Swappable Container Waterborne Transport Battery

Call Identifier: H2020-LC-BAT-2020

Topic: LC-BAT-11-2020

Reducing the Cost of Large Batteries for Waterborne Transport

D4.2
Smart Cell EMC Compatibility

9 July 2021

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 963603.

1. CONTENTS

GLOSSARY OF TERMS

Term	Definition
BCU	Battery Controller Unit
BMS	Battery Management System
EMC	Electromagnetic compatibility
MCU	Master Control Unit
PCB	Printed Circuit Board
SCS	Smart Cell Supervisor
SCU	String Controller Unit

DOCUMENT PROPERTIES

Project Information	
Program	Reducing the Cost of Large Batteries for Waterborne Transport
Project Acronym	Current Direct
Grant Agreement Number	963603
Deliverable Number	D4.2
Work Package/Task Related	WP4 / T4.3

Document Information	
Document Name	CD_D4.2_SCS_EMC_Compatibility_v1.0
Date of Delivery	9 July 2021
Status and Revision	Initial Public Release, Version 1.0
Number of Pages	17

Responsibility	
Work Package Lead	Spear Power Systems
Work Package Partners	VUB, WARTSILA NORWAY, Blackstone, VITO, KOTUG, Foreship, LR
Reviewer(s)	LR, Foreship, Spear Power Systems
Approver	Spear Power Systems

Dissemination Level	
Type (Distribution Level)	☒PU, Public
	☐CO, Confidential, only for members of the consortium (including the Commission Services)
	☐EU-RES, Restricted, Classified Information
	☐EU-CON, Confidential, Classified Information
	☐EU-SEC, Secret, Classified Information

REVISION HISTORY

Version	Issue Date	Changes Made / Reason for Issue
1.0	09-Jul-2021	Initial Version Submitted

“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

Current Direct, a new research and innovation project funded by the European Commission's Horizon 2020 program, will revolutionize the way we move goods and people by water. The vast majority of water transport in Europe is propelled by dirty, noisy diesel engines. By cutting the cost of today's marine battery-electric drivetrains in half and relieving ship owners of the burden of capital expense, Current Direct will enable rapid adoption to reduce greenhouse emissions.

Current Direct's innovative Energy as a Service platform will enable ship owners to accelerate their participation in the shift to clean energy while creating new business opportunities for shipyards and local entrepreneurs. By changing the model for acquiring and storing energy aboard vessels, Current Direct will create a new energy economy, adding thousands of new jobs. Current Direct provides a vehicle for energy companies, institutional investors, and government stakeholders to participate in the green transformation of Europe's merchant and passenger fleet.

Current Direct brings together thirteen dynamic partners from across Europe's marine electrification value chain. The project is led by Spear Power Systems, makers of the world's lightest, most flexible marine batteries certified to the most stringent international safety standards. Blackstone Technology is lowering the cost of manufacturing tomorrow's 3D printed lithium-ion cells using state of the art active materials from Umicore. The University of Hasselt will use its electrochemical expertise to develop physics-based models of the Current Direct cells that will help optimize the life and return on investment of battery systems deployed across Europe as part of the Current Direct Energy as a Service platform developed by the accomplished engineers and data scientists at Rhoé Urban Technologies and Aviloo. Naval architecture and marine engineering company Foreship will lend its expertise to EDP CNET's in-depth knowledge of electrical markets to ensure the Current Direct platform targets optimal vessels and locations maximizing reductions in emissions. VUB's material science experts are creating low-cost composites to improve the safety of battery packs that are designed for recyclability and feature VITO's smart cell monitoring electronics. Wärtsilä will develop modular battery containers and charging infrastructure that will be certified to innovative standards developed together with Lloyd's Register. The project will culminate in a demonstration of the Current Direct battery, shore charging, and asset management platform by Kotug in Rotterdam.

The Current Direct EcoSystem is shown in Figure 1.

