Swappable Container Waterborne Transport Battery

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Reducing the Cost of Large Batteries for Waterborne Transport

D7.1
Standards for Power & Communication

28 November 2024

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GLOSSARY OF TERMS

Term	Definition
Battery space	Space In Container where Batteries Are Located
Auxiliary space	Space In Container where Other Equipment Is Located
BMS	Battery Management System
CD	Current Direct
CD.ESS	Current Direct Energy Storage System
DMZ	Demilitarised Zone
EaaS	Energy as a Service
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMS	Energy Management System
ES-Trin	European Standard Laying Down Technical Requirements for Inland Navigation
F&G	Fire and Gas
FCR	Frequency Containment Reserve
FiFi	Firefighting
HMI	Human Machine Interface
IT	Information Technology
Inland Waterway Vessel	A Vessel Intended Solely or Mainly for Navigation on Inland Waterways
JIP	Joint Industry Project
MBF	Maritime Battery Forum
Motor cargo	A Vessel, Other Than a Motor Tanker, Intended for The Carriage of Goods
Motor tanker	A Vessel Intended for The Carriage of Goods in Fixed Tanks.
OT	Operational Technology
Passenger vessel	A Day Trip or Cabin Vessel Constructed and Equipped to Carry More Than 12 Passengers
PCS	Power Conversion System
PMS	Power Management System
Pusher	A Vessel Specially Built to Propel a Pushed Convoy
Short Sea Shipping	Maritime Transport Between Ports in Mainland Europe
SOC	State Of Charge
SOH	State Of Health
Tug	A Vessel Specially Built to Perform Towing Operations

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“This document reflects only the author’s view and the Agency is not responsible for any use that may be made of the information it contains”.

PROJECT SUMMARY

The transport sector contributes to almost a quarter of Europe's greenhouse gas (GHG) emissions. Compared to other sectors, such as agriculture or energy industries, it is the only sector with emissions higher than that of 1990. Waterborne transport emissions represent around 13% of the overall EU greenhouse gas emissions from the transport sector. Moreover, waterborne transport emissions could increase between 50% and 250% by 2050 under a business-as-usual scenario, undermining the objectives of the Paris agreement. The challenge for a large-scale adoption and implementation of batteries for waterborne transport is mainly related to the high costs of the battery systems and cells.

The Current Direct project addresses these challenges by proposing an innovative lithium-ion cell optimized for waterborne transport, using novel manufacturing techniques allowing for a consistent cost reduction compared to the current market prices. Additionally, a swappable containerized energy storage system optimized for cost and operation in the waterborne transport industry will be developed.

The overarching aim of the Current Direct project is to develop and demonstrate an innovative interchangeable waterborne transport battery system and EaaS Platform in an operational environment at the Port of Amsterdam at TRL7 that facilitates fast charging of vessels, fleet optimization and novel business models. The Current Direct project is dedicated to (i) significantly reduce the total cost of waterborne transport batteries, (ii) cut GHG emissions of the marine transport sector through electrification of vessel fleets, (iii) increase the energy density of waterborne battery cells and (iv) trigger investments for innovation, job and knowledge creation in the European marine transport and battery sector.

The Current Direct Ecosystem is shown in Figure 1.

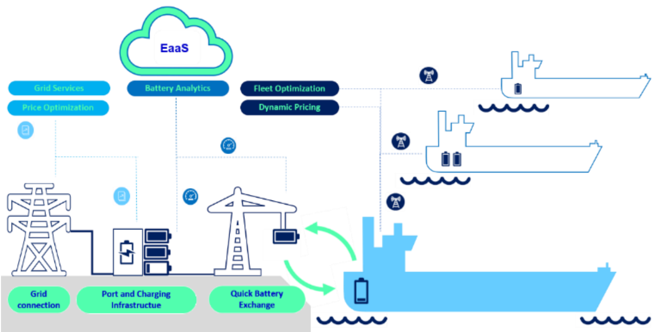

Figure 1. Current Direct Ecosystem

1. EXECUTIVE SUMMARY

Existing standards for power and communications in the maritime industry, applicable rules from class society, and rules and requirements from authorities have been evaluated to determine an applicable scheme for standards for power and communication for the Current Direct project. Searching for applicable standards in the maritime industry has identified a lack of defined holistic standards applicable for a swappable battery container solution. A review of other industries has identified that the automotive industry standards are more mature than the maritime industry when it comes to battery charging standards and solutions. This study has discovered a lack of rules and standards for swappable battery containers and recommends that further development of these is needed to meet the fast-upcoming demands from the industry. Standards gathered in this document, together with a risk-based design approach will create a framework for the Current Direct project and will be used to validate the design process.

During the process to find applicable standards, it is concluded that there is a gap between established standards and what is needed in the future for swappable containers providing energy for propulsion of waterborne transport. Current Direct as a project seeks to remove this barrier through the adoption of a risk-based design approach in addition to the applicable and relevant parts of the identified maritime industry standards and standards from other applicable industries, for example, the automotive industry. There is a need to establish dedicated standards for swappable container solutions in the maritime industry, to meet future solutions from the industry. Class societies, IWW regulators and other regulatory authorities will need to collaborate with the industry in the development of new rules and standards to be ready for future design solutions from the industry.

To summarise the outcome of this study, a matrix for applicable standards has been made as shown in The study carried out and reported by this document fully achieved the objective of the Tasks T7.1 of the Current Direct Project by identifying the most suitable and safest electrical and communication interfaces for the container system. This has been achieved by focusing on the performance requirements, transversal (safety and security) requirements, of single components and their integration.

