



----- POWER STORAGE IN D OCEAN -----

## **D6.1. Regulation: State of the Art and Gaps (M24)**



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## Author List

| Organization | Name                    | Contact Information          |
|--------------|-------------------------|------------------------------|
| ABS          | Demetres Armanes        | DArmanes@eagle.org           |
| ABS          | Ioannis Dermentzoglou   | idermentzoglou@eagle.org     |
| ABS          | Jevon Chan              | JevChan@eagle.org            |
| CTN          | Fernando de Miquel      | fernandodemiguel@ctnaval.com |
| TPH          | Maria Dolores Fernández | mdfernandez@tphispania.com   |

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## 1 INTRODUCTION

For over 60 years, the dominant form of ship propulsion consisted of diesel engines delivering thrust directly to the water via a shaft and propeller. As technology evolves and regulatory complexities increase, the marine industry is faced with the reality of both complying with environmental requirements and meeting operational demands. To deal with these challenges, owners and operators are turning to more non-conventional sources of energy to power and propel vessels. One alternative to the conventional mechanical propulsion arrangement is an electric propulsion system, which allows for the propulsion requirements of the vessel to be provided by an electric distribution system, driving electric propulsion motors or thrusters and optimizing its efficiency by means of Energy Storage Systems. Hybrid and all-electric power systems offer the opportunity to improve safety, reliability, operational efficiency, fuel consumption, and environmental footprint. They may extend the equipment maintenance intervals when compared to conventional mechanical power systems, supporting therefore Autonomous operations.

The operating environment, typical in the marine and offshore industries, may differ however from those considered when an Energy Storage System was originally designed and so necessitates a review of the environmental and operational aspects prior to adoption. The Poseidon Project developed this document to provide reference to the regulatory state of the art concerning Energy Storage Systems and regulatory gaps, specific to two new energy storage technologies for the marine environment, the Kinetic Energy Storage and the Superconducting Magnetic Energy Storage. It is envisioned that this document will clarify the overall regulatory compliance ecosystem for Energy Storage Systems onboard marine vessels and facilitate development of specifications for the installation and safe operation of novel Energy Storage Systems in various marine and offshore applications.

## 2 TERMINOLOGY

**All-Electric Power System:** An electric power system made up of one or a combination of energy storage system (ESS) and/or energy transformation device (ETD), including other non-conventional sources of electric power (e.g., solar and wind-electric power). An internal combustion engine-generator set may be used as an emergency source of electric power only.

**All-Electric Vessel:** A vessel fitted with means to operate on all-electric power systems.

**Alternative Designs/Arrangements:** Designs or arrangements that are not addressed by existing Class Rules, international regulations and standards but may meet the intent of these requirements. These designs/arrangements do not incorporate **new technologies** or **novel concepts**.

**Classification society (Class):** Is a non-governmental organization that establishes and maintains technical standards for the construction and operation of ships and offshore structures. Classification societies certify that the construction of a vessel complies with relevant standards and carry out regular surveys in service to ensure continuing compliance with the standards. Currently, more than 50 organizations describe their activities as including marine classification, twelve of which are members of the International Association of Classification Societies. A classification certificate issued by a classification society recognized by the proposed ship register is required for a ship's owner to be able to register the ship and to obtain marine insurance on the ship and may be required to be produced before a ship's entry into some ports or waterways and may be of interest to charterers and potential buyers.

**Conventional Electric Power Generation:** Internal combustion engine-generator sets, and/or shaft generators (for the purpose of the use of this document).

**Conventional Technologies:** Technologies that can be qualified by existing Rules and standards.

**Conventional Designs/Arrangements:** Designs or arrangements for which Classification Societies have detailed prescriptive requirements. Known applications of proven technologies.

**Energy Storage System (ESS):** A system composed of an energy storage transformation device, a converter (if necessary), controls, and ancillary components and equipment. It is capable of delivering/capturing electrical/mechanical energy to/from a load at the required voltage and rate (power) and can accommodate the load rate of change of power.

**Existing Application:** A design or process that has been accepted previously by a Classification Society for which there is at least one complete 5-year survey cycle of proven experience in the proposed environment.

