battery pack and 870kW on starboard battery pack.

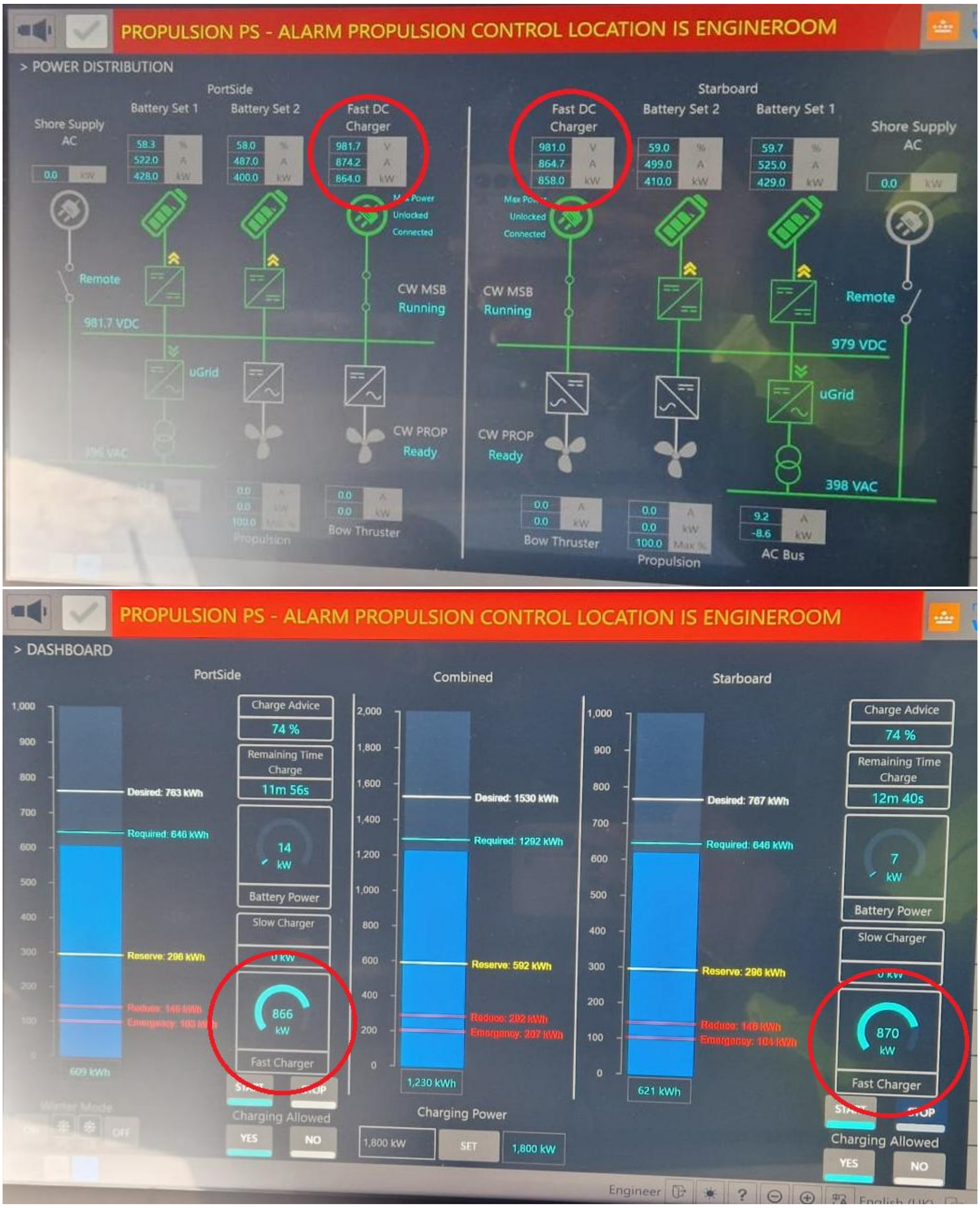
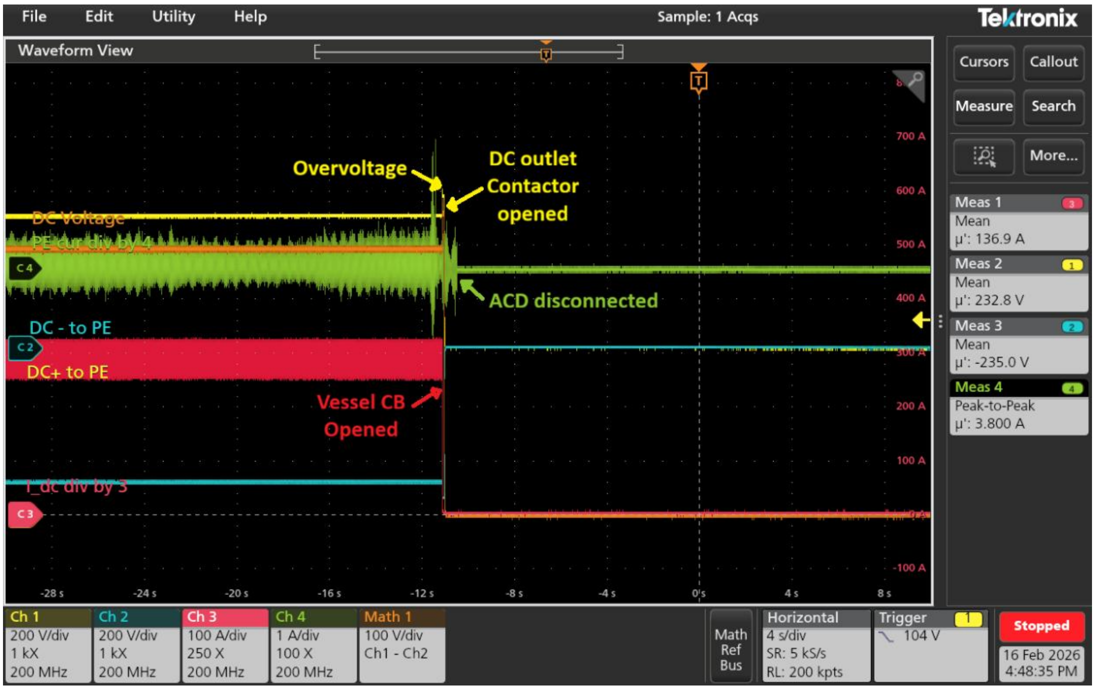