Additionally, the objective of the Task T7.2 has been achieved by developing the standardized open-source communication protocols that will be used for interfacing the container with the vessel's energy management system and the shoreside infrastructure.

Table 1. This matrix lists the standards identified and what part of the Current Direct project they apply to. Other stakeholders in the maritime industry may find this matrix useful when approaching similar challenges within this type of swappable container solution.

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Additionally, the objective of the Task T7.2 has been achieved by developing the standardized open-source communication protocols that will be used for interfacing the container with the vessel's energy management system and the shoreside infrastructure.

Table 1. Matrix of Applicable Standards

Standard	Description	Container	Shore	Swapping	Vessel
CCS2	Industry Standard Vehicle Connector for Charging of Electric Vehicles.	X	X		X
EN-13155-2020	Cranes-Safety-Non-Fixed Load Attachments	X		X	
IEC 60079	Explosive Atmosphere Standards	X	X		X
IEC 60092-352	Electrical Installations in Ships: Choice and Installation of Electrical Cables	X			X
IEC 60309-1 (4)	Standards For LV DC Industrial Sockets and Plugs	X	X		X
IEC 60533	EMC Compatibility in Ships	X			X
IEC 60909	Short-Circuit Currents in Three-Phase AC. Systems	X	X		X
IEC 60947	Low Voltage Switchgear and Control Gear	X	X		X
IEC 61363	Electrical Installations of Ships and Mobile and Fixed Offshore Units	X			X
IEC 61851	Electric Vehicle Conductive Charging System	X	X		
IEC 62196	Plugs, Socket-Outlets, Vehicle Connectors and Vehicle Inlets	X	X		X
IEC 62271	High-Voltage Switchgear and Control Gear		X		
IEC 62443	Industrial Communication Networks – Network and System Security	X	X		X
IEC 80005-1 (2)	Shore Power And Communication Connections	X	X		
IEEE 1584	Arc Flash Analysis	X	X		X
IEEE 946	Standard For Calculating DC Short Circuit Current	X	X		X
ISO 11898 Series	CAN Bus Specification	X			
ISO 15118	Road Vehicle to Grid Communication Interface	X	X		
ISO 668-2020	Classification, Dimension, Capacity Specification	X			
ISO 1161-2016	Specification Of Container Corners	X			
ISO 3874-2017	Twist-Lock Handling and Securing			X	
NFPA 70E	Personal Protective Equipment and Warning Labels	X	X	X	X

2. SPECIFIC OBJECTIVES FOR WORK PACKAGE 7

2.1. Introduction

The objective of the WP7 is to optimize and standardize design, production, verification, and validation processes in order to ensure the highest quality of the developed deliverables, provide a reduction in cost associated with these processes, and focus on the management of the Risks associated with production from Health & Safety and Environmental aspects including Security considerations.

WP7 will be achieved by addressing the best combination of existing technical and procedural requirements drawn from both the Industrial Standards and the EU National Administrations Regulations, avoiding duplication, and identifying optimum verification, validation, and acceptance criteria.

Specific Objectives:

- Develop standardized interfaces for EaaS Platform.
- Develop standardized communication protocols for EaaS Platform and external gateways.
- Design of standardization and certification plans for marine battery systems.
- Perform risk based HSE assessment before system integration and demonstration.
- Develop production process efficiency plan for the battery cell

2.1.1. T7.1 Development of Standardized Interfaces

This task will focus on the Integration process, will set the performance requirements, transversal (safety and security) requirements, and establish the Verification and Validation process to be applied to each and every step of the project.

A vessel and infrastructure study will be performed to determine the most suitable and safest electrical and communication interfaces for the container system. This task will be input for T7.2 and WP6, specifically tasks T6.2, T6.3, and T6.5.

2.1.2. T7.2 Development of Standardized Communication Protocols

Dependent on the results of T7.1, this task will develop the standardized open-source communication protocols (whether based on Modbus TCP/IP, Modbus RS485, among others) that will be used for the container's design and production for interfacing with the vessel's energy management system and the shoreside infrastructure. Protocol commonality between the various systems will be critical so that components and costs are minimized. This task will serve as input for tasks T6.2, T6.3 and T6.5.