**Hybrid Electric Power System:** A system combining internal combustion engine driven generators and/or shaft generator/motor driven by main engine with an ESS consisting of batteries, supercapacitors, fuel cells, KESS, SMES, and/or other technologies to form the power generation and propulsion system of the vessel.

**International Maritime Organization (IMO):** Is a specialized agency of the United Nations responsible for regulating maritime transport.

**International Association of Classification Societies (IACS):** Is a technically based non-governmental organization that currently consists of twelve-member marine classification societies. More than 90% of the world's cargo-carrying ships' tonnage is covered by the classification standards set by member societies of IACS. Marine classification is a system for promoting the safety of life, property and the environment primarily through the establishment and verification of compliance with technical and engineering standards for the design, construction and life-cycle maintenance of ships, offshore units and other marine-related facilities. These standards are contained in rules established by each Society. IACS provides a forum within which the member societies can discuss, research, and adopt technical criteria that enhance maritime safety and environmental protection.

**Integrated Electric Power System (IEPS):** A system where a set of generators supply power to the vessel service loads as well as the propulsion loads. Sometimes it is also termed an integrated electric propulsion system.

**Kinetic Energy Storage (KES) or Flywheel energy storage (FES)** works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy. When energy is extracted from the system, the flywheel's rotational speed is reduced as a consequence of the principle of conservation of energy; adding energy to the system correspondingly results in an increase in the speed of the flywheel.

**New Technology:** Any design (material, component, equipment or system) or process which does not have prior in-service experience, and/or any Classification Rules, Statutory Regulations or industry standards that are directly applicable. Use of technology that has not been accepted previously or with limited (less than one complete 5-year survey cycle) or no proven experience in the proposed environment. Previous acceptance can be by any classification society. A shorter period may be accepted if the technology is installed on multiple vessels and subject to an equivalent Survey.

**Novel Concept:** A marine vessel or offshore unit that with the inclusion of new technologies, the service scope, functional capability, and/or risk profile is appreciably altered.

**Peak Shaving:** Any of the various strategies to reduce main electric power generation during certain periods, and to store energy to supply the demand of electricity during other operating times. The goal is to store energy during periods of low power demand and release energy during high peaks of power demand (typically by the ESS).

**Power Backup (PBU) Mode:** The operating mode where the energy storage system (ESS) is connected to the ship's electrical main or distribution system and is able to reliably provide power for a minimum period. This is also known as the spinning reserve mode. Operating a redundant diesel generator as spinning reserve provides power in a failure condition. Running an extra engine creates a less efficient, lower load condition with higher emissions. Providing this spinning reserve via stored energy, rather than an additional diesel generator, allows the electrical system to operate with fewer generators at higher load. The stored energy (lithium-ion batteries) provides power in the event of a loss of generator until a standby generator can be started and connected to the power system.

**Prescriptive Requirements:** Detailed criteria that specify how the requirements are to be met.

**Recognized Standard:** Published national or international standards acceptable to ABS. Examples include but are not limited to the American Society of Mechanical Engineers (ASME), American Society of Testing and Materials (ASTM), Department of Transportation (DOT), Japanese Industrial Standard (JIS), German Design Standard (DIN), British Standard Code of Practice (BSI), International Standard Organization (ISO), American Petroleum Institute (API), which are recognized by Class, as being acceptable standards for a specific purpose or service. Each standard is to be used independently and in a consistent manner.

**Supplemental Source of Electric Power:** Electric power generation or capacity supplied by an alternative source of power that is in addition to the vessel's main or emergency electric power generation (e.g., Solar, Wind, ESS, etc.). Supplemental electrical power is not to be included in the determination of the required number of generators or capacity for the vessel.

**Superconducting magnetic energy storage (SMES)** systems store energy in the magnetic field created by the flow of direct current in a superconducting coil that has been cryogenically cooled to a temperature below its superconducting critical temperature.

**Transitional Source of Power:** An emergency source of power usually produced by diesel generators, gas turbine generators or steam turbine generators but can also be supplied by alternative sources such as electric batteries, super-capacitors, and fuel cells, specifically for use when transferring from one source of power to another, and intended to be provided for a specified, finite period of time.