Figure 18 EV dashboard showing MW fast charging (~1.72MW) on both vessel battery packs, Portside and Starboard.

4.2 Emergency stop verification

There are situations wherein the charging session must be stopped due to any emergency on the system, such as a communication loss or ACD disconnection, the system must react quickly to prevent arcing on the ship interface and ACD connection. The system has only a few seconds to stop the power transfer before the disconnection occurs, and this process must be executed safely and without causing any damage to the equipment on the EVSE or EV.

In an emergency stop situation, the system must interrupt the current abruptly. This will cause overvoltage and the system needs to mitigate the consequences of that. To halt the current flow, first the EV opens its circuit breaker (CB) to protect the vessel, this will stop the charging current. The EVSE then opens the DC outlet contactors, and finally the ACD will disconnect. Figure 19 presents this process, where DC+ referred to PE (yellow) scaled by a factor of 2, DC- referred to PE (blue) scaled by a factor of 2, charging current (red) scaled by a factor of 3, PE current (green) scaled by a factor of 4 and DC voltage (orange) scaled by a factor of 2.



Meas 1 (3) Mean μ': 136.9 A

Meas 2 (1) Mean μ': 232.8 V

Meas 3 (2) Mean μ': -235.0 V

Meas 4 (4) Peak-to-Peak μ': 3.800 A

Ch 1: 200 V/div, 1 kX, 200 MHz

Ch 2: 200 V/div, 1 kX, 200 MHz

Ch 3: 100 A/div, 250 X, 200 MHz

Ch 4: 1 A/div, 100 X, 200 MHz

Math 1: 100 V/div, Ch1 - Ch2

Horizontal: 4 s/div, SR: 5 kS/s, RL: 200 kpts

Trigger (1): 104 V

16 Feb 2026 4:48:35 PM

Figure 19 emergency stop of the system, DC+ referred to PE (yellow) scaled by a factor of 2, DC- referred to PE (blue) scaled by a factor of 2, charging current (red) scaled by a factor of 3, PE current (green) scaled by a factor of 4 and DC voltage (orange) scaled by a factor of 2.

