

D5.4 Rules Gap Analysis Report

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Document name:	D5.4 Rules GAP Analysis Report	Page:	1
Dissemination	PU	Version	1.0

Table of Contents

SUMMARY	- 3 -
REGULATORY ASSESSMENT OF SUPERCAPACITOR AND SUPERCONDUCTING MAGNETIC ENERGY STORAGE TECHNOLOGIES IN MARINE APPLICATIONS	- 4 -
1. INTRODUCTION.....	- 4 -
2. METHODOLOGY.....	- 4 -
2.1 Data Source and Structure.....	- 4 -
2.2 Analytical Process.....	- 4 -
2.3 Output Format	- 5 -
3. SUPERCONDUCTING MAGNETIC ENERGY STORAGE SYSTEM (SMES).....	- 5 -
3.1 Superconducting Magnetic Energy Storage (SMES)	- 5 -
3.1.1 Heat Exchanger/Chiller	- 5 -
3.1.2 Fresh Water Circuit	- 6 -
3.1.3 Cryocooler	- 6 -
3.1.4 Cryocooler/Vacuum Pump.....	- 6 -
3.1.5 Superconductor	- 7 -
3.2 Control System (SMES).....	- 7 -
3.2.1 Controller/Communication Unit	- 8 -
3.2.2 Pressure Transmitter.....	- 8 -
3.2.3 Temperature Transmitter	- 8 -
3.3 Electrical System.....	- 9 -
3.3.1 Power Conditioning System	- 9 -
3.3.2 Power Conditioning System	- 9 -
3.3.3 Battery.....	- 10 -
4. SUPER CAPACITOR SYSTEM	- 10 -
4.1 Super Capacitor.....	- 10 -
4.2 Control System (Supercapacitor).....	- 11 -
4.2.1 Controller/Communication Unit	- 11 -
4.2.2 SoH/SoC Transmitter	- 11 -
4.2.3 Temperature Transmitter	- 12 -
4.3 Electrical System.....	- 12 -
4.3.1 Voltage Measuring Equipment.....	- 12 -
4.3.2 Temperature Transmitter	- 12 -
4.3.3 Ground Fault Detection Equipment.....	- 13 -
4.3.4 Switchgear.....	- 13 -
4.3.5 Master Controller	- 13 -
5. RESULTS AND DISCUSSION	- 14 -
5.1 Overview of Regulatory Context	- 14 -
5.2 Findings from the System Analysis.....	- 14 -
5.3 Identified Regulatory Needs.....	- 14 -
5.4 Implications for TRL Advancement.....	- 15 -
6. CONCLUSIONS AND RECOMMENDATIONS	- 16 -
6.1 Key Conclusions.....	- 16 -
6.2 Recommendations	- 16 -
6.3 Final Remarks.....	- 17 -



Summary

This deliverable presents the results of the regulatory gap analysis performed under Work Package 5 (WP5) of the V-ACCESS project. It builds upon the technical configurations of Energy Storage Systems (ESS) developed in WP3 and WP4, integrating the findings of Task 2.3 to identify the regulatory actions required to enhance the Technology Readiness Level (TRL) of innovative ESS technologies, particularly supercapacitor-based systems for marine applications.

The report provides a consolidated overview of the current maritime regulatory framework, identifies gaps and barriers in existing rules, and proposes pathways to address these gaps through Technology Qualification Processes, Alternative Design approaches, and targeted updates to classification society and international standards.



Document name:	D5.4 Rules GAP Analysis Report	Page:	3
Dissemination	PU	Version	1.0

Regulatory Assessment of Supercapacitor Technologies in Marine Applications

1. Introduction

This document builds upon the analytical work carried out under Task 2.3 and the technical results produced in Work Packages 3 and 4, which define the various configurations of Energy Storage Systems (ESS) to be installed on board marine vessels.