### 3 REGULATORY COMPLIANCE GUIDANCE FOR MARINE ENERGY STORAGE SYSTEMS

Energy Storage Systems (ESS) for Marine and Offshore applications can broadly include the following components and their various combinations:

- 1) Batteries
- 2) Supercapacitors
- 3) Kinetic Energy Storage Systems (KESS), (for example Flywheels)
- 4) Superconducting Magnetic Energy Storage (SMES)

Although batteries and supercapacitors can be considered as **Conventional Technologies** due to existing Class Rules [1, 2], their technology is continuously evolving with respect to materials and design. **Alternative arrangements** or new batteries and supercapacitor technologies may be considered by Class, provided it can be shown, through either satisfactory service experience or a systematic analysis based on sound engineering principle, to meet the overall safety standards set by existing Class Rules.

KESS and SMES can be considered as **New Technologies**, at their individual components level, since they do not have prior in-service experience, and/or any Class Rules, Statutory Regulations or marine industry standards that are directly acceptable by Class. A full overview of such technologies is outlined in Appendices 1 and 2.

Recognizing the rapid adoption of **New Technologies** onboard modern vessels, International Maritime Organization (IMO) Goal Based Standards (GBS) have been incorporated into the **prescriptive requirements** (Rules) of ABS [3]. Similar approaches could be identified by other Classification Societies for their existing Class requirements. Existing Class requirements often prescribe a specific technological solution. Since Goal Based Standards do not dictate specific technical solutions, they are better suited to accommodate future technological developments.

With the introduction of Goal Based Standards by IMO, there are now two paths for compliance with the ABS Class Rules:

- i) The prescriptive ABS requirements remain valid. A vessel or a system is considered to comply with the Goals and Functional requirements within the scope of class, when compliance with the applicable prescriptive requirements has been demonstrated. This path is applicable to Batteries and Supercapacitors, as they are considered **Conventional Technologies**, in most cases.
- ii) **Alternative Designs/Arrangements, New Technologies, and Novel Concepts** may comply with the Goal Based Standards in accordance with the procedure outlined in Figure 1 below. The New Technology path is applicable to KESS and SMES.

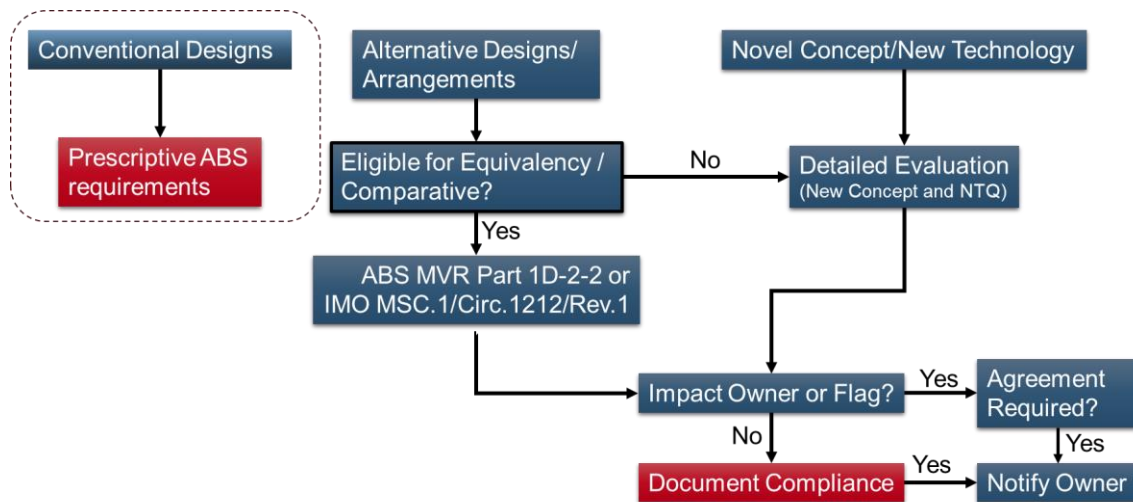


Figure 1 - Procedure for Applying Goal Based Standards

**Alternative Designs/Arrangements, New Technologies, and Novel Concepts** that follow other recognized approaches may be accepted by Class [4, 5].

It is noted that where the ABS Class Rules require compliance with “recognized standards” and the standard has a proven record in marine and offshore applications, the standard may be accepted without going through the equivalency process.