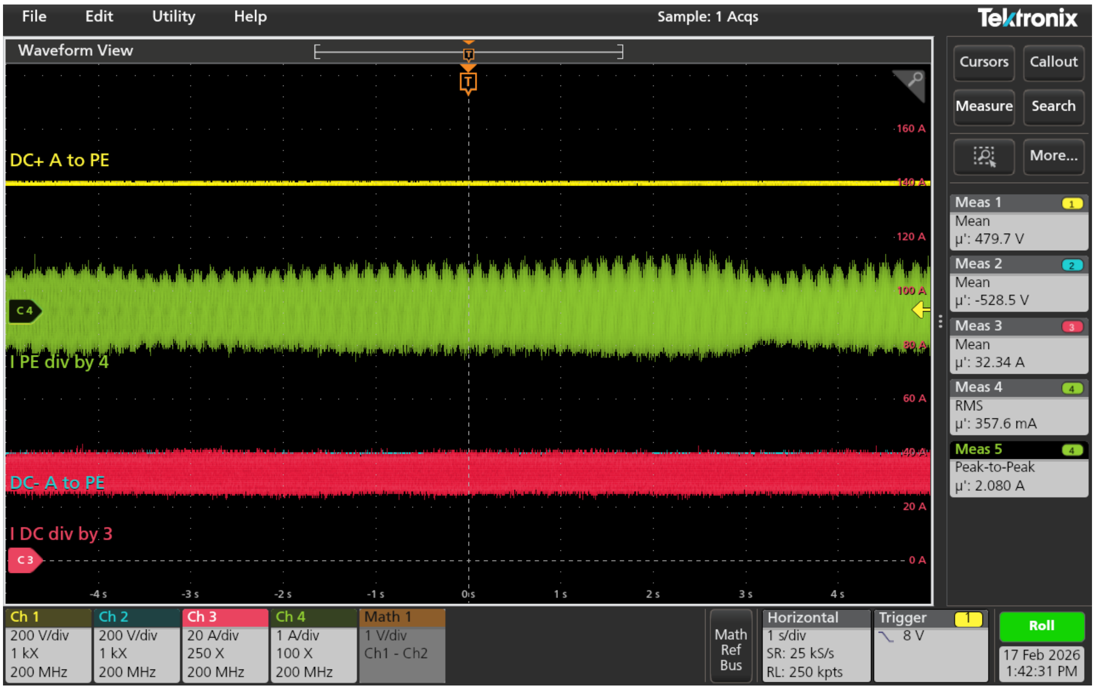
4.3 PE leakage current measurement

The PE leakage current flowing from EVSE to the EV was evaluated during the charging session test. Measurements of the PE current were taken at three power levels: 100kW, 500kW and 900kW per side (portside and starboard), with the intention of assessing the relationship between PE current and charging power. Table 1 summarizes the PE RMS and peak-to-peak current values corresponding to each charging power level.

Table 1 – Summary of PE RMS and peak-to-peak current

DC output power	RMS current	Peak-to-peak current
100 kW	1.43 A	8.32 A
500 kW	1.26 A	8.80 A
900 kW	2.22 A	12.32 A

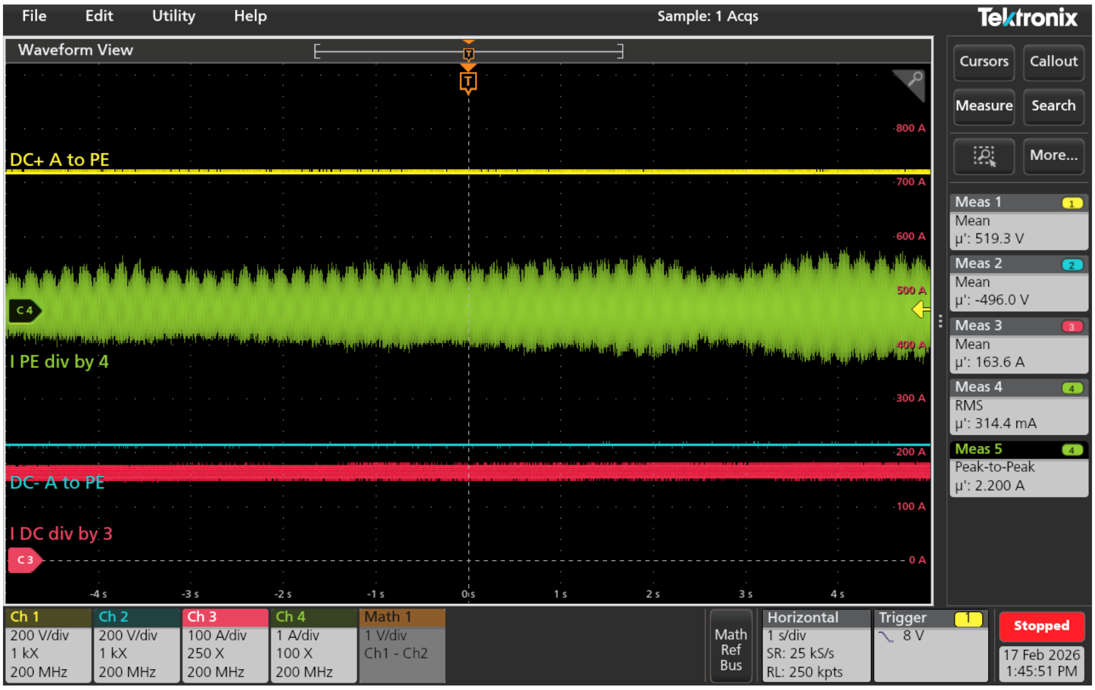
Figure 20, Figure 21 and Figure 22 shows the PE current during the charging session at 100kW, 500kW and 900kW charging power, respectively.



Meas 1 Mean μ': 479.7 V
Meas 2 Mean μ': -528.5 V
Meas 3 Mean μ': 32.34 A
Meas 4 RMS μ': 357.6 mA
Meas 5 Peak-to-Peak μ': 2.080 A

Ch 1 200 V/div 1 kX 200 MHz
Ch 2 200 V/div 1 kX 200 MHz
Ch 3 20 A/div 250 X 200 MHz
Ch 4 1 A/div 100 X 200 MHz
Math 1 1 V/div Ch1 - Ch2
Horizontal 1 s/div SR: 25 kS/s RL: 250 kpts
Trigger 8 V
17 Feb 2026 1:42:31 PM