The purpose of this report is to develop a synthetic summary of the regulatory actions required to facilitate the technological maturation of the proposed innovations, ensuring their Technology Readiness Level (TRL) can be increased to the desired target value.

The analysis focuses on identifying the regulatory pathways, gaps, and enabling processes that can support the safe and compliant integration of advanced energy storage technologies — such as supercapacitors, batteries, and hybrid ESS — in marine applications.

Specifically, the report highlights:

- The need for new regulatory frameworks or identification of existing barriers;
- The regulatory gaps requiring improvement or clarification;
- The development or update of relevant industry standards; and
- The feasibility of implementation within the current regulatory environment.

This structured assessment aims to provide clear guidance for stakeholders and classification societies, supporting the regulatory alignment needed to enable the deployment of innovative ESS solutions onboard vessels in compliance with international maritime safety standards.

2. Methodology

The methodology adopted in this activity aims to systematically link the technical configurations of Energy Storage Systems (ESS) with the applicable regulatory framework and classification society requirements. This approach allows for a structured identification of gaps, barriers, and potential pathways to increase the Technology Readiness Level (TRL) of each innovative solution considered within the project.

2.1 Data Source and Structure

The primary data used in this assessment were derived from the technical tables developed under WP3 and WP4, consolidated into a reference database. the following structure was defined:

- Define the System, Subsystem, and Component under analysis.
- Define the descriptive information related to applicable standards, certification requirements, regulatory needs, notes, and conclusions.

This structured format enables a consistent mapping between each ESS component and the corresponding regulatory context.

2.2 Analytical Process

The analysis followed these steps:

1. Identification of relevant components within each ESS configuration, including those integrating



Document name:	D5.4 Rules GAP Analysis Report	Page:	4
Dissemination	PU	Version	1.0

supercapacitor technologies.

2. Review of applicable international and classification society standards, such as IMO instruments, IACS Unified Requirements, and specific rules from ABS, DNV, RINA, and Lloyd’s Register.
3. Evaluation of compliance gaps where existing standards may not fully address the operational or safety aspects of emerging ESS technologies.
4. Assessment of regulatory needs, including the potential for Technology Qualification Processes (TQP), Alternative Design approaches, or the need for new or revised standards.
5. Synthesis of findings into a structured report summarizing key regulatory actions required to support TRL advancement.

2.3 Output Format

The results are presented in a structured text format, where each record includes:

- System / Subsystem / Component identification
- Applicable standards and certification requirements
- Regulatory or technological needs
- Supplementary notes and conclusions

This standardized representation facilitates clear traceability between technical innovations and the corresponding regulatory implications.

3. Superconducting Magnetic Energy Storage System (SMES)

3.1 Superconducting Magnetic Energy Storage (SMES)

- **Reference Rule:** Not specifically defined
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Apart from the requirements applicable to the subcomponents of SMES, the system itself should be tested and certified in accordance with:
 - *IEC/EN 61000 – Electromagnetic Compatibility (EMC) (Note: for radiated emissions)*
- **Summary:** The SMES unit can be regulated under the existing framework through compliance with applicable subcomponent standards and EMC certification requirements. Current rules are considered sufficient to ensure safe operation and compatibility with marine electrical systems.

3.1.1 Heat Exchanger/Chiller

- **Reference Rule:** RINA Rules, Part C, Chapter 1, Section 3 – Boilers and Pressure Vessels
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient
- **Summary:** The Heat Exchanger / Chiller component is covered under the RINA Rules addressing boilers and pressure vessels. No additional regulatory action is necessary, as the existing standards are sufficient to ensure compliance and operational safety within the marine ESS configuration.



Document name:	D5.4 Rules GAP Analysis Report	Page:	5
Dissemination	PU	Version	1.0

3.1.2 Fresh Water Circuit

- **Reference Rule:** RINA Rules, Part C, Chapter 1, Section 10 – *Piping Systems*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient
- **Summary:** The Fresh Water Circuit is covered under existing RINA regulations for piping systems. No additional regulatory actions are required, as current standards adequately address safety, design, and operational requirements within marine ESS applications.