When there are no specific standards in the ABS Rules applicable to the proposed alternative, it may be evaluated based on recognized industry standards. It is the responsibility of the submitter to justify the suitability of industry standards and practices. The evaluation is to consider use in a marine environment (i.e. dynamic loads due to vessel motions, vibration, exposure to corrosive saltwater environment, etc.)

Where ABS Class Rules do not address a specific design, arrangement, or equipment, IACS Member’s Rules may be considered so long as the proposed alternative is not less effective than permitted by the ABS Rules. Individual Rule cites should not be applied without consideration of the overall requirements applicable to equipment, systems, or designs. As will be clarified in the following sections, all applicable IACS Unified Requirements have been incorporated into ABS Rules for Energy Storage Systems.

Industry Standards may also be accepted for equipment, components and systems which have specific requirements in the Rules.

The following sections provide the ABS Goal Based Standards (GBS) design exploration trajectory, considering the current international regulatory landscape of marine Energy Storage Systems, as presented in Figure 2:

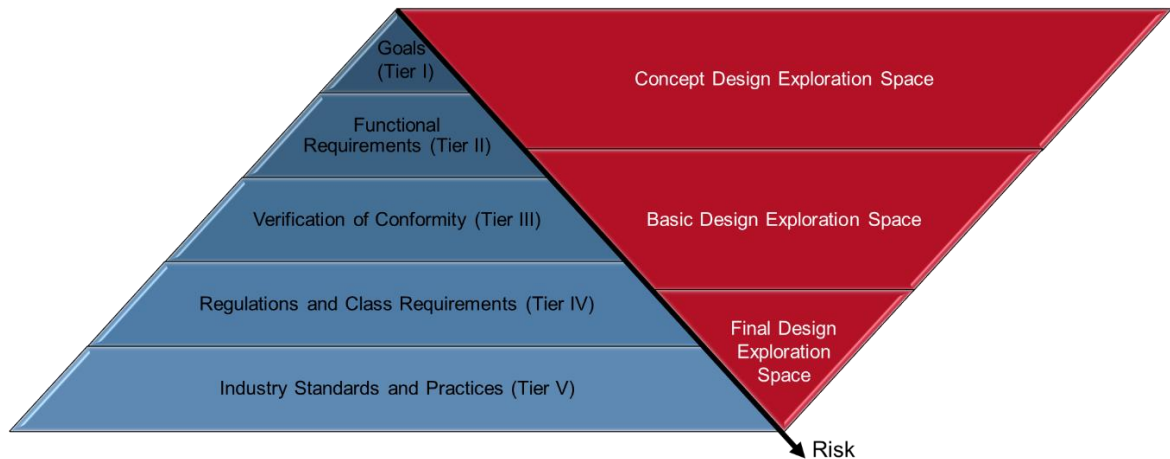


Figure 2 - Goal Based Standards design exploration trajectory

Tier I Goals “are high-level objectives to be met. A goal should address the issue(s) of concern and reflect the required level of safety.” Applicable Tier I Goals, should be identified very early at the design exploration stage, to clarify the responsibilities that the design needs to address without extending its scope to the scope of other systems onboard [6].

Tier II Functional Requirements “provide the criteria to be complied with in order to meet the goals.” Applicable, Tier II Functional Requirements should be defined as a result of applicable Goals. Functional Requirements better clarify the boundaries and interfaces of the design with other systems onboard [6].

Tier III Verification of Conformity “provides the instruments necessary for demonstrating and verifying that the associated rules and regulations for ships conform to the goals and functional requirements.” [6]. In this document, a clear correlation between Functional Requirements and ABS Rules requirements was provided, to assist with the regulatory compliance of detailed design decisions of ESS based on KESS and SMESS.

Tier IV Regulation and Class Requirements provide the detailed criteria that specify **how** the requirements are to be met.

Finally, Tier V Industry Standards and Practices provide detailed test criteria and conditions that need to be considered in addition to Tier IV requirements.