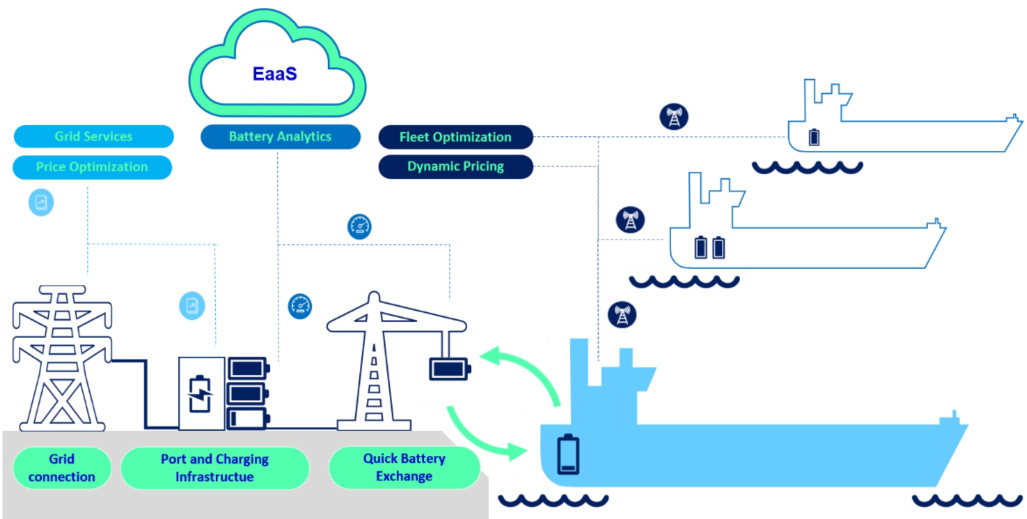

Figure 1. Current Direct EcoSystem

1. EXECUTIVE SUMMARY

The objective of this report is to verify that the Smart Cell Supervisor can communicate without interruption in the full shipboard EMC spectrum. At this time the report is unable to conclude this objective since the required EMC Testing has not been completed and is yet to be undertaken. The delay in undertaking the EMC Testing activities is attributed to global supply and demand constraints that are currently limiting the availability of the hardware required to construct the SCS components for EMC Testing.

The project partners are actively working with several suppliers to resolve this issue, but this delay will likely have a material impact on the project schedule. This is reflected in the EMC Test Timeline.

Further updates to this report and deliverable will be required and these are planned as follows:

Version	Schedule	Scope
v1.0	M6	This Initial Report
v2.0	M10	Updated to reflect final SCS EMC Design Review
V3.0	M11	Updated to reflect actual Hardware Design
V4.0	M16	Final Report updated following completion of EMC Testing and Results

2. SPECIFIC OBJECTIVES FOR WORK PACKAGE 4

This WP encompasses the design, prototyping, verification testing, and demonstration build of the Current Direct Waterborne Transport Battery optimized for inland and short sea shipping applications. It includes the development of key subsystems that improve safety, reduce cost, improve life, and increase energy density.

Subsystem development will begin immediately at the start of the project, while the battery design will not start until milestone M2 with the requirements freeze.

Specific Objectives:

- Design a safe, low cost, long life, energy-dense Current Direct Waterborne Transport Battery
- Develop and test ultrasound sensors for determining SOC and SOH
- Develop and test BMS single-cell supervisor
- Develop and test composite structural and thermal plate battery module construction
- Create a thermal model of the battery system to understand heat distribution and dissipation
- Produce prototype Current Direct battery modules
- Test Current Direct battery modules for performance and safety certification
- Design a marine, safety-certified, swappable container for the Current Direct battery
- Integrate and test the Current Direct battery, container, and subsystems

3. INTRODUCTION

The Current Direct maritime application environment presents a unique source of demanding electromagnetic interference and compatibility which is of particular importance when designing a battery system due to the large number of sensors used and their susceptibility to noise and interference.

The identification of applicable EMC standards and a comprehensive test strategy is critical to ensure the successful deployment of Current Direct Smart Cell Supervisor in the maritime operating environment.

This report describes the electromagnetic compatibility (EMC) of the battery management system (BMS) as the combination of a Master Control Unit (MCU) and Smart Cell Supervisor (SCS) components that connect to individual battery cells or cell groups (parallel-connected individual battery cells). The completed BMS further comprises multiple String Controller Units and a Battery Controller Unit.

This document introduces the set-up of the BMS with emphasis on the part of the system under the EMC study. The document further presents the current state of EMC testing and compatibility of the baseline solution based on tests that were performed on VITO's industrial SCS solution. Finally, the document outlines the EMC test plan that will be passed by the final solution for the combination of MCU + SCS.