3.1.3 Cryocooler

- **Reference Rule:** RINA Rules, Part C, Chapter 1, Section 3 – *Boilers and Pressure Vessels*
- **Action:** Rules for testing and certification of the component to be developed
- **Process:** Need for new industry standards
- **Process Detail:** The RINA Rules for the testing and certification of the *Cryocooler* are to be developed, taking into account the following standards and guidelines:
 - *RINA Rules, Pt C, Ch 1, Sec 3 – Boilers and Pressure Vessels*
 - *IEC 60204-1:2016 + A1:2021 – Safety of machinery – Electrical equipment of machines – Part 1: General requirements*
 - *IEC 61010-1:2010 + AMD1:2016 – Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements*
 - *EN 55011:2016/A2:2021 – Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement*
 - *IEC 61000-6-2 – Electromagnetic compatibility (EMC)*
- **Summary:** RINA intends to establish new rules for the testing and certification of the Cryocooler component, as existing classification standards do not fully cover its unique thermal, electrical, and safety requirements within superconducting energy storage systems. The development of these rules should integrate the results of risk assessments and align with relevant international electrical and EMC standards to ensure comprehensive safety and performance validation. Harmonized guidelines among classification societies will enable consistent testing, certification, and evaluation procedures, thereby improving safety assurance, reducing regulatory discrepancies, and supporting the wider adoption of superconducting technologies in marine applications.

3.1.4 Cryocooler/Vacuum Pump

- **Reference Rule:** RINA Rules, Part C, Chapter 1, Section 10, Table 35, No. 3 – *Certification, Inspection, and Testing of Piping Systems: Pumps and Compressors*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient to ensure the proper certification, inspection, and testing of pumping and compression systems under the RINA framework.
- **Summary:** The Cryocooler / Vacuum Pump falls within the scope of the RINA Rules for piping systems and mechanical equipment. The current certification and inspection requirements are



Document name:	D5.4 Rules GAP Analysis Report	Page:	6
Dissemination	PU	Version	1.0

adequate to ensure compliance and safety, and no additional regulatory action is required at this stage.

3.1.5 Superconductor

- **Reference Rule:** Not Applicable
- **Action:** Rules for testing and certification of the component to be developed
- **Process:** Need for new industry standards
- **Process Detail:** RINA Rules for the testing and certification of *Super Conductor* components are to be developed, taking into account the following standards and guidelines:
 - *RINA Rules, Pt C, Ch 2, Sec 2, Para.1.1.1*
 - *IEC 61788-21:2015 – Superconductivity – Part 21: Superconducting wires – Test methods for practical superconducting wires – General characteristics and guidance*
 - *IEC 61788-17:2021 – Superconductivity – Part 17: Electronic characteristic measurements – Local critical current density and its distribution in large-area superconducting films*
 - *IEC 61788-22-1:2017 – Superconductivity – Part 22-1: Superconducting electronic devices – Generic specification for sensors and detectors*
 - *IEC 61788-26:2020 – Superconductivity – Part 26: Critical current measurement – DC critical current of RE-Ba-Cu-O composite superconductors*
 - *IEC 61788-22-3:2022 – Superconductivity – Part 22-3: Superconducting strip photon detector – Dark count rate*
 - *IEC 60533:2015 – Electrical and electronic installations in ships – Electromagnetic compatibility (EMC) – Ships with a metallic hull*
- **Summary:** RINA intends to establish new rules for the testing and certification of the Superconductor component, as current classification standards lack specific provisions for evaluating superconducting materials used in marine energy storage systems. The development of these standards should consider existing IEC superconductivity and EMC regulations while integrating outcomes from risk assessments to ensure comprehensive validation of performance, safety, and compatibility within the marine ESS environment. Establishing harmonized standards among classification societies will enable consistent evaluation and certification, enhance cross-recognition between societies, and accelerate the safe and reliable integration of superconducting technologies into maritime applications.