Figure 3 below illustrates the number of requirements identified in this document (all GBS Tiers), for six major regulatory levels of Marine Energy Storage Systems:

- 1) IMO regulatory level
- 2) IACS regulatory level
- 3) Portion of a Vessel regulatory level
- 4) ESS Marine Arrangements regulatory level
- 5) ESS Marine Functions regulatory level
- 6) ESS individual equipment or component level

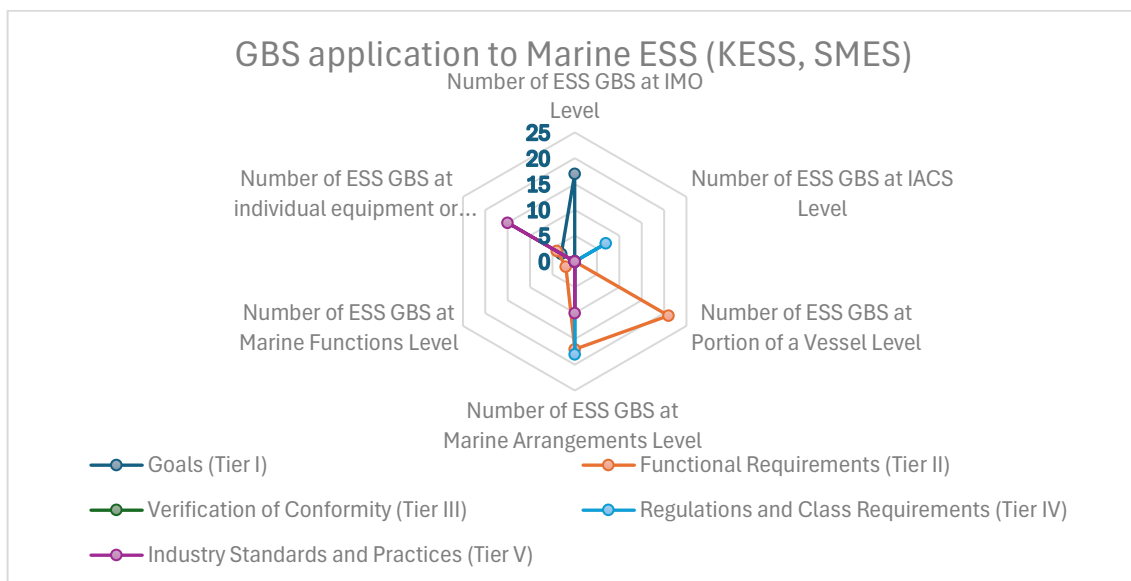


Figure 3 – Goal Based Standards of Marine ESS at various regulatory levels,

When "Class" is shown in the 5th column of the below tables, it means that this item is generally covered by mandatory requirements within the Class Rules. When "Statutory" is indicated, this item is covered by IMO or ILO requirements for a typical trading cargo vessel. When "Other" is shown, the item is outside the scope of Class and International requirements but may be covered by other regulatory bodies. Finally, when "No" is shown in the ESS Regulatory Gap column, it means that there are clear requirements for that level of the ESS design, alternatively the gap is identified.

### 3.1 GBS APPLICATION TO IMO INTERNATIONAL CONVENTIONS OR CODES, RELEVANT TO ENERGY STORAGE SYSTEMS

It is noted that when a goal-based approach is used as the basis for compliance with Administration (Flag State) and Coastal State requirements, the Administration is to be contacted, either directly or through a classification society acting as a Recognized Organization (RO), to obtain an understanding as to the extent to which the Administration is prepared to consider alternatives to international conventions/codes requirements listed in the below Tables.

Table 1 - GBS of ESS at IMO Level

| PROPULSION, MANEUVERING, STATION KEEPING – The ESS shall be designed, constructed, operated, and maintained to... |        |                                                                                                                                                    |                           |                        |            |                    |
|-------------------------------------------------------------------------------------------------------------------|--------|----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|------------------------|------------|--------------------|
| TOPIC                                                                                                             | Number | Goal (Tier I)                                                                                                                                      | ESS Onboard Arrangement * | Class/Statutory/ Other | Reference  | ESS Regulatory Gap |
| PROP                                                                                                              | 1      | provide sufficient thrust/power to move or maneuver the vessel when required.                                                                      | HEP, HPHS                 | Class/Statutory        | SOLAS II-1 | No                 |
| PROP                                                                                                              | 7      | be provided with means to reduce the risk of <i>impending or imminent slowdown or shutdown</i> . (SOLAS II-1 Reg 31-6.1 or SOLAS II-1 Reg 31-2.10) | HEP, HPHS                 | Class/Statutory        | SOLAS II-1 | No                 |