3. STANDARDS FOR POWER & COMMUNICATION

3.1. Standardised Interfaces

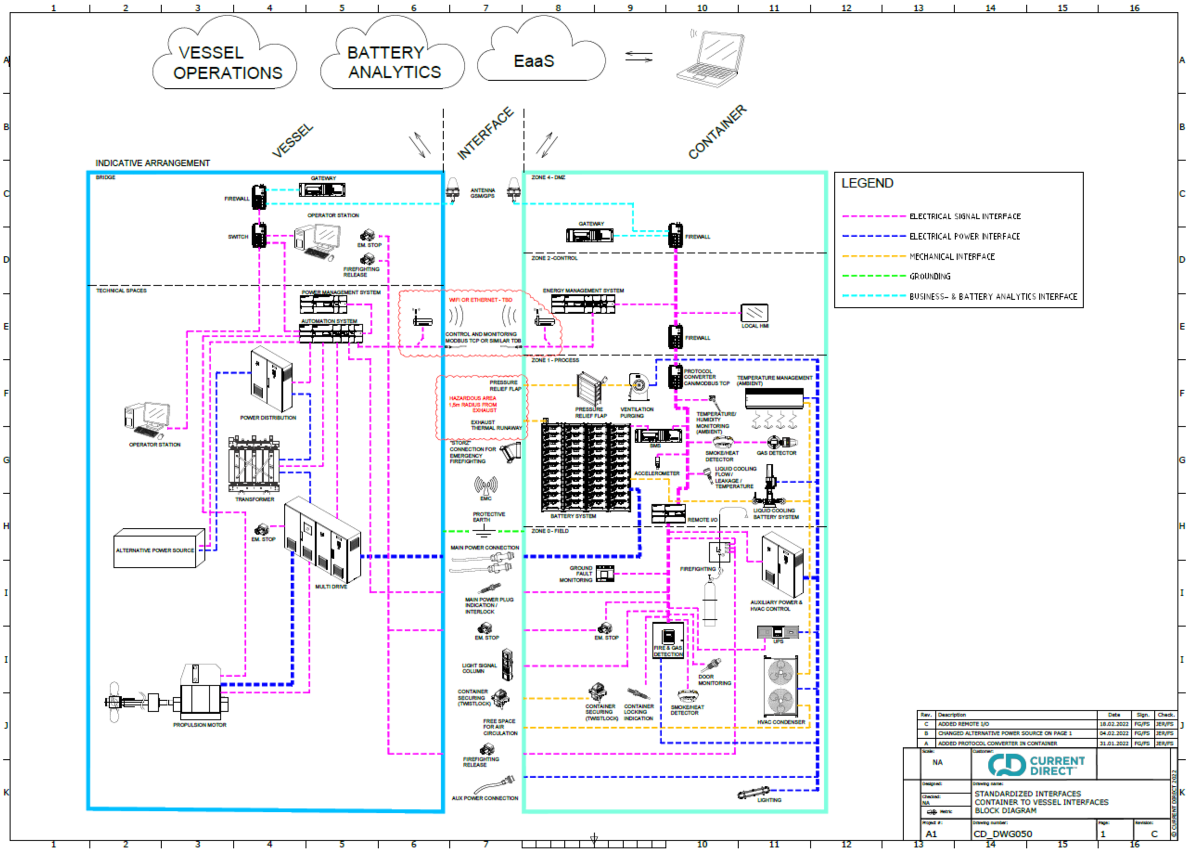

Figure 2 Standardized Interface Block Diagram

Class Society requirements and Flag State requirements form the basis for shipbuilding. For some ship types like sea-going vessels, these are mandatory. For others like inland waterways, they are voluntary. Furthermore, the land-based industry shall comply with national and/or regional requirements addressing electrical systems, fire safety, etc.

A swappable container used for powering vessels and charged onshore will need to comply with both maritime and land-based sets of rules and regulations.

The IEC/IEEE 80005 series for “Utility connections in port” covers power and communication connection to vessels. However, it does not include a charging/discharging scenario for batteries. The automotive industry is more mature including standards but cannot be transferred to the maritime industry directly. Two of the most relevant in this case are: “IEC 61851 Electric vehicle conductive charging system” and “ISO 15118 Road vehicles — Vehicle to grid communication interface”.

There exists an active Project Authorization Request (PAR), P80005-4. IEEE SA states the following: “This part of IEC/IEEE 80005 describes low voltage DC shore connection (DCSC) systems up to and including 1500 V DC. It applies onboard the ship and on shore, to supply the ship with electrical power from shore.” This is the most concrete and promising initiative related to DC and shore connection.

General industry standards for communication and cyber security, such as “IEC 62443 Industrial communication networks – Network and system security”, are applicable.

3.1.1. EV Industry Protocols and Standards Example

There exists a strong parallel between the Current Direct swappable battery solution standardisation gaps and those faced in the automotive EV industry. It is, therefore, useful to identify that for maritime transportation there needs to be a shift toward standardisation of interfaces at the highest level e.g., ISO/IEC bodies.

As an example, as EVs have become a natural part of the transportation ecosystem, there has been a shift toward the standardization of chargers and the introduction of new industry protocols for interoperability covering accessories, communications and charging topologies. This shift addresses the challenge to keep up with new developments and ensure that technologies comply with the latest regulations and standards and that end-users are not faced with an obsolescence issue for each new EV that is purchased or operated.

In the automotive industry interoperability of charging infrastructures is a key success factor for E-Mobility. Standards like ISO/IEC 15118 and IEC 61851-1 are developed to ensure base-level interoperability of front-end communication and signalling processes for smart charging between electric vehicles and charging stations.

Figure 3 provides an overview of EV industry standards and how they are applied to each aspect of the EV transportation ecosystem. The determination and creation of a standardisation map of interfaces between swappable battery containers and the ships that they need to power in the maritime industry need to be achieved to underpin the exploitation of the solution.