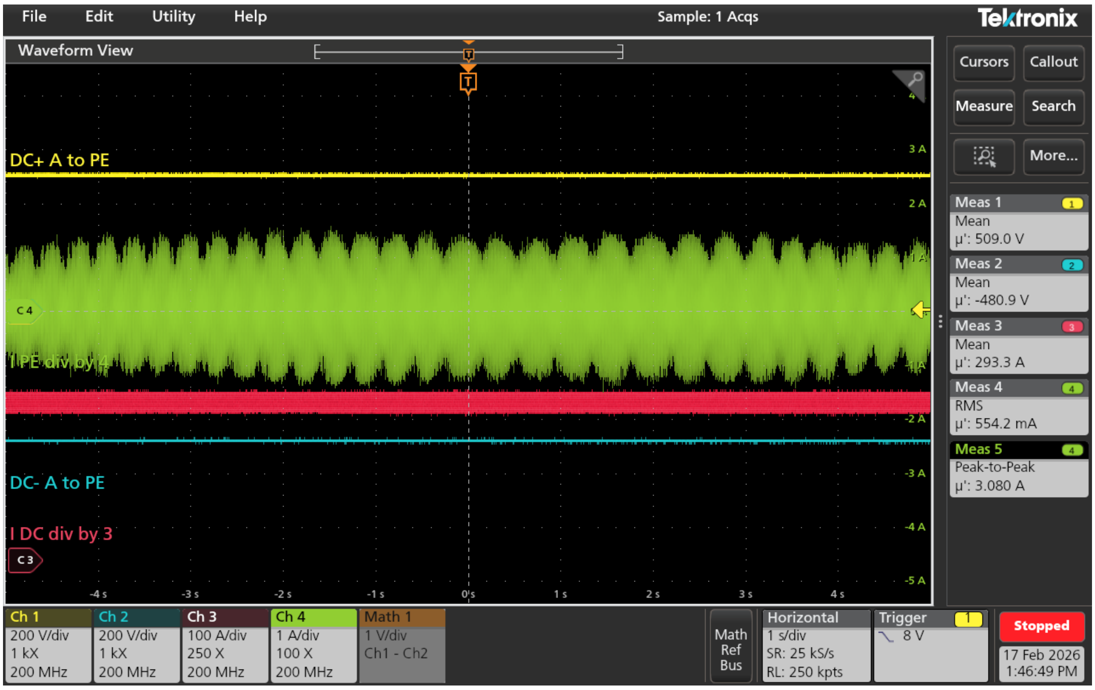
Figure 20 PE current (green) during a 100kW charging session, the RMS value was 1.43A and peak-to-peak was 8.32A.



Meas 1 Mean μ': 519.3 V
Meas 2 Mean μ': -496.0 V
Meas 3 Mean μ': 163.6 A
Meas 4 RMS μ': 314.4 mA
Meas 5 Peak-to-Peak μ': 2.200 A

Ch 1 200 V/div 1 kX 200 MHz
Ch 2 200 V/div 1 kX 200 MHz
Ch 3 100 A/div 250 X 200 MHz
Ch 4 1 A/div 100 X 200 MHz
Math 1 1 V/div Ch1 - Ch2
Horizontal 1 s/div SR: 25 kS/s RL: 250 kpts
Trigger 8 V
17 Feb 2026 1:45:51 PM

Figure 21 PE current (green) during a 500kW charging session, the RMS value was 1.26A and peak-to-peak was 8.8A.



Sample: 1 Acqs

Meas 1 Mean μ': 509.0 V

Meas 2 Mean μ': -480.9 V

Meas 3 Mean μ': 293.3 A

Meas 4 RMS μ': 554.2 mA

Meas 5 Peak-to-Peak μ': 3.080 A

Ch 1 200 V/div 1 kX 200 MHz

Ch 2 200 V/div 1 kX 200 MHz

Ch 3 100 A/div 250 X 200 MHz

Ch 4 1 A/div 100 X 200 MHz

Math 1 1 V/div Ch1 - Ch2

Horizontal 1 s/div SR: 25 kS/s RL: 250 kpts

Trigger 8 V

17 Feb 2026 1:46:49 PM

Figure 22 PE current (green) during a 900kW charging session, the RMS value was 2.22A and peak-to-peak was 12.32A.

A closer examination of the noise frequency in the PE current shows that the dominant component corresponds to twice the switching frequency of the power converters.

Sample: 4 Acqs

Δa: 382.758 mA Δa/Δt: 2.80 kA/s

a: 219.556 A a: 219.938 A

Meas 1 Mean μ': 217.7 A

Meas 2 Mean μ': 522.5 V

Meas 3 Mean μ': -496.0 V

Meas 4 Peak-to-Peak μ': 1.680 A

Meas 5 Mean μ': 1.018 kV

Ch 1 200 V/div 1 kX 200 MHz

Ch 2 200 V/div 1 kX 200 MHz

Ch 3 100 A/div 250 X 200 MHz

Ch 4 1 A/div 100 X 200 MHz

Math 1 100 V/div Ch1 - Ch2

Horizontal 200 μs/div SR: 125 MS/s RL: 250 kpts

Trigger 104 V

17 Feb 2026 10:49:07 AM

Figure 23 Main noise frequency on the PE current, that is the two times the power converter switching frequency.