\*NOTE: Please refer to section GBS APPLICATION TO ESS MARINE ARRANGEMENTS

**POWER GENERATION & DISTRIBUTION** – The ESS shall be designed, constructed, operated, and maintained to...

| TOPIC | Number | Goal (Tier I)                                                                                                                                             | ESS Arrangements | Class/Statutory/Other | Reference  | ESS Regulatory Gap |
|-------|--------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------|------------|--------------------|
| POW   | 1      | Provide safe and reliable storage and supply of fuel/energy/power.                                                                                        | All              | Class/Statutory       | SOLAS II-1 | No                 |
| POW   | 2      | Provide power to enable the machinery/equipment/electrical installation to perform its required functions necessary for the safe operation of the vessel. | All              | Class/Statutory       | SOLAS II-1 | No                 |
| POW   | 6      | Have fail-safe features that prevent progressive failure in the event of failure of any single component                                                  | All              | Class/Statutory       | SOLAS II-1 | No                 |
| POW   | 8      | Maintain Continuity of Power Supply.                                                                                                                      | All              | Class/Statutory       | SOLAS II-1 | No                 |

**FIRE SAFETY** – The ESS shall be designed, constructed, operated, and maintained to...

| TOPIC | Number | Goal (Tier I)                                                                        | ESS Arrangements | Class/Statutory/Other | Reference  | ESS Regulatory Gap |
|-------|--------|--------------------------------------------------------------------------------------|------------------|-----------------------|------------|--------------------|
| FIR   | 1      | Prevent the occurrence of fire and explosion                                         | All              | Class/Statutory       | SOLAS II-1 | No                 |
| FIR   | 2      | Reduce the risk to life caused by fire.                                              | All              | Class/Statutory       | SOLAS II-1 | No                 |
| FIR   | 3      | Reduce the risk of damage caused by fire to the ship, its cargo and the environment. | All              | Class/Statutory       | SOLAS II-1 | No                 |

**EER - ESCAPE, EVACUATION, RESCUE** – The ESS shall be designed, constructed, operated, and maintained to...

| TOPIC | Number | Goal (Tier I)                                                                                                                                | ESS Arrangements | Class/Statutory/Other | Reference  | ESS Regulatory Gap |
|-------|--------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------|------------|--------------------|
| SAFE  | 1-1    | Minimize danger to persons on board, the vessel, and surrounding equipment/installations from hazards associated with machinery and systems. | All              | Class/Statutory       | SOLAS II-1 | No                 |
| SAFE  | 2      | Provide suitable and readily available illumination.                                                                                         | All              | Class/Statutory       | SOLAS II-1 | No                 |

**SAFETY MANAGEMENT** – The ESS shall implement a safety and environmental management system to....

| TOPIC | Number | Goal (Tier I)                                                                                                    | ESS Arrangements | Class/Statutory/Other | Reference  | ESS Regulatory Gap |
|-------|--------|------------------------------------------------------------------------------------------------------------------|------------------|-----------------------|------------|--------------------|
| MGMT  | 5-1    | Facilitate safe access, ease of inspection, survey, and maintenance of vessel, machinery, and electrical systems | All              | Class/Statutory       | SOLAS II-1 | No                 |

**AUTOMATION (CONTROL, MONITORING and SAFETY SYSTEMS)** – The ESS shall be designed, constructed, operated, and maintained to...