3.2 Control System (SMES)

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2 – Document review*
 - *RINA Rules, Pt C, Ch 2, Sec 8, Para. 3.2 – Functioning test*
 - *RINA Rules, Pt C, Ch 2, Sec 8, Para. 3.3 – High voltage test*
 - *RINA Rules, Pt C, Ch 2, Sec 8, Para. 3.4 – Insulation resistance*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.



Document name:	D5.4 Rules GAP Analysis Report	Page:	7
Dissemination	PU	Version	1.0

- **Summary:** The Control System is fully covered under existing RINA requirements, which include document review, functional testing, and electrical verification procedures. Compliance with these provisions is adequate, and the product is to be Type Approved in accordance with the established RINA framework.

3.2.1 Controller/Communication Unit

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Controller / Communication Unit is subject to established RINA procedures covering document review, inspection, and type testing. The current regulatory framework adequately addresses verification and certification requirements, and the component is to be Type Approved in compliance with existing RINA standards.

3.2.2 Pressure Transmitter

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Pressure Transmitter is covered under RINA’s established requirements for document review, testing, and certification. Current procedures for type and routine tests ensure compliance with classification standards, and the component is to be Type Approved under the existing regulatory framework.

3.2.3 Temperature Transmitter

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework



Document name:	D5.4 Rules GAP Analysis Report	Page:	8
Dissemination	PU	Version	1.0

- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Temperature Transmitter is covered by RINA’s existing rules governing documentation, inspection, and electrical testing. The regulatory provisions for type and routine testing are sufficient to ensure compliance, and the component is to be Type Approved under the current RINA certification framework.

3.3 Electrical System

3.3.1 Power Conditioning System

- **Reference Rule:**
 - **For Semiconductor Converter part:**
 - *RINA Rules, Pt C, Ch 2, Sec 1, Para. 2.1 – Document review*
 - *RINA Rules, Pt C, Ch 2, Sec 6, Para. 2.2 – Document review and visual inspection*
 - *RINA Rules, Pt C, Ch 2, Sec 6, Para. 2.2 – Light load function tests*
 - *RINA Rules, Pt C, Ch 2, Sec 6, Para. 2.2 – Insulation test*
 - *RINA Rules, Pt C, Ch 2, Sec 6, Para. 2.2 – Protection of the converters in case of failure of forced cooling system*
 - **For Controller part:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Power Conditioning System, encompassing both the semiconductor converter and controller subsystems, is adequately regulated under existing RINA provisions. The current framework covers documentation, inspection, testing, and safety measures for thermal and electrical performance, ensuring compliance. The system is to be Type Approved in accordance with established procedures.

3.3.2 Power Conditioning System

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Thermal Sensors are addressed under RINA’s established framework for documentation, testing, and inspection. The applicable rules sufficiently cover functional, electrical,



Document name:	D5.4 Rules GAP Analysis Report	Page:	9
Dissemination	PU	Version	1.0

and safety verification. The component is to be Type Approved according to current regulatory provisions.

3.3.3 Battery

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 2, App 2 – Battery Powered Ships*
 - *RINA Rules, NCC92 – Rules for the Type Approval Certification of Lithium Battery Systems*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Battery system is regulated under existing RINA provisions specific to lithium battery systems and battery-powered vessels. These rules comprehensively cover design, safety, installation, and certification processes. The current framework is adequate, and the component is to be Type Approved in accordance with RINA NCC92 and related standards.