3.1. Smart Cell Supervisor

The Current Direct BMS hardware consists of several components. The Smart Cell Supervisor (SCS) is the lowest level component, and it is closely coupled in a 1:1 relationship to each (set of parallel-connected) single battery cells.

Its design for the application in the Current Direct project is based on VITO's Voltage Balancing Unit (VBU) as both perform similar functions. The SCS is a planned development of the VBU to comply with the project's specifications and requirements. To operate the VBUs, and hence also the SCSs, one master board is needed for multiple VBUs or SCSs. This master board is referred to as BMS Master for the current VITO solution and as Master Control Unit (MCU) for the final Current Direct solution. The current version of the BMS Master and the VBUs are designed for industrial applications and have undergone EMC testing and proven to be compliant within that application.

The SCSs will require an MCU as a driver and gateway to higher-level BMS components as provided by Spear Power Systems, this being the String Controller Units and a Battery Controller Unit. The combination of MCU and SCSs will finally comply with maritime requirements.

It is understood and acknowledged that there are differences between the existing VBU and the future SCS (and BMS Master and MCU) that are relevant in the context of EMC:

1. The waveform linking the MCU to the SCS will be a sine-like wave compared to the currently applied block wave;
2. The SCS will be capable to draw limited power from the battery cells to perform measurements while the MCU is powered down;
3. Components will be added to the SCS to comply with maritime regulations. These components provide redundant overvoltage and overtemperature protection.

These changes require further specific EMC testing that will be performed according to maritime standards on prototypes of the new hardware.