4.4 EMC results

EMC measurements were carried out during the charging session to estimate the common-mode noise present in the system's voltage and current, as well in the PE current. Since the HYPOBATT system is not a final product and is part of ongoing developments towards maritime-MCS standardization, these measurements serve as a benchmark for future evaluation and continued development.

Compared with other types of electrical vessels, the common-mode voltage and currents levels observed are relatively low compared to other vessel charging applications seen by the HYPOBATT partners. This can be explained by the lower number of on-board switching power converters on the vessel, as well the EMC mitigation measures implemented in the power cabinet. The PE common-mode current shows a similar spectrum and magnitude compared with the charging common-mode current.

4.4.1 Common mode Voltage measurements

The charging voltage was measured and the FFT calculated on the waveform to assess the common-mode noise, Figure 24 shows the results.

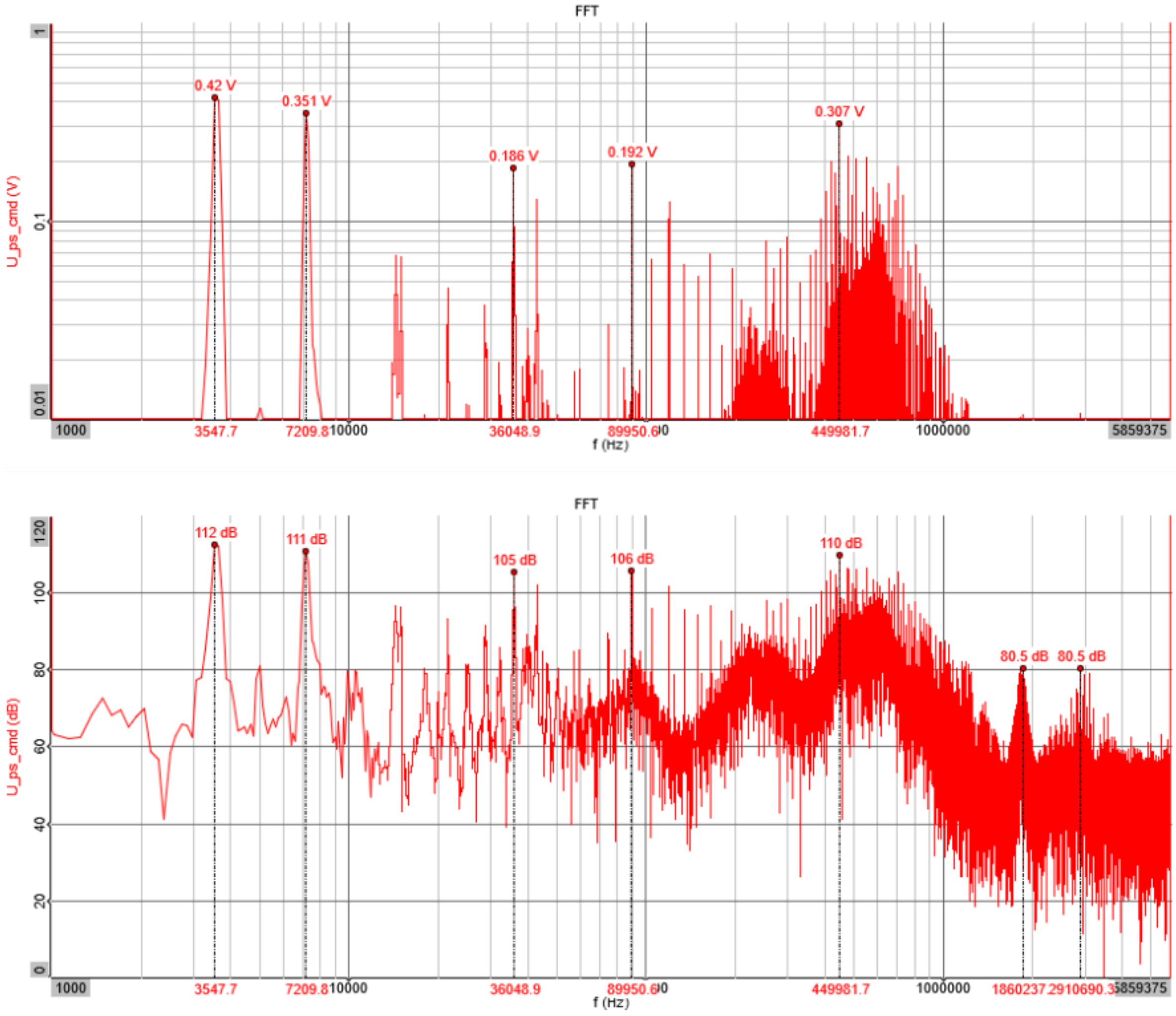


Figure 24 Common mode voltage FFT (peak values and peak values on dB(mV)).