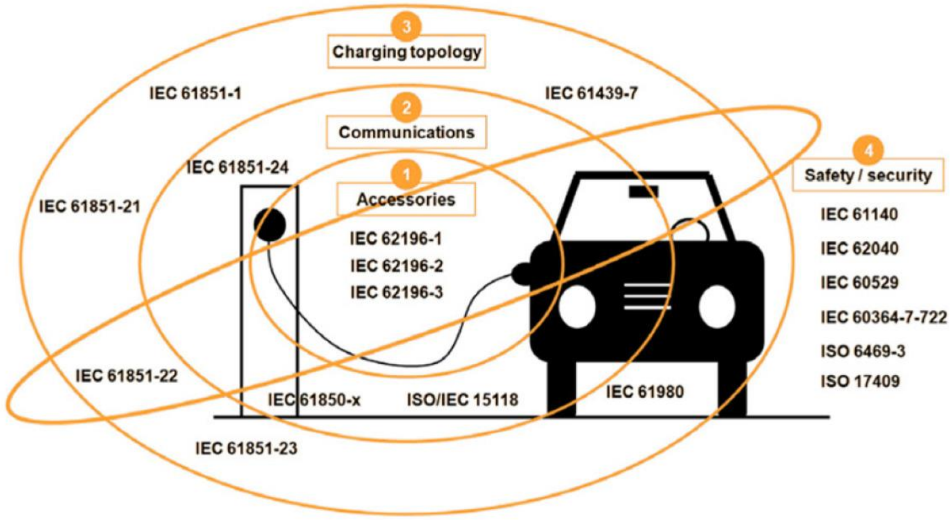

Figure 3 Overview EV Industry Standards

3.1.2. Battery Container Standardization Joint Industry Project

The Maritime Battery Forum Battery Container Standardization JIP is an effort to define standard interfaces for both swappable and fixed battery containers. Several MBF members have developed containerized battery systems, and these are being brought together to evaluate the possibilities for standardization of interfaces between these containers and the ships that they need to power. The results from the Current Direct project deliverable will be used as input for the Joint Industry Project.

Current participants in the project are as follows and it is expected that additional participants will be added during the project.

- VARD
- Spear Power Systems
- Kongsberg Maritime
- Lloyd’s Register
- American Bureau of Shipping

- Wärtsilä
- Corvus Energy

The goal of the MBF JIP is to define guidelines for standardized interfaces for both swappable battery containers and fixed battery containers. A guideline, endorsed by the participating MBF members, will be delivered. The second step will be to investigate the topic of standardized certification methods for containerized battery systems which will utilise the Current Direct project Deliverable D7.3 as its primary input.

3.2. Mechanical Interfaces

3.2.1. Container General

Container mechanical measurements shall be built according to:

- ISO 668-2020. Classification, dimension, capacity specification.
- ISO 1161-2016 Specification of container corners

3.2.2. Container Locking

The container shall be locked in position with a Twist lock. One in each corner.

Twist locks are to be of the certified type according to ISO 3874-2017 Handling and Securing.

Twist lock to be operated manually or semi-automatically.

Conical guiding is to be arranged in each corner of crib foundations for safe and fast handling.

3.2.3. Container Lifting

Lifting of the container can be executed by any ISO-certified lifting device e.g., crane, forklift, Jib crane, rail mounted gantry crane.

All lifting devices shall be class approved, certified and have a suitable SWL.

Lifting shall be executed according to EN-13155-2020. Cranes-Safety-Non-fixed load attachments.

3.2.4. Container Orientation

The orientation of the battery container onboard the vessel and on the charging station shall be marked to reduce the possibility of the crane operator loading the container 180 degrees swapped from its correct orientation.

Dependent on the different vessel infrastructure requirements it will be necessary to change the container orientation.

For the demonstration unit, the manual connection of the main power plug(s) and manual confirmation of container orientation will be used.

For commercialization, the container design will determine if a mechanical or electrical interlock is required. If the connection is to be automated an additional interlock shall be provided, confirming orientation before electrical connections are made.

3.2.5. Exhaust (Thermal runaway)

The exhaust gases from a thermal runaway in the battery will be led through a dedicated exhaust channel and out to open air. There will be an EX-zone around the exhaust vent outlet compliant with IEC 60079 Series Explosive Atmosphere Standards.

It will be possible to purge the exhaust channel after a thermal runaway.

3.2.6. HVAC

HVAC shall be provided for the Battery Space, and it is unlikely to be required within the auxiliary space. This arrangement will be finalised during detail design.

3.2.7. Battery Space Pressure Relief Flap / Purging

A mechanical relief flap shall be installed in the battery container. The flap will be normally closed.

The flap will function as an over/under pressure relief and is required when the fire extinguishing medium has been released within the container. During fire extinguishing release, excess air will flow through the flap to the open air. The flap will automatically close when the pressure has been equalized.

3.2.8. Maintenance Access

Access to the container battery modules will be via normally closed bolted A60 hatches, only accessible by authorized personnel. Hatches shall be of sufficient size to facilitate the replacement of battery service modules and normal maintenance activities. The hatches shall comply with the IP55 grade required in the IWW ES-Trin rules.

Access to the container auxiliary space will be via A60, hinged door, and IP55. A locking system and a sealed label shall be provided and only accessed by authorized personnel.

3.3. Electrical Interfaces

Figure 4 provides a preliminary vessel single-line diagram to identify the electrical interfaces between the swappable battery container and the vessel.