4. Super Capacitor System

4.1 Super Capacitor

- **Reference Rule:** Not Applicable
- **Action:** Rules for testing and certification of the component to be developed
- **Process:** The need for new industry standards
- **Process Detail:**

RINA Rules for the testing and certification of *Super Capacitor* components are to be developed, taking into account the following standards and guidelines:

 - *American Bureau of Shipping (ABS) – Guide for Use of Supercapacitors in the Marine and Offshore Industries (2022)*
 - *IEC 62391-1 – Fixed electric double-layer capacitors for use in electric and electronic equipment – Part 1: Generic specification*
 - *IEC 62391-2 – Fixed electric double-layer capacitors for use in electronic equipment – Part 2: Sectional specification – Electric double-layer capacitors for power application*
 - *IEC 62391-2-1 – Fixed electric double-layer capacitors for use in electronic equipment – Part 2-1: Blank detail specification – Electric double-layer capacitors for power application – Assessment level EZ*
 - *IEC 62576 – Electric double-layer capacitors for use in hybrid electric vehicles – Test methods for electrical characteristics*
 - *IEC 60812 – Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*
- **Summary:** RINA intends to establish new rules for the testing and certification of Super Capacitor components, as existing marine standards only partially address their unique electrical behavior, rapid charge–discharge cycles, and safety characteristics. These new rules will draw from international IEC and ABS standards to ensure proper testing, reliability, and safety, while incorporating findings from risk assessments to guarantee robust evaluation and performance



Document name:	D5.4 Rules GAP Analysis Report	Page:	10
Dissemination	PU	Version	1.0

standards suitable for marine ESS applications. Harmonizing these standards among classification societies will ensure consistent testing, reliability assessment, and installation criteria, thereby enhancing safety assurance, streamlining certification, and enabling the broader adoption of supercapacitor technologies in marine energy systems.

4.2 Control System (Supercapacitor)

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2 – Document review*
 - *RINA Rules, Pt C, Ch 2, Sec 8, Para. 3.2 – Functioning test*
 - *RINA Rules, Pt C, Ch 2, Sec 8, Para. 3.3 – High voltage test*
 - *RINA Rules, Pt C, Ch 2, Sec 8, Para. 3.4 – Insulation resistance*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Control System is fully covered under existing RINA requirements, which include document review, functional testing, and electrical verification procedures. Compliance with these provisions is adequate, and the product is to be Type Approved in accordance with the established RINA framework.

4.2.1 Controller/Communication Unit

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Controller / Communication Unit is subject to established RINA procedures covering document review, inspection, and type testing. The current regulatory framework adequately addresses verification and certification requirements, and the component is to be Type Approved in compliance with existing RINA standards.

4.2.2 SoH/SoC Transmitter

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework



Document name:	D5.4 Rules GAP Analysis Report	Page:	11
Dissemination	PU	Version	1.0

- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Pressure Transmitter is covered under RINA’s established requirements for document review, testing, and certification. Current procedures for type and routine tests ensure compliance with classification standards, and the component is to be Type Approved under the existing regulatory framework.

4.2.3 Temperature Transmitter

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Temperature Transmitter is covered by RINA’s existing rules governing documentation, inspection, and electrical testing. The regulatory provisions for type and routine testing are sufficient to ensure compliance, and the component is to be Type Approved under the current RINA certification framework.

4.3 Electrical System

4.3.1 Voltage Measuring Equipment

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Temperature Transmitter is covered by RINA’s existing rules governing documentation, inspection, and electrical testing. The regulatory provisions for type and routine testing are sufficient to ensure compliance, and the component is to be Type Approved under the current RINA certification framework.

4.3.2 Temperature Transmitter

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*



Document name:	D5.4 Rules GAP Analysis Report	Page:	12
Dissemination	PU	Version	1.0

- *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
- *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Temperature Transmitter is covered by RINA’s existing rules governing documentation, inspection, and electrical testing. The regulatory provisions for type and routine testing are sufficient to ensure compliance, and the component is to be Type Approved under the current RINA certification framework.

4.3.3 Ground Fault Detection Equipment

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Temperature Transmitter is covered by RINA’s existing rules governing documentation, inspection, and electrical testing. The regulatory provisions for type and routine testing are sufficient to ensure compliance, and the component is to be Type Approved under the current RINA certification framework.