4.4.2 Common mode Current measurements

The same was done for the charging current, Figure 25 presents the results.

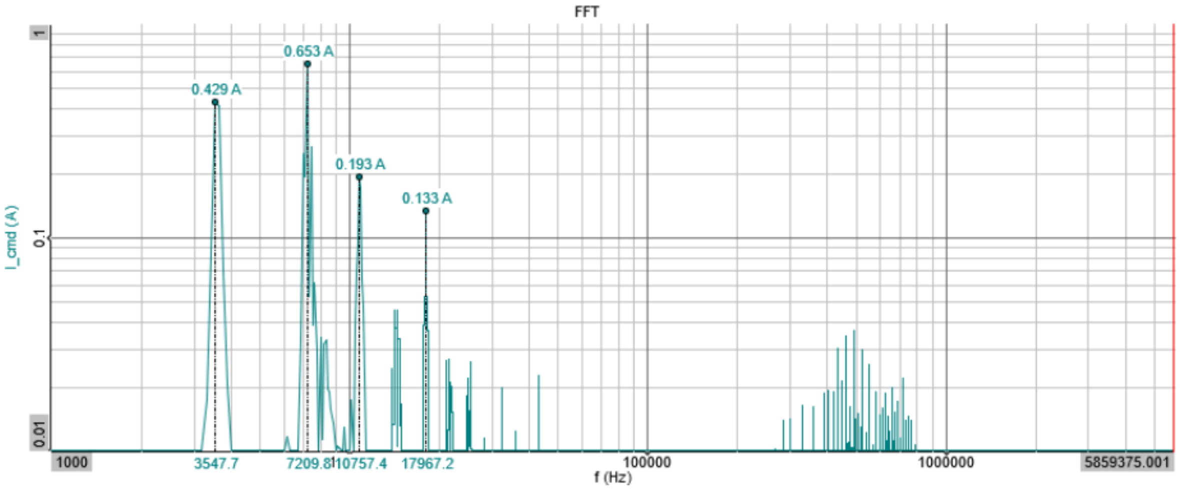


Figure 25 Common mode current FFT (peak values).

4.4.3 Common mode PE current measurements

For the CM PE current, Figure 26 shows the FFT of the peak values with a sample rate of 100kHz.

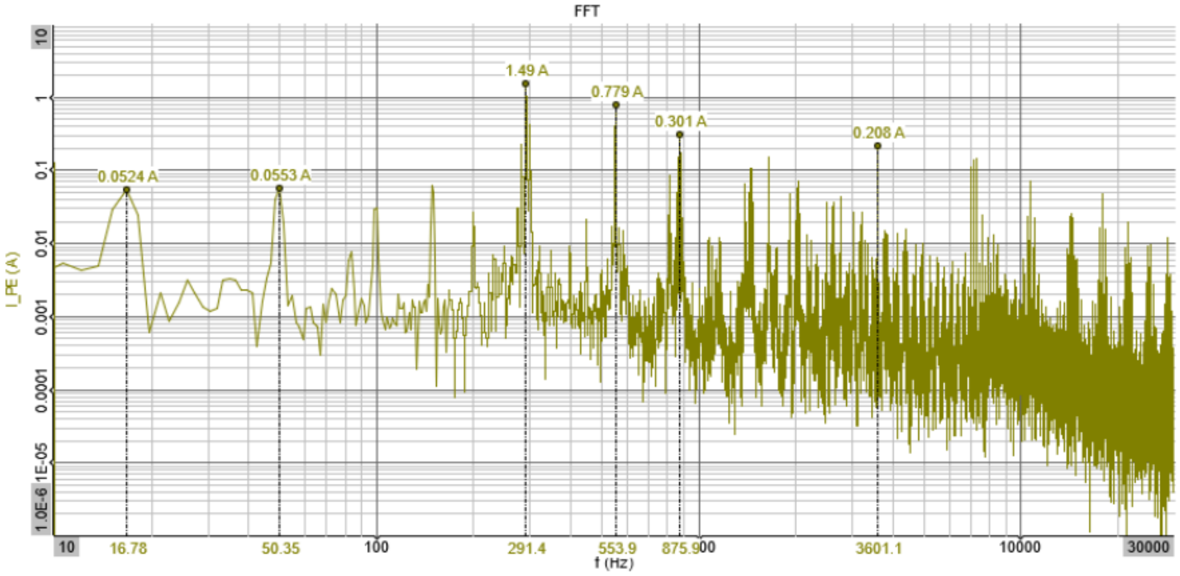


Figure 26 FFT of PE current, with 100 kHz sample rate.

4.5 TEST CONCLUSIONS

The test successfully validated the complete operational charging session of the HYPOBATT megawatt-class charging system, following and aligned with the MCS standard IEC 61851-23-3. Once the system was connected, the communication EVSE-EV began and the EVSE regulate high charging currents with stable voltage control, achieving sustained power levels of up to 875 kW on a single battery pack. The system demonstrated its full capability by simultaneously charging both vessel battery packs at power levels exceeding 1.7 MW, confirming that the HYPOBATT system supports reliable and repeatable megawatt-level operation. More than 25 successful charging sessions were performed, underlining that the system worked predictably. The emergency stop test confirmed that the system can safely and rapidly halt power transfer in fault conditions such as communication loss or unintended ACD disconnection, preventing arcing and protecting both the vessel and the EVSE.