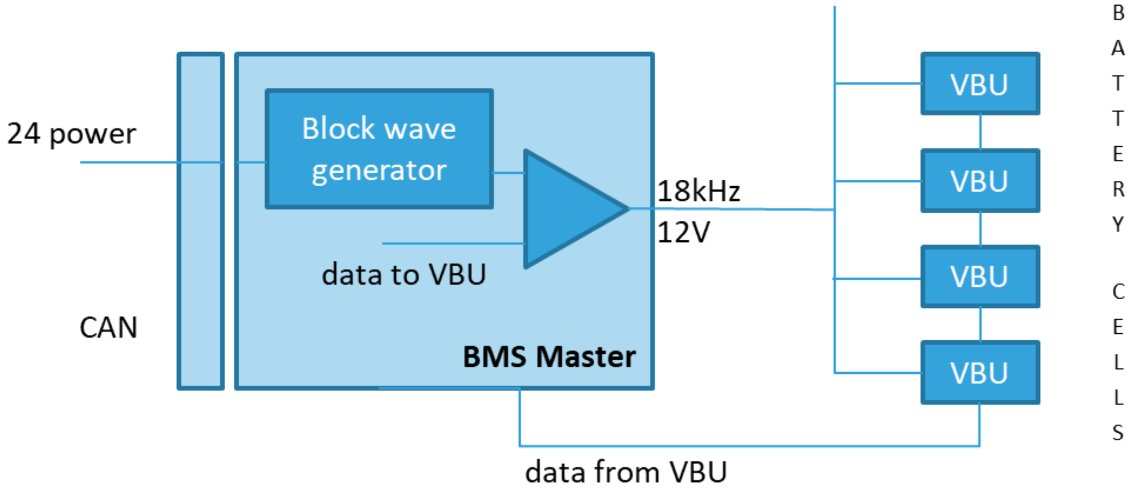

Figure 2 VITO Reference BMS Solution – Hardware Block Diagram

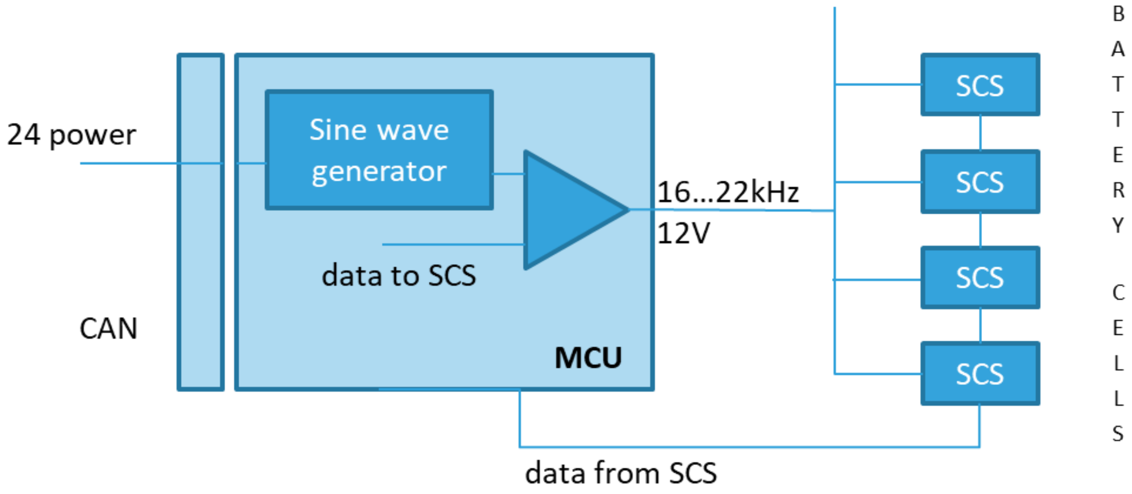

Figure 3 Adapted VITO BMS Solution for The Current Direct Project - Hardware Block Diagram

4. REFERENCE SOLUTION AND EMC TEST RESULTS

This section provides an overview of the reference VITO BMS solution and EMC Tests completed and the results generated.

For EMC testing the VITO BMS was assembled and integrated into an industrial-style 14 NMC cell battery with a casing (Figure 4). This system is self-powered in the sense that the BMS draws its power from the battery leaving only the battery terminals and a CAN bus connection exposed to the outside world (Figure 5).