| TOPIC | Number | Goal (Tier I)                                                                                                                                                              | ESS Arrangements | Class/Statutory/Other | Reference  | ESS Regulatory Gap |
|-------|--------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------|------------|--------------------|
| AUTO  | 1      | Perform its functions as intended and in a safe manner                                                                                                                     | All              | Class/Statutory       | SOLAS II-1 | No                 |
| AUTO  | 2      | Indicate the system operational status and alert operators of any essential machinery/systems deviate from its defined design/operating conditions or intended performance | All              | Class/Statutory       | SOLAS II-1 | No                 |
| AUTO  | 3      | Have an alternative means to enable safe operation in the event of an emergency or                                                                                         | All              | Class/Statutory       | SOLAS II-1 | No                 |

|                           |   |                                                                                                                                                                                                                        |     |                 |            |    |
|---------------------------|---|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----------------|------------|----|
| failure of remote control |   |                                                                                                                                                                                                                        |     |                 |            |    |
| AUTO                      | 5 | Be provided with a safety system that automatically leads machinery being controlled to a failsafe state in response to a fault which may endanger the safety of persons on board, machinery/equipment or environment. | All | Class/Statutory | SOLAS II-1 | No |

### 3.2 GBS APPLICATION TO IACS UNIFIED REQUIREMENTS FOR ENERGY STORAGE SYSTEMS

It is noted the **Alternative Designs/Arrangements** for batteries and supercapacitors may be considered for Class Rules based on IACS Unified Requirements (UR), provided that the alternative meets the intent of these URs and can provide an equivalent level of safety as a conventional design. However, **Conventional Designs/Arrangements** for batteries and supercapacitors are to comply fully with the Class Rules and IACS Unified Requirements.

Although the below IACS Unified Requirements are common for all IACS members, it is noted that Functional Requirements (Tier II), Verification of Conformity (Tier III), specific Class Requirements (Tier IV) and recognized International Standards (Tier V) of the GBS framework, maybe different between Classification Societies. This document focuses on the GBS incorporation to the American Bureau of Shipping (ABS) requirements for Energy Storage Systems involving Supercapacitors, Kinetic Energy Storage (Flywheels) and Superconducting Magnetic Energy Storage components, either individually or in combinations.

Table 2 - GBS of ESS at IACS Level

| UR  | Regulations and Class Requirements (Tier IV) | ESS Arrangements | Class/Statutory /Other | Reference | ESS Regulatory Gap                                                              |
|-----|----------------------------------------------|------------------|------------------------|-----------|---------------------------------------------------------------------------------|
| E5  | Voltage and frequency variations             | All              | Other                  | IACS      | Applicable to batteries. Not direct reference to Supercapacitors, KESS or SMES. |
| E10 | Type specification for Type Approval         | All              | Other                  | IACS      | Applicable to control, monitoring, alarm and protection functions of ESS.       |

|            |                                                                                                    |     |       |      |                                                                                                                                                                                                                                                                                     |
|------------|----------------------------------------------------------------------------------------------------|-----|-------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>E15</b> | Electrical Services Required to be Operable Under Fire Conditions and Fire Resistant Cables        | All | Other | IACS | Applicable only if ESS is used during emergency conditions.                                                                                                                                                                                                                         |
| <b>E21</b> | Requirements for uninterruptible power system (UPS) units as alternative and/or transitional power | All | Other | IACS | Applicable to ESS functions that: <ul style="list-style-type: none"> <li>• Deliver AC output voltage not exceeding 1 KV,</li> <li>• Incorporate an energy storage device not exceeding 1.5 KV DC,</li> <li>• Have a primary function to ensure continuity of load power.</li> </ul> |
| <b>E22</b> | Computer-based systems                                                                             | All | Other | IACS | Applicable to ESS Energy Management functions and their integration with Power Management System (PMS) and as per UR E10                                                                                                                                                            |
| <b>E24</b> | Harmonic Distortion for Ship Electrical Distribution System including Harmonic Filters             | All | Other | IACS | Applicable if the DC/AC converter is within the scope of supply of the ESS vendor.                                                                                                                                                                                                  |
| <b>E27</b> | Cyber resilience of on-board systems and equipment                                                 | All | Other | IACS | Applicable as per UR-E22 and UR-10.                                                                                                                                                                                                                                                 |

### 3.3 GBS APPLICATION TO PORTIONS OF A VESSEL EQUIPED WITH ENERGY STORAGE SYSTEMS

The GBS approach may be applied to **alternative arrangements, novel concepts, or new technologies** used for specific parts of the vessel, for example the location of the Energy Storage System onboard.