The PE current assessment showed that protective earth currents values remained within expected limits and did not scale proportionally with output power. EMC results presented a promising result, with a relatively low noise, further investigation can be done.

5. KÖTTER WERFT SYSTEM VESSEL INTEROPERABILITY TESTING

The mechanical interface with a ship-based connection system under real operational conditions. The activity contributes directly to WP4 (system integration) and WP5 (demonstration and validation) by verifying the functionality of the ACD when deployed on an external vessel platform. The tests were carried out at Kötter Werft in Haren (Ems), Germany, using the inland cargo vessel Marino (GMS – Gütermotorschiff), representing a realistic operational environment for inland waterway applications.

The ACD was installed on the shore-side infrastructure, while the corresponding ship interface was mounted on the vessel. The integration was performed under practical shipyard conditions, ensuring that the validation reflects real deployment constraints rather than laboratory assumptions. The use of a GMS vessel is particularly relevant, as such vessels exhibit horizontal movement and alignment variability during docking, which are critical factors for automated connection systems.

The validation focused on **mechanical connection and disconnection**, emergency release functionality, and the system's ability to compensate for horizontal vessel movement. During testing, the ACD successfully established mechanical connection with the ship interface in a consistent and repeatable manner. The connection process was completed within 30 seconds, meeting the defined operational target. Disconnection under normal conditions was also performed reliably and within the expected time range, with no mechanical obstruction or residual locking observed.

In addition to the mechanical validation, the testing also provides evidence of the interoperability capability of the ACD and the associated charging infrastructure. The successful operation of the system on the GMS vessel Marino, which represents an external and non-prototype platform, demonstrates that the ACD is not limited to a single vessel design but can interface with **different ship types and configurations**. The mechanical connection principles, alignment tolerance, and compensation mechanisms proved to be sufficiently robust to accommodate **variations in vessel geometry and docking conditions**. This indicates that the system is capable of being deployed across a broader range of inland vessels, supporting standardized ship-to-shore charging concepts and fulfilling the interoperability objectives defined within WP5.

Table 2 Summary of KPI Assessment for ACD Validation

KPI Parameter	Requirement	Result	Status
Connection time	≤ 30 s	≤ 30 s	Pass
Mechanical success rate	≥ 95%	100%	Pass
Horizontal compensation capability	Functional	Verified	Pass

Figure 27 Mechanical Connection Between ACD and Ship Interface

Figure 27 illustrates the mechanical connection between the ACD and the ship interface during the docking process. A secure and stable coupling is achieved within the defined operational time, confirming reliable system performance. The mechanism accommodates positional tolerances and vessel movement, ensuring consistent functionality under real conditions.

6. DISSEMINATION, EXPLOITATION AND STANDARDISATION

D5.5 is a public document. The content will be 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 has been used as DEMO products of the respective system components and their mutual interfaces in the real-life validation at Frisia port and Kötter Werft. The proposed EVSE-EV communication platform has been used successfully and will be promoted towards future Marine-MCS standardization work within the technical committees of IEC 80005 (shore-connection) and IEC 61851 (conductive charging).

The pictures and videos of the realized DEMO products and real-life demonstration already have been and will continue to be used in numerous dissemination post on LinkedIn and the HYPOBATT website. Also, already further distribution of the footage and results has been done by the different project partners in the form of presentations (Damen at WattsUp and CharIn M-MCS taskforce meeting, Heliox, Frisia, STT) and posts on their respective websites. Additionally, the advanced training program-2 has been recorded, in which the results from this deliverable were used.

The results will furthermore be used in the final version of the HYPOBATT whitepaper, outlining the consortium proposed solutions for M-MCS shore connected automated conductive charging. 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 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. The IMD limitations in relation to Y-capacitance aspects as marked as a risk in this project need to be further discussed outside of the HYPOBATT consortium in an attempt to standardize them.

7. RESULTS AND DISCUSSION

7.1 Achieved results reflected to the objectives

- **Main objective:** Test and validate the full-scale multi-MW charger system on the marine environment, based on the requirements mutually defined in D1.4, the development and prototype testing done for the power cabinet in D3.4 and D3.5, and for the ACD system in D4.4 and D4.5, respectively.
    - Testing: **done**
    - KPIs: **verified and met**
    - Basic functions: **done**
    - Non-functional requirements, e.g. climate conditioning: **done**
    - Functional requirements, e.g. starting power conversion, pre-charging, insulation testing and power circulation: **done**
    - Charging session execution based on interaction with DC outlet and ACD: **done**
    - Masterplan containing all essential steps for the system test has been made, based on the requirements D1.4 and test plan presented in D3.4: **done**
    - Present results on a real marine environment of the charging system: **done**
- **Additional objectives are as follows:**
    - Provide a report on validation of charging system: **done**
    - Verify functional and non-functional specifications in charger: **done**
    - Produce hyper vessel charger: **done**
    - Present test results of successfully charging session, detailing each step of the charging sequence: **done**, this report
    - Test of EVSE-EV communication following MCS standard: **done**, this report
    - Show evidence of safe charging session, through protections and emergency stops: **done**, this report
    - Present a multi-MW charging session result: **done**, this report

7.2 Discussion

The different open-points in compliance to standardisation as discussed in previous design deliverables provide sufficient inducement for discussion, especially in the M-MCS taskforce that should, to our opinion, lead to an additional part in the conductive charging standard.