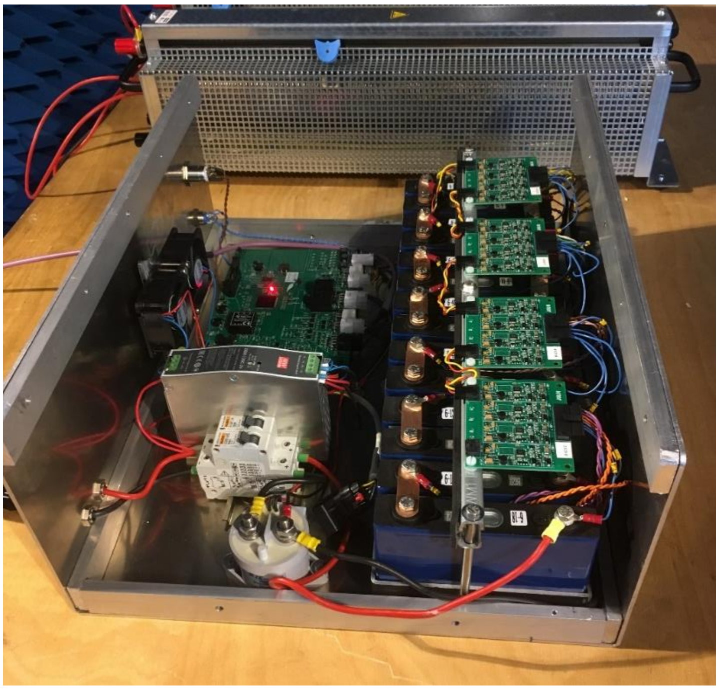

Figure 4 Picture Showing the Inside of the Reference BMS EMC Test Battery

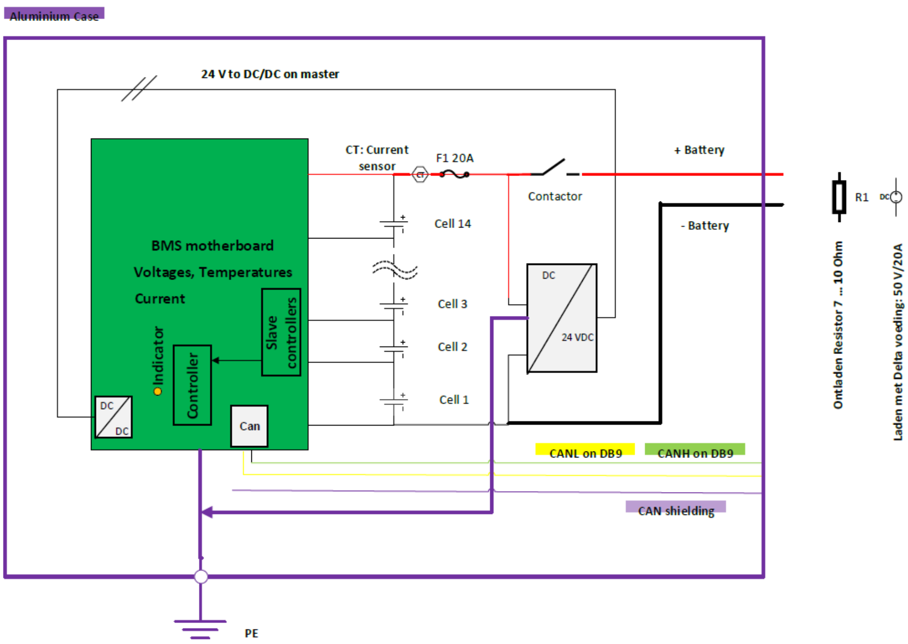

Figure 5 Block Diagram of the Device Under Test

An overview of the EMC tests, their related standards, reports, and results are presented in Table 1.

Table 1. EMC Tests, Related Standards, Reports and Results

EMC Test	Standard	Report Reference	Result
Electrostatic discharge Immunity (ESD)	IEC 61000-4-2 Ed. 2.0: 2008 EN 61000-4-2: 2009	30-DS25-CO-200121_1355	PASS
Electrical fast transient/ burst immunity (EFT)	EN 61000-4-4:2012	30-DS25-CO-200121_1355	PASS
Surge immunity	EN 61000-4-5 2006	30-DS25-CO-200121_1355	PASS
Conducted Emissions	EN55022 for class B devices	30-DS25-BMS-VITO-EMC Test 9) p18	PASS [1]
Radiated Emissions	EN55022 for class B devices	30-DS25-BMS-VITO-EMC Test 25) p43	PASS [1,2]
Conducted Immunity	IEC 61000-4-6	30-DS25-BMS-VITO-EMC	PASS
Radiated Immunity	IEC 61000-4-3	30-DS25-BMS-VITO-EMC	PASS

[1] Dedicated measure taken on the original BMS master to ensure EMC compliance:

- Replace internal DC/DC converter (CUI/TRACO)
- Minor changes to master PCB power supply circuit (component values)

These measures were determined by an elimination process during EMC testing and were forwarded to the production version.

[2] Dedicated measures taken on the battery system to ensure EMC compliance:

- Remove contactor and fuse, reroute wires
- 10nF Y cap added (battery + and - to chassis)
- 470nF X2 cap added (battery + to -)

Where a load was required, either wound rheostats or lamps were used. A Delta Power DC power supply was used as a charger.

The following integration guidelines were found to provide improved EMC performance:

DC Power Cables

- Keep the + and the – of the DC Power Cable short together; avoid loops
- Avoid loops in DC Power Cable as much as possible
- Keep the length as short as possible for the DC Power Cables
- Keep the DC Power Cables as close as possible to a conductive plate

Signal Cables

- Use twisted pair 0.5 mm^2 (20AWG) non shielded cable between the slave boards hosting the VBUs; maximum parasitic capacitor 200 pF per cable
- Keep the Signal Cables as far as possible away from the DC Power Cables
- Keep the Signal Cables as close as possible to a conductive plate
- If Signal Cables cross the DC Power Cables, do it with a right angle
- Use shielded twisted pair cable for CANbus communication

Earthing

- Never combine noisy, “high power” circuit grounds with “low powered” signal circuit grounds
- Keep high power grounds as short as possible
- Keep low power grounds together; keep them as short as possible
- Ensure good conductive contact between metal chassis (earth) and grounding signal.