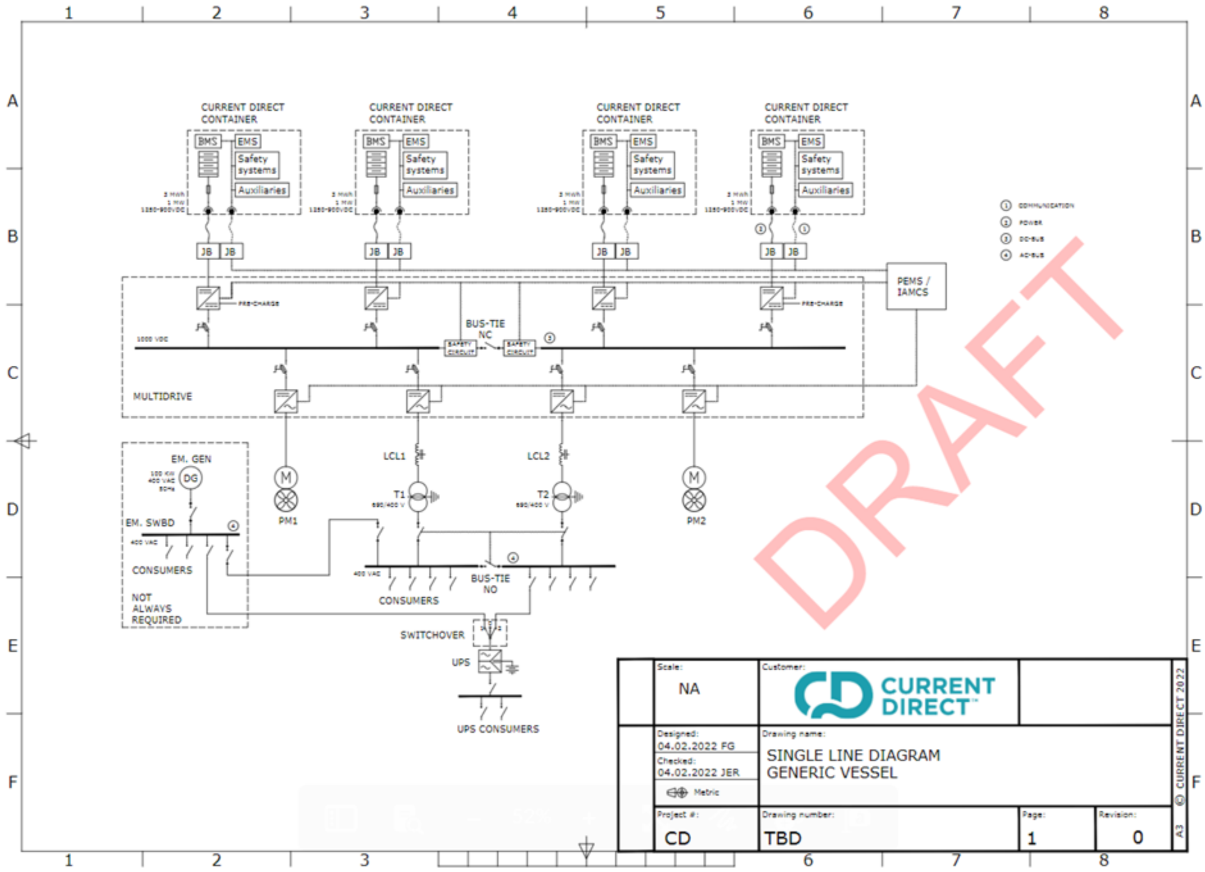

Figure 4 Preliminary Vessel Single Line Diagram

3.3.1. DC Main Power Connection

The socket for the DC main power connection between the battery and the vessel/charging station is of CCS2 type and mounted on the CD container in a housing that will electrically seal when plugged in. It is equipped with a socket cover and protected to IP44 when connected. CCS2 socket complies with the “IEC62196 Plugs, socket-outlets, vehicle connectors and vehicle inlets”. This automotive industry standard has been used as there is no standard for charging connectors for the maritime industry. Some adjustments to the CCS2 standard will be needed to comply with ES-Trin requirements.

The mobile counterparts comprising the flexible cables and male plug connectors are mounted on the vessel and charging station.

For maximum safety, no transfer of power will be allowed until the plugs are in the correct position within the socket and there is no active voltage on the socket side. These will be provided with mechanical, electrical and software interlocks.

The mechanical interlock will prevent a manual switch from closing if the plug is not inserted correctly and the plug from being removed unless the switch is opened.

The design, testing and dimensioning of the DC main connection shall comply with specifications following IEC 60309-1 (4) standards for LV DC industrial sockets and plugs. Relevant clauses from IEC/IEEE 80005-1 (2) (3) that apply for shore power and communication connections shall also be used.

3.3.1.1. Vessel DC Main Power Interface Requirements

The CD container will be able to be connected to a DC switchboard busbar connection, multidrive common DC busbar arrangement or to a DC-link of an AFE feeding AC switchboard. The DC switchboard busbar arrangement shall be designed to comply with protection and discrimination requirements like LV distribution switchboards and control gear assemblies.

If the vessel AFE (multidrive) cabinet does not allow direct connection of battery cables, a separate cable connection box joined to the DC-link of the AFE (or common DC bus of the multidrive) will be provided. The battery cables are permanently terminated in this box.

3.3.1.2. Shore DC Main Power Interface Requirements

The short circuit withstand ratings of the charger power cabinet design will consider similar fault current contributions as for the vessel multidrive and conversely the contribution from the utility grid is used instead of the vessel grid.

3.3.2. Auxiliary Power socket

A separate AC socket will be implemented in the container design for connecting 400VAC auxiliary power during non-operational states such as storage, transport etc. A commonly available standard plug type complying with IEC 60309 shall be used to allow for use of already available connections on shore installations, lorries etc. The EMS in the container shall provide monitoring and safety as well as operation of the system for connecting and disconnecting auxiliary power.

3.3.3. Shore Auxiliary Power Interface Requirements

Provision will be made for 400 VAC auxiliary connection feeder to the CD container from the charging station.

The socket outlet and plugs shall comply with IEC 60309.