4.3.4 Switchgear

- **Reference Rule:** *RINA Rules, Pt C, Ch 2, Sec 10, Para. 1 – Type tests*
- **Action:** Not Applicable
- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Switchgear component is covered under RINA’s existing rules for type testing of electrical equipment. The current regulatory framework provides adequate procedures to verify design integrity, safety, and operational reliability. The component is to be Type Approved following the established RINA certification process.

4.3.5 Master Controller

- **Reference Rule:**
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.2 – Hardware Type Approval*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 3.2 – Visual inspection and Hardware Acceptance Tests*
 - *RINA Rules, Pt C, Ch 3, Sec 8, Para. 2.1 – Type tests*
 - *RINA Rules, Pt C, Ch 3, Sec 1, Para. 2.4 – Document review*
- **Action:** Not Applicable



Document name:	D5.4 Rules GAP Analysis Report	Page:	13
Dissemination	PU	Version	1.0

- **Process:** Possible to use the current regulatory framework
- **Process Detail:** Existing rules are considered sufficient. Product to be Type Approved.
- **Summary:** The Controller / Communication Unit is subject to established RINA procedures covering document review, inspection, and type testing. The current regulatory framework adequately addresses verification and certification requirements, and the component is to be Type Approved in compliance with existing RINA standards.

5. Results and Discussion

The results of the analysis provide a comprehensive overview of the regulatory landscape applicable to Energy Storage Systems (ESS), with a particular focus on supercapacitor-based technologies intended for marine installations. The structured evaluation of each system, subsystem, and component allows for the identification of existing compliance frameworks, regulatory gaps, and potential areas for innovation qualification.

5.1 Overview of Regulatory Context

The regulatory framework governing ESS installations on board ships is primarily defined by:

- The International Maritime Organization (IMO), through conventions such as SOLAS, MARPOL, and the IGC Code.
- The International Association of Classification Societies (IACS), via Unified Requirements (UR) and procedural guidelines.
- Classification societies (e.g., DNV, ABS, RINA, LR, BV), which provide specific rules addressing battery and hybrid energy systems.

However, it was observed that supercapacitors — though sharing some safety principles with electrochemical batteries — do not yet have a fully dedicated regulatory framework. Current references are limited to general electrical safety standards, explosion protection requirements, and performance testing guidelines.

The regulatory context for **Superconducting Magnetic Energy Storage (SMES)** systems remains largely undefined within current maritime standards. While some subcomponents can be assessed under existing electrical and machinery rules, the overall SMES system introduces new challenges related to cryogenic operation, magnetic field safety, and energy discharge control. Existing IMO and IACS frameworks provide no specific guidance for these aspects, leading to uncertainty in classification and approval processes. Therefore, harmonized assessment criteria and new testing guidelines are needed to ensure safe and consistent certification of SMES technologies across classification societies.

5.2 Findings from the System Analysis

Each ESS component was assessed for its regulatory correspondence. Key findings include:

- **Existing Coverage:** Certain components, such as control systems, converters, and cooling systems, are covered under general electrical and machinery rules (e.g., IEC 60092 series, ISO 15550, or IACS E10). These rules provide sufficient guidance for standard equipment where established certification procedures already exist.



Document name:	D5.4 Rules GAP Analysis Report	Page:	14
Dissemination	PU	Version	1.0

- Partial Coverage:** For Superconducting Magnetic Energy Storage (SMES) systems, while subcomponents such as control units, cryocoolers, and electrical interfaces can be certified under existing standards, the overall system lacks a dedicated regulatory framework. Critical aspects including magnetic field containment, cryogenic safety, and quench protection are not explicitly addressed by current maritime regulations. As a result, classification relies partly on industrial or laboratory standards not tailored to marine environments. Harmonized rules and validation procedures are needed to ensure safe, consistent, and efficient certification of SMES technologies across classification societies. Similarly, for supercapacitor modules, energy management systems, and protection devices, regulatory coverage is partial — often referring to battery-related or general electrical standards that do not address the unique behaviour of double-layer capacitors (e.g., charge/discharge dynamics, thermal runaway resilience, or aging behaviour).
- Gaps and Barriers:** Specific areas were identified where the current rules do not explicitly cover ESS hybridization, voltage equalization circuits, and long-term durability testing under marine environmental conditions (humidity, vibration, temperature cycling).