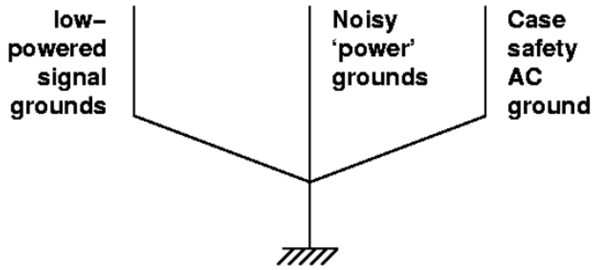

Figure 6 Grounding Guidelines

Enclosure Box

- Ensure good conductive contact between the whole enclosure box (no paint, ….)

5. EMC TEST STANDARDS AND STRATEGY

The maritime application environment presents a source of demanding electromagnetic interference which is of particular importance when designing a battery system due to the large number of sensors used. The identification of applicable standards and a comprehensive test strategy is critical to ensure the successful deployment of Current Direct in the maritime operating environment.

In this section, a comprehensive EMC test strategy is outlined. This test strategy will be applied throughout the development of Current Direct and incorporate all applicable certification standards and tests.

5.1. EMC Test Strategy

To manage and mitigate the risk of EMC, validation testing will begin at the component level during Current Direct's development. After subcomponents are validated, testing will then be conducted at the system level. Following this, the Current Direct project will then be tested to receive EMC certification from the relevant authorities per the identified standards and project requirements as defined under WP2 Specification and Requirements.

5.1.1. EMC Validation Steps Summary

EMC validation can be summarized in three main steps:

1. **EMC Component Tests:** This step aims to validate individual components separately before being integrated into the larger battery system. This step allows the development effort to be de-risked before conducting system-level validation. These tests must represent the real application environment.
2. **EMC System Validation:** This step aims to validate the fully integrated system to ensure fully compatible operation. This ensures that the system will pass all expected criteria before being subjected to certification tests. These tests must represent the real application environment.
3. **EMC Certification:** This step aims to perform the regulatory EMC tests to have the certification from an accredited laboratory.

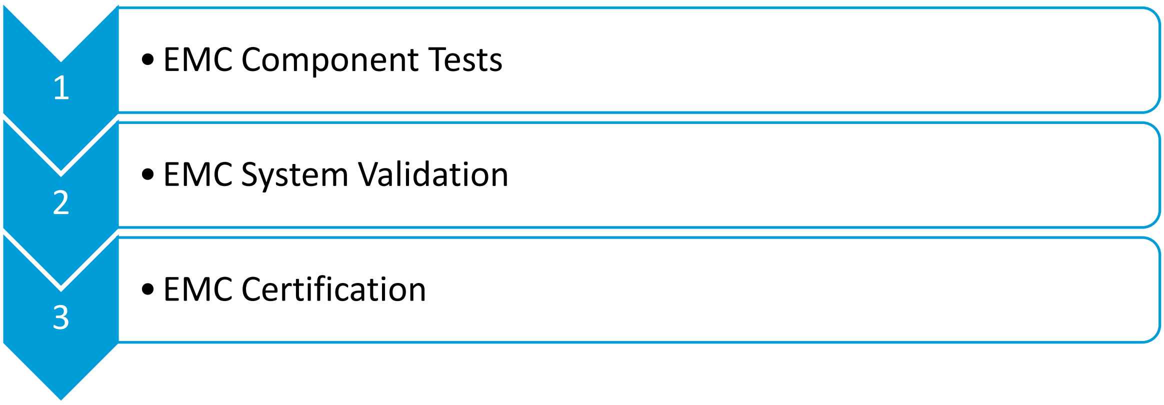

Figure 7 EMC Validation Steps

5.1.2. Test Flow Chart

Validation tests will be conducted with 2 samples in the sequence shown below in Figure 8. If the results are different or there is doubt in performance during characterization, additional tests will be performed on the 3rd sample.

The test laboratory will be organized and run under ISO/IEC 17025. All test equipment used for measuring must be calibrated as per ISO/IEC 17025.

A full list of equipment used will be captured and recorded in the report together with the expiration date of the calibration.