3.3.4. Cabling

All shipboard cables should be type approved by relevant class society and/or flag state. Installation of cables and cable dimensioning shall comply with the applicable parts of IEC 60092.

Power cables between power electronics and transformer/filter should be shielded for EMC interference.

3.3.5. Protective Earthing

The container shall be connected to protective earth (PE) when not being transported. This will be the first connection to be made when connecting the container to either vessel or charging station.

The PE connection will be achieved by using a main power connector that includes a PE pin that is longer than the other pins and connects first.

The selected power plug for the demonstration unit, CCS-2, is designed as per IEC 62196 which defines the connection sequence with the earth pin as the first to connect and last to disconnect.

3.3.6. Electromagnetic Compatibility (EMC) / Electromagnetic Interference (EMI)

EMC is not a physical interface but is considered an important standard interface that needs to be actively managed. The container and its connections shall comply with the applicable parts of IEC61000 and IEC 60533to ensure that the equipment does not generate or is not affected by electromagnetic disturbance.

3.3.7. Electrical Studies

Electrical studies such as short circuit current calculation, selectivity analysis, arc flash calculation and electrical load balance shall be conducted for the electrical system. These are applicable for both the container itself and when the container is connected to a vessel or a charging station.

The above-mentioned electrical studies are not in themselves interfaces. However, they do define and determine the design of interface solutions and are therefore briefly described in this report.

Relevant standards and classification- and/or flag state requirements shall be followed.

3.3.7.1. Applicable Standards

- IEC 61363 - Electrical Installations of Ships and Mobile and Fixed Offshore Units
  - Standard for calculating a.c. short circuit currents onboard ships.
- IEC 60909 – Short-circuit currents in three-phase a.c. systems
  - Standard for calculating a.c. short circuit currents onshore.
- IEEE 946 – DC short circuit
  - Standard for calculating d.c. short circuit current. Contribution from the ESS shall be calculated for maximum short circuit at beginning of life and minimum short circuit at end of life.
- IEEE 1584 – Arc flash analysis
  - Standard for calculating energy levels created by arcing at short circuit. Used to ensure worker safety
- NFPA 70E – Personal protective equipment and warning labels
  - Standard to determine minimum PPE at a certain energy level, calculated in the arc flash analysis.
- IEC 60947 – Low voltage switchgear and control gear
  - Standard for LV switchgear. The standard describes required selectivity of LV breakers.
- IEC 62271 – High-voltage switchgear and control gear
  - Standard for HV switchgear. The standard describes required selectivity of HV breakers

3.4. Communication Interfaces

3.4.1. Communication and Control Overview

Figure 5 illustrates the internal and external communication and control interfaces of the swappable container.

The development of standardized open source communication protocols (whether based on Modbus TCP/IP, Modbus RS485, or others) will be used for the container's design and production for interfacing with the vessel's energy management system, shoreside infrastructure and cloud-hosted platforms. Protocol commonality between the various systems will be critical so that components and costs are minimized and industry adoption maximised.