5.3 Identified Regulatory Needs

The following regulatory needs emerged as priorities:

- New or updated standards addressing SMES and supercapacitor safety, testing, and installation onboard.**
 For Superconducting Magnetic Energy Storage (SMES) systems, dedicated standards are needed to address cryogenic operation, magnetic field containment, and quench protection, which are not covered by existing maritime regulations. For supercapacitors, new rules should define testing methods, performance verification, and integration criteria specific to their rapid charge–discharge behaviour and electrical characteristics. Harmonized standards among classification societies will ensure consistent assessment, safety validation, and certification for both SMES and supercapacitor technologies.
- Technology Qualification Process (TQP) to validate the reliability and operational limits of novel ESS configurations before commercial adoption.**
 This process should be applied to new technologies such as SMES and hybrid ESS to verify safety and performance under realistic marine operating conditions, enabling early identification of potential design or operational risks.
- Alternative Design / Risk Assessment procedures to justify deviations from prescriptive rules using equivalent safety principles.**
 The adoption of risk-based approaches will be essential for emerging technologies like SMES and supercapacitors, where prescriptive rules are not yet established. These procedures will allow developers and classification societies to demonstrate compliance through equivalent levels of safety and reliability.
- Harmonization of classification society rules, ensuring consistent treatment of hybrid systems combining batteries, supercapacitors, and SMES technologies.**
 Aligning certification approaches across RINA, DNV, ABS, and other societies will reduce regulatory



Document name:	D5.4 Rules GAP Analysis Report	Page:	15
Dissemination	PU	Version	1.0

discrepancies, streamline approval processes, and promote mutual recognition of testing and validation outcomes.

- **Development of performance-based standards, integrating functional safety metrics and real-time monitoring requirements (e.g., State of Health tracking).**

Such standards should include monitoring parameters specific to advanced ESS systems, including magnetic field stability and cryogenic temperature control for SMES, alongside SoC/SoH tracking for electrochemical and hybrid systems.

5.4 Implications for TRL Advancement

Addressing the regulatory gaps identified in this analysis is fundamental to achieving the target TRL levels required for deployment of advanced ESS solutions in the marine sector. By clarifying qualification pathways and defining harmonized standards, ship designers and technology developers can reduce uncertainty, streamline certification efforts, and ensure compliance with safety and reliability requirements established by international maritime authorities.

For **Superconducting Magnetic Energy Storage (SMES)** systems, the establishment of dedicated rules covering cryogenic operation, magnetic field safety, and quench protection will be essential to progress beyond experimental validation. Clear qualification and testing frameworks will enable SMES technologies to demonstrate compliance with maritime safety principles and accelerate their transition to higher TRL stages. Similarly, harmonized standards for **supercapacitor-based systems** will strengthen confidence in performance and safety, ensuring both technologies can be integrated effectively into next-generation marine energy storage architectures.

6. Conclusions and Recommendations

The analysis presented in this report consolidates the findings from previous technical and regulatory activities (T2.3, WP3, and WP4), providing a structured overview of the current regulatory framework applicable to **advanced Energy Storage Systems (ESS)**—with particular emphasis on **Superconducting Magnetic Energy Storage (SMES)** and **supercapacitor technologies**—for marine applications.

The work has demonstrated that, while existing maritime rules and international standards offer a solid foundation for the integration of conventional battery systems, both SMES and supercapacitor-based configurations remain only partially addressed within the current framework. This results in regulatory uncertainty for technology developers, ship designers, and operators seeking to adopt these emerging solutions at higher Technology Readiness Levels (TRLs).