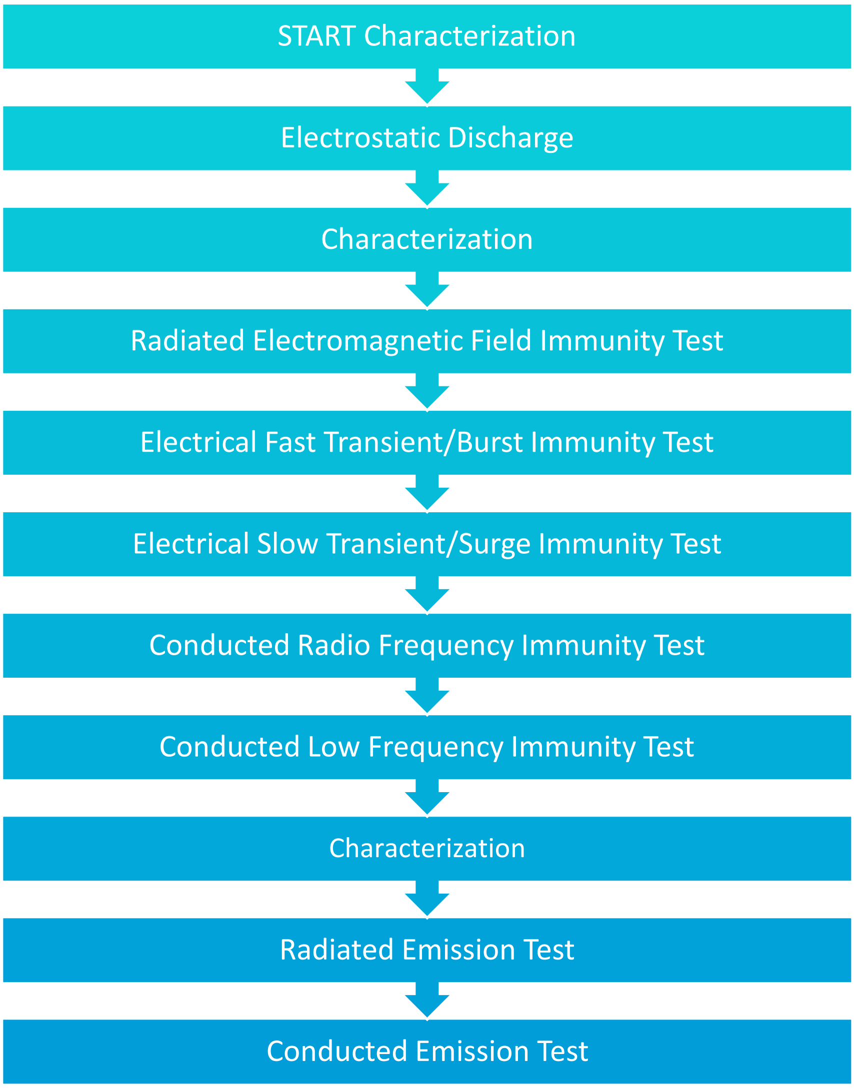

Figure 8 Test Flow Chart

These EMC tests are chosen from the reference standard: DNVGL-CG-0339. The structure was defined to make the most onerous and stressful tests first. The emission tests are conducted at the end of the test sequence to check and confirm whether the immunity test had any effect on the product. The functional characterization will be conducted after the Electrostatic Discharge test and immunity tests to verify acceptable component operation.

Current Direct components will be classified into two categories according to risk levels and the sources of noise. This grouping can be shown below in Table 2.

- Category A: Immunity Risk + No Source of Noise.
- Category B: Immunity Risk + Source of Noise

Table 2 Applicable Tests for Each Category

Tests	Category A	Category B
Emissions	NA	A
Immunity	A	A
ESD	A	A

A: applicable // NA: not applicable // O: Optional (for information only)

5.2. Applicable Test Standards

The reference applicable test standards are based on the international maritime standard DNVGL-CG-0339. This standard covers all EMC aspects (ESD, Immunity and Emission). Furthermore, it gives the test levels as well as the acceptance criteria. These standards are used for certification, but their test conditions and acceptance criteria will be made more demanding for both the component and system validation tests to capture the true operating environment conditions.

Table 3 provide the list of applicable standards.