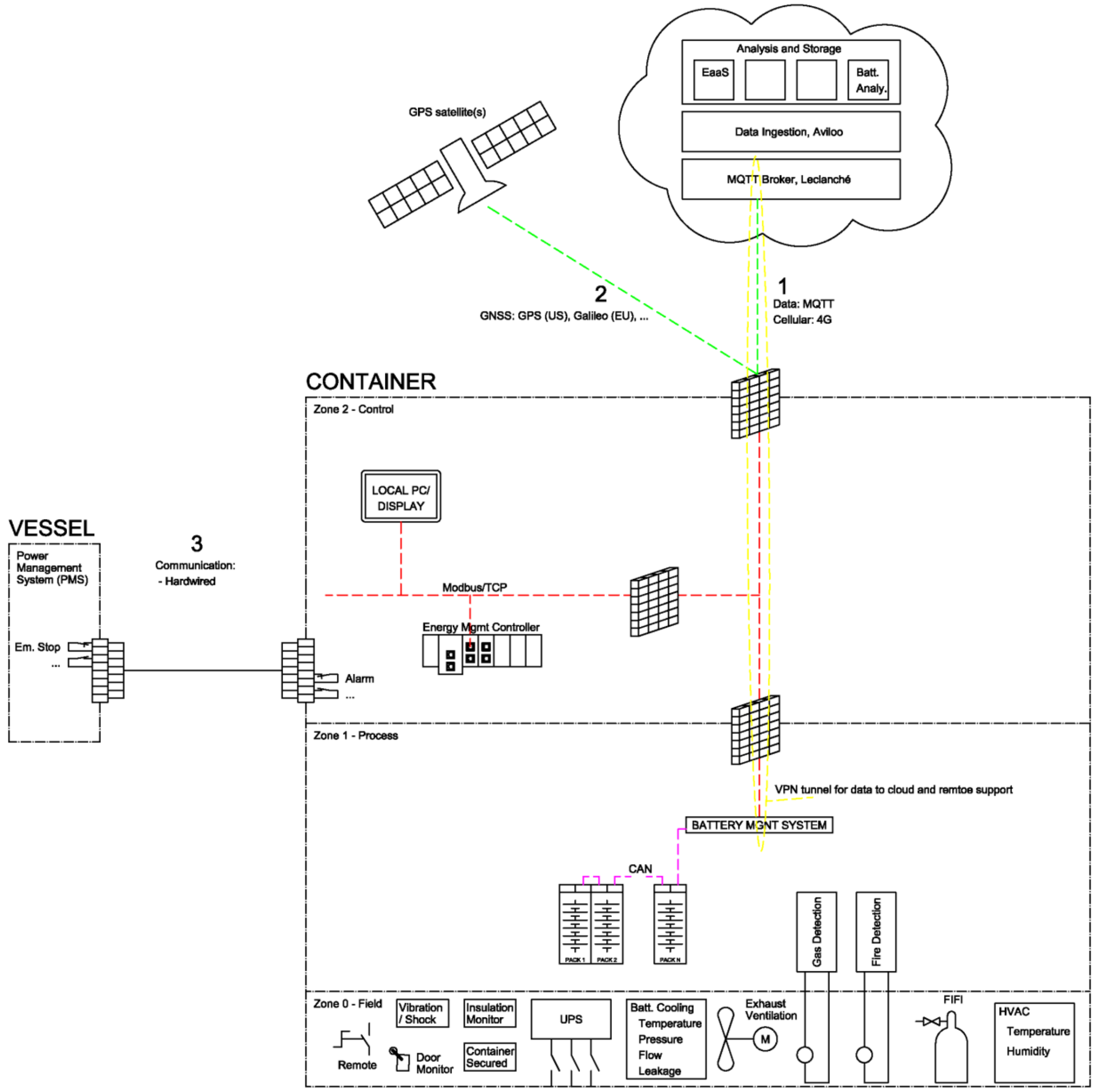

Figure 5 Illustrative Communication and Control Interfaces

3.4.2. External Container Interfaces

3.4.2.1. Container - Cloud

The container will interface to cloud-based services including Energy-as-a-Service (EaaS) and remote battery analytics platform. Traditionally, Information Technology (IT) systems and Operational Technology (OT) systems have been isolated. Therefore, different protocols are typically in use in IT systems compared with OT systems. Communication protocols between container and cloud will be selected from those commonly found in Internet-of-Things (IoT) environments. The IoT protocol MQTT is growing in the maritime industry for communication from vessel equipment to the cloud. Current Direct project will use this protocol for communication from the container to the mentioned cloud-based services. MQTT is defined by https://mqtt.org/, and is an oasis specification standard following the ISO/IEC-020922.

Data to be transferred would be measurements from container and battery analytics data, tracking of container location and optimization of battery and container utilization.

3.4.2.2. Container - GPS

The container will continuously receive GPS position. This interface may be a stand-alone physical unit or may be integrated with the same physical unit as the cloud interface. Current Direct targets to use a component including both GPS communication and data communication between container and cloud, see above 3.4.2.1.

The Global Navigation Satellite System (GNSS) interface will be connected to several satellite systems like GPS (USA), Galileo (EU), etc.

3.4.2.3. Container - Vessel/Charging Station

The Power Management System (PMS) of a vessel is controlling the electrical system including generators, switchboards, breakers, etc. The Energy Management System is a part of the container.

The container will have an interface to the vessel, and this interface will be the same for the container and the shore charging station. This interface, which is an interface between EMS and PMS, could be a combination of hardwired signals for safety such as emergency stop and bus communication based on an industry-standard protocol, e.g. Modbus TCP/IP or Modbus RS485. Regarding the demonstrator vessel it has been investigated and concluded that this interface will be a hardwired interface.

3.4.2.4. Vessel/Charging Station – Cloud

In general, the vessel and the charging station could have communication to multiple cloud-based services. It has been investigated and concluded that there will not be an interface from the vessel or from the charging station directly to the cloud for EaaS. Nevertheless, it is assumed that the vessel and the charging station will have cloud connections outside the scope of Current Direct.

3.4.3. Internal Container Interfaces

3.4.3.1. Demilitarized Zone (DMZ)

DMZ topology is an architecture to safely transfer data to and from the container whilst maintaining security. Key elements are separation of networks and protection by use of firewalls. The demonstrator vessel and container will not be using DMZ architecture. The industry standard for security in OT environments are IEC 62443 Industrial communication networks – Network and system security. International Association Classification (IACS), various classification societies and Wärtsilä base their cyber security on this framework. The Current Direct will use IACS UR E26 “Cyber Resilience of Ships” and E27 “Cyber Resilience of On-Board Systems and Equipment” as guideline for cyber security.

3.4.3.2. Control Level

This level includes the Energy Management System (EMS). Historically Modbus/RTU has been widely used and a candidate for the future is OPC UA. Today the protocol commonly used is Modbus/TCP.

IEC/IEEE 80005 Utility connections in port – Part 2: High and low voltage shore connection systems – Data communication for monitoring and control specifies the protocol to be used, and IP addresses and Modbus register schema to be used.

A Human Machine Interface HMI will be included in the container design to provide local functionality. The HMI will provide information regarding container status. The HMI indicators shall be following the IMO code on alerts and indicators, 2009.

A vessel including a bridge and a machinery space will have requirements for the local operation of the propulsion plant. However, some vessels may have a common location defined as bridge and machinery space. Furthermore, what local operation of propulsion means would depend on the topology and the equipment. The implementation of HMI for use as a local operation will be addressed during the detailed design phase.

For the demonstrator vessel, Modbus/TCP will be the communication protocol internally for the Energy Management System (EMS).

3.4.3.3. Process Level

This level includes the Battery Management System (BMS), and the communication protocol used by Leclanché is CAN as defined in ISO 11898 series.

Communication protocol between EMS and BMS will be Modbus/TCP.

3.4.3.4. Field Level

At this level, there will be several hardwired signals such as digital and analogue inputs and outputs that shall comply with established and recognised maritime and industrial standards governing the design and performance.