- **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 have been taken to provide all mechanical barriers further derisking the possibility of a potential touch current. Nevertheless, the presence of 2 parallel circuits and therewith required dual IMDs exceed the allowed CM measurement currents.

- **Leakage current:** as indicated in Figure 28, 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. Testing has proved that the leakage currents exceed the MCS allowed limits, which must be further investigated and reduced towards commercial implementations.

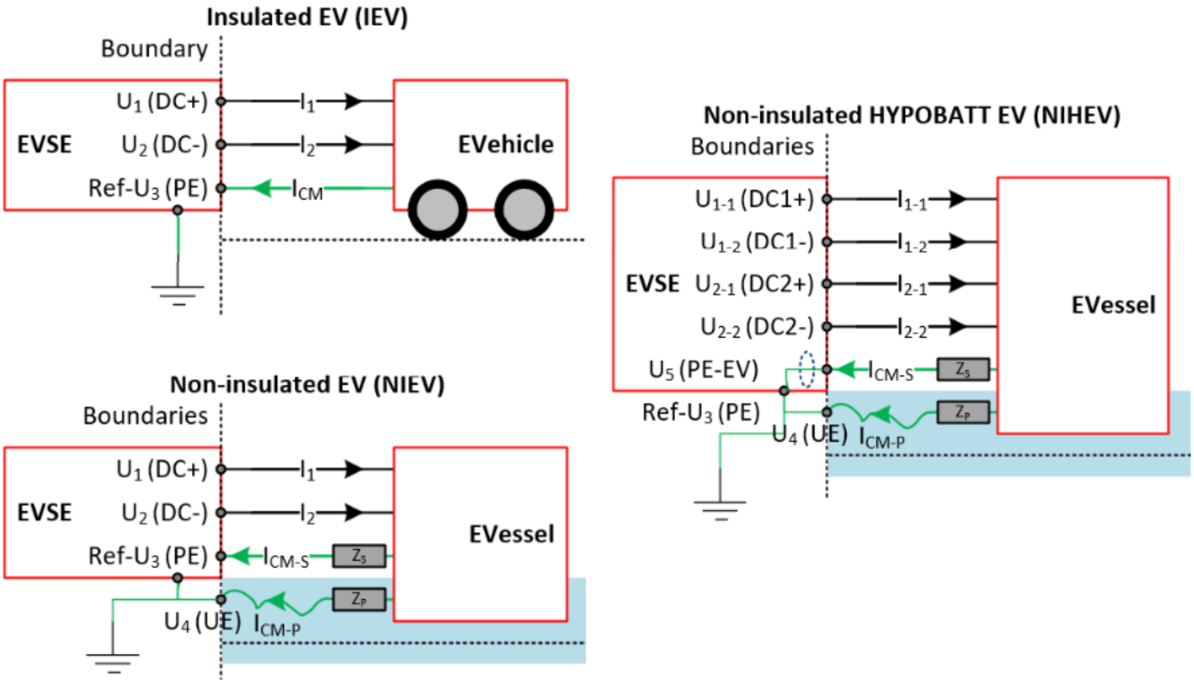


Figure 28 differences in IT charging network situations between EVSE and (non)insulated EVs wherein the non-insulated IT networks have an undefined earth (UE) return via a parasitic impedance, Z_P, alongside of the defined return impedance, Z_S.

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8. 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 the main objective of testing and demonstrating 5 charging sessions has been successfully achieved!

The tests successfully validated the complete operational charging session of the HYPOBATT megawatt-class charging system, following and aligned with the MCS standard IEC 61851-23-3. The system demonstrated its full capability by simultaneously charging both vessel battery packs at power levels exceeding 1.7 MW, confirming that the HYPOBATT system supports reliable and repeatable megawatt-level operation.

8.1 Identification of contribution per partner

HELIOX has led this task, composed and edited this report.

STT performed the second ACD DEMO testing case in Haren, Germany. Additionally, STT provided measurement results from ACD perspective during the testing.

Damen provided the vessel side integration, PMS communication and measurement results during the testing.

STT, Frisia, DAMEN and Heliox strongly partnered in achieving the installation, commissioning, site acceptance and certainly in the verification phase of this project. Each took care of its own responsibilities, but cooperation and collaboration really brought us to the successful results in the implementation. True teamwork!

9. REFERENCES

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