Table 3 List of Applicable Standards

Standard	Description
(IACS) – Unified Requirements	UR E10 – Test Specification for Type Approval
Lloyd's Register Type Approval System – Dec 2020	Test Specification no.1 – Performance and Environmental Test Specification for the following Environmentally Tested Products used in Marine Applications: Electrical Equipment, Control and Monitoring Equipment, Instrumentation and Internal Communication Equipment, Programmable Electronic Systems
DNVGL-CG-0339:2019	Environmental test specification for electrical, electronic, and programmable equipment and systems.
IEC 60945 Ed 3	Maritime navigation and radiocommunication equipment and systems – General requirements – Methods of testing and required test results.
IEC 61000-4-2:2008	Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test.
IEC 61000-4-3:2020	Electromagnetic compatibility (EMC) - Part 4-3: Testing and measurement techniques - Radiated, radiofrequency, electromagnetic field immunity test.
IEC 61000-4-4:2012	Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test.
IEC 61000-4-5:2014	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test.
IEC 61000-4-6:2013	Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields.
CISPR 16-2-1:2014	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-1: Methods of measurement of disturbances and immunity - Conducted disturbance measurements.

Standard	Description
CISPR 16-2-2:2010	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-2: Methods of measurement of disturbances and immunity - Measurement of disturbance power.
CISPR 16-2-3:2016	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurement.

5.3. Initial Report Applicability

Current Direct's battery management data acquisition system will be based on the Single Cell Supervisor (SCS). To operate the SCSs, a Master Control Unit (MCU) is needed. The prior iteration of this system consisting of a Voltage Balancing Unit (VBU) and BMS Master has been developed and is being deployed in industrial applications. In this context, the following EMC tests were performed.

Emission Tests:

- Conducted emissions according to EN55022
- Radiated emissions according to EN55022

Immunity Test:

- Conducted immunity according to IEC 61000-4-6
- Radiated immunity according to IEC 61000-4-3
- Surge test according to IEC 61000-4-5
- Electrical fast transient/Burst test according to IEC 61000-4-4
- Electrostatic Discharge according to IEC 61000-4-2

The above tests are then compared against maritime test standards outlined in DNVGL-CG-0339:

- For the Emissions aspect: The performed emissions tests were in accordance with EN55022 (equivalent to CISPR 22). DNVGL-CG-0339 requires performing emissions tests according to the CISPR 16 standard.
- For the Immunity aspect: The performed tests did not consider conducted low-frequency immunity according to IEC 60945 standard. For the other immunity tests, the tests applied the same requirements covered by the DNVGL standards.

As previously explained, the conditions and test levels on the prior test conducted are not representative of real maritime operational environments. A new EMC test for both the components and complete system will be developed with more demanding test levels and an extended frequency band to ensure compatibility within this operating environment.

6. EMC TEST TIMELINE

To comply with the Current Direct project and maritime application requirements in general, the current VITO BMS technology based on a BMS Master and cell connected VBUs needs a hardware redesign as explained in section **Error! Reference source not found.**.

This will influence the EMC performance of the BMS component, being the SCS in combination with an MCU. Two main steps in this redesign process are

1) finalization of the new hardware design
2) approved functionality on the revised hardware that has been taken through to production

When both steps are completed, hardware can be subjected to EMC tests.

The final EMC performance of the BMS component will be assessed per the project EMC test plan based on international standards and operational environment conditions.

Table 4 gives an overview of the activities that compose the EMC test schedule within the Current Direct project, including indicate schedule dates and supporting comments. The scheduled date is estimated based on current lead times of critical components required for the SCS design development.

Table 4 Overview of EMC Test Schedule

Activity	Description	Schedule	Comment
EMC Test Plan Completed	Detailed EMC Test Plan	M7	Includes overall Project Component and System EMC Test Plan
SCS Design Development	In accordance with Project Specification and Requirements	M7-M9	
SCS EMC Design Review	Review of CD Design	M10	Iterative according to design cycles
SCS and MCU Hardware Design Complete	Revised hardware for SCS and MCU based on project and maritime application requirements	M11	The final hardware design depends on the project's requirements freeze and passed feasibility check
SCS and MCU Hardware Delivered	Revised hardware for SCS and MCU approved functionality	M12	The delivery of the revised hardware is subjected to the risk of the global shortage of electronic components.
SCS Hardware & Software Testing	Test cycle to verify BMS hardware & software functionality	M12	
SCS EMC Pre-Compliance Testing	Testing at partners' labs to check on EMC performance to assist design changes	M13	Iterate design according to Pre-Testing
SCS EMC Testing	EMC test execution	M15	