Local / Remote Selector

Selection of local operation may be implemented by use of a selector switch, or it could be implemented in the HMI.

Door / Hatch Monitoring

A container with batteries could represent a risk related to explosive gases or gases harmful to human beings. Mitigation of such risks may include monitoring of doors/hatches or procedures for opening the container, or a combination of both.

Insulation Monitoring

The CD container DC bus is an isolated system. Meaning, that in the case of an earth fault, little or no current will flow to the ground. Electrical insulation to earth is, therefore, continuously monitored and an "Insulation Low" Alarm indicating earth fault or low impedance loop to the ground is sent to EMS control. This alarm will also be extended to the main alarm handling system outside the CD container.

Visual and audible signals will be indicated to initiate operator intervention.

UPS

The following events or alarms will be monitored for the CD container UPS system (batteries, charging device, ventilation). These alarms will be logged by the EMS and a common alarm extended to the alarm handling system outside the CD container.

- Failure of charging
- Automatic bypass in operation
- Failure of ventilation
- Battery protective device operation

Fire & Gas Detection

The container will include detectors for fire and gas, where detectors are continuously monitored by the control system and any fault detected will initiate an alarm on a manned operator station e.g., the bridge.

A confirmed fire or gas detection will trigger an alarm announcement and actions such as shutdown and starting of ventilation.

Fire Fighting

There will be delivered and installed a fire extinguishing system with a product certificate from recognized class society. This FiFi system is installed to extinguish any fire in the battery space and may be released from the bridge or locally at the container. The bottle containing the fire extinguishing medium will be installed in the auxiliary space of the container.

A standard emergency push button is placed at the recessed end of the container. The additional manual emergency release is installed directly on the bottle. It will also be possible to release the system from the bridge. If any failure with the FiFi system should occur, an alarm will be visible in the local HMI, audible outside the container and visible/audible at the bridge.

As a last resort for firefighting, a means for filling the container with water will be installed. A Storz connection is installed at the recess part of the container to enable the local fire department to connect and fill the container with water. This feature is applicable when the container is onshore and complies with the local fire department requirements.

Water Cooling System

The cooling system provided is an air-to-water system, where the air is circulated outside, and chilled water is distributed inside the container. Some free space/area will be reserved.

Chilled water is used to maintain the battery cell/module temperature, battery space and auxiliary space. An environmentally friendly cooling agent is used in the system.

HVAC

Ventilation for the battery space has independent ducting only serving this space. In case of a failure in one of the battery modules, the resulting flammable and toxic gas will be led to open air through the closed battery rack TR exhaust ventilation system.

An EX-certified fan will supply air to the battery space. The fan may be started manually from the outside container. Penetrations through the container boundary to open air are protected from water ingress commensurate with the IP55 rating.

Vibration / Shock

Shock and vibration sensors shall be installed to monitor the G-forces inflicted on the container in service and especially during lifting and handling operations. Output data from the sensor log will be used to prepare maintenance and service for the container.

Container Locked in Position

The demonstrator will not include detectors for containers locked in position. This is however a feature that will be evaluated for a commercial solution as required.

4. CONCLUSIONS

Mechanical Interfaces

The document outlines the mechanical interface requirements for a container, including general measurements, locking mechanisms, lifting procedures, orientation, exhaust management, HVAC, pressure relief, and maintenance access. Key standards referenced include ISO 668-2020, ISO 1161-2016, ISO 3874-2017, EN-13155-2020, and IEC 60079 Series. The container must be locked with certified twist locks, lifted by ISO-certified devices, and oriented correctly to avoid misloading. Exhaust gases from thermal runaway will be managed through a dedicated channel, and HVAC will be provided for the battery space. A mechanical relief flap will handle pressure changes during fire extinguishing, and maintenance access will be restricted to authorized personnel through bolted hatches and locked doors.

Electrical Interfaces

The document outlines the electrical interfaces for a swappable battery container on a vessel. It includes a preliminary vessel single-line diagram and details the DC main power connection using a CCS2 socket, which complies with IEC62196 standards. Safety measures include mechanical, electrical, and software interlocks. The vessel and shore DC main power interface requirements are specified, along with auxiliary power socket details for 400VAC connections. Cabling must be type-approved, and protective earthing is mandatory. EMC/EMI compliance is required, and various electrical studies such as short circuit current calculation and arc flash analysis must be conducted. Relevant standards like IEC 61363, IEC 60909, IEEE 946, IEEE 1584, NFPA 70E, IEC 60947, and IEC 62271 are to be followed.

Communication Interfaces

The document details the communication and control interfaces for a swappable container in maritime applications, using standardized open-source protocols like Modbus TCP/IP and Modbus RS485. It will communicate with cloud services via MQTT for data transfer, including battery analytics and GPS tracking, and interface with the vessel's Power Management System (PMS) and shore charging stations using industry-standard protocols. Internally, it will use a Demilitarized Zone (DMZ) architecture for secure data transfer and adhere to IEC 62443 cybersecurity standards. The Energy Management System (EMS) will use Modbus/TCP, and the Battery Management System (BMS) will use the CAN protocol. The container will feature safety and monitoring systems such as fire and gas detection, insulation monitoring, and a water-cooling system, along with a Human Machine Interface (HMI) for local operation and status monitoring. Shock and vibration sensors will monitor G-forces during service, aiding in maintenance and service preparation. The demonstrator will not include detectors for containers locked in position, but this may be considered for commercial solutions.