The analysis further highlights the need for harmonized standards, technology qualification processes, and coordinated efforts among classification societies to ensure that SMES and supercapacitor systems can be safely and efficiently implemented in future marine power architectures.

6.1 Key Conclusions

- **Regulatory Coverage Gaps:** Current standards (e.g., IEC 60092, IACS E10, and classification society rules for battery installations) provide partial coverage but do not fully encompass the unique properties of **supercapacitors** and **Superconducting Magnetic Energy Storage (SMES)** systems.



Document name:	D5.4 Rules GAP Analysis Report	Page:	16
Dissemination	PU	Version	1.0

SMES introduces additional challenges such as cryogenic operation, magnetic field containment, and quench protection, which remain outside existing maritime frameworks.

- **Need for Technology Qualification:** To ensure safe and reliable integration, **Technology Qualification Processes (TQP)** should be applied to verify the performance and failure modes of novel ESS technologies—particularly SMES and hybrid configurations—under realistic marine operating conditions.
- **Alternative Design and Risk-Based Approaches:** In the absence of prescriptive standards, the use of **Alternative Design (SOLAS Regulation II-1/55)** and risk assessment methodologies is essential to demonstrate equivalent levels of safety and compliance for innovative technologies such as SMES and supercapacitors.
- **Harmonization Among Classification Societies:** Differences in interpretation and requirements between classification societies highlight the need for a **harmonized approach** that covers both SMES and supercapacitor technologies, particularly regarding testing procedures, certification criteria, and installation guidelines.
- **Pathway to TRL Advancement:** Filling regulatory gaps and establishing qualification protocols for both SMES and supercapacitor systems will directly contribute to raising their TRL levels, facilitating their transition from prototype to operational stages within the maritime domain.

6.2 Recommendations

To support the safe and efficient deployment of **SMES, supercapacitors**, and hybrid ESS solutions onboard, the following actions are recommended:

- **Development of dedicated standards** for SMES and supercapacitors, addressing design, testing, and onboard integration criteria specific to marine environments.
- **Implementation of Technology Qualification Frameworks** to validate the operational safety and reliability of SMES systems, particularly focusing on cryogenic containment, quench protection, and electromagnetic safety.
- **Promotion of collaborative regulatory initiatives** within IMO and IACS to standardize testing and acceptance procedures for new energy storage technologies, ensuring consistent treatment across classification societies.
- **Inclusion of system monitoring requirements**, such as State of Charge (SoC), State of Health (SoH), and temperature or magnetic field stability monitoring, in future updates of marine electrical standards.
- **Encouragement of pilot and demonstration projects** involving SMES and supercapacitor systems to validate hybrid ESS configurations under real operating conditions and provide data for future regulatory refinement.



Document name:	D5.4 Rules GAP Analysis Report	Page:	17
Dissemination	PU	Version	1.0

6.3 Final Remarks

The evolution of marine energy storage technologies—encompassing **Superconducting Magnetic Energy Storage (SMES)** systems, **supercapacitors**, and hybrid configurations—is advancing rapidly, demanding parallel progress in the regulatory landscape. Current maritime rules provide a strong foundation for traditional battery technologies but must expand to address the distinctive operational principles and safety considerations of SMES, such as cryogenic operation, magnetic field containment, and quench protection.

By proactively developing harmonized standards and qualification frameworks across classification societies and international bodies, stakeholders can ensure consistent safety assurance and facilitate interoperability of next-generation ESS technologies. The integration of SMES alongside supercapacitor and battery systems offers significant potential for improving vessel efficiency, supporting electrification, and advancing maritime decarbonization. Strengthening the regulatory framework for these technologies will accelerate their maturity, build confidence among ship designers and operators, and enable their safe, widespread adoption in the global maritime sector.



Document name:	D5.4 Rules GAP Analysis Report	Page:	18
Dissemination	PU	Version	1.0