All possible interfaces and known integrations are to be evaluated and are to consider the following factors, to confirm the compatibility of the **alternative design/arrangement** to the other surrounding **conventional designs/arrangements** aspects and systems:

- i) Personnel health and safety
- ii) Asset protection
- iii) Environmental protection

This evaluation and consideration are to include both the interfaces within the vessel or offshore unit and external to it, as applicable.

The integration/interfacing of alternatives with conventional technologies and/or the asset is not to introduce new hazards or undesirable events, unless the associated risks can be mitigated to an acceptable level. Relevant functional requirements are listed below.

Table 3 - GBS of ESS at Portion of a Vessel level

| TOPIC                                                            | Number | Functional Requirements (Tier II)                                                                                                                                                                                                                                                         | ESS Arrangements | Class/ Statutory/ Other | Reference | ESS Regulatory Gap |
|------------------------------------------------------------------|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------------------------|-----------|--------------------|
| <b>Fire Safety (FIR)</b>                                         |        |                                                                                                                                                                                                                                                                                           |                  |                         |           |                    |
| <b>FIR</b>                                                       | FR1    | The location of the switchboard, distribution equipment and main source of power is to be arranged such that the integrity of main electrical power may be affected only by a fire, flooding or similar casualty in one space.                                                            | All              | Class                   | ABS       | No                 |
| <b>FIR</b>                                                       | FR2    | Provide means to shutdown the power ventilation system covering high fire risk areas in the event of a fire. The shutdown means are to be in a location outside the affected space and in location not likely to be cut off in the event of fire and in centralized firefighting stations | All              | Class                   | ABS       | No                 |
| <b>Safety of Personnel (SAFE)</b>                                |        |                                                                                                                                                                                                                                                                                           |                  |                         |           |                    |
| <b>SAFE</b>                                                      | FR1    | Provide conditions for the safe use of hull return and earthing systems.                                                                                                                                                                                                                  | All              | Class                   | ABS       | No                 |
| <b>SAFE</b>                                                      | FR2    | Provide protection to prevent accidental contact with live parts of the assembly.                                                                                                                                                                                                         | All              | Class                   | ABS       | No                 |
| <b>SAFE</b>                                                      | FR3    | Provide an external insulation enclosure for switchgear and control gear assemblies for protection of the equipment from electric hazards.                                                                                                                                                | All              | Class                   | ABS       | No                 |
| <b>SAFE</b>                                                      | FR4    | Provide enclosure with suitable degree of protection against ingress of foreign objects and liquids based on location and personnel accessibility of installation.                                                                                                                        | All              | Class                   | ABS       | No                 |
| <b>Automation: Control, Monitoring and Safety Systems (AUTO)</b> |        |                                                                                                                                                                                                                                                                                           |                  |                         |           |                    |
| <b>AUTO</b>                                                      | FR1    | Provide overload protection to the energy storage system when arranged for feedback operation                                                                                                                                                                                             | All              | Class                   | ABS       | No                 |
| <b>AUTO</b>                                                      | FR2    | Provide safety measures and alarms to protect the energy storage system                                                                                                                                                                                                                   | All              | Class                   | ABS       | No                 |
| <b>AUTO</b>                                                      | FR3    | Provide coordination for all protective devices to allow the system to open the protective device closest to the fault first to protect the healthy portion of the system.                                                                                                                | All              | Class                   | ABS       | No                 |
| <b>AUTO</b>                                                      | FR4    | Provide safety measures and alarms to protect the electrical distribution system from harmonics                                                                                                                                                                                           | All              | Class                   | ABS       | No                 |
| <b>AUTO</b>                                                      | FR5    | Provide means to initiate disconnect of equipment and be designed such that a single failure will not result in the loss of duplicated essential equipment                                                                                                                                | All              | Class                   | ABS       | No                 |
| <b>AUTO</b>                                                      | FR6    | Provide means to monitor the emergency disconnect circuits to alert the crew of any failures.                                                                                                                                                                                             | All              | Class                   | ABS       | No                 |
| <b>Communications (COMM)</b>                                     |        |                                                                                                                                                                                                                                                                                           |                  |                         |           |                    |
| <b>COMM</b>                                                      | FR1    | Provide means of communication from the navigation bridge to essential interior locations.                                                                                                                                                                                                | All              | Class                   | ABS       | No                 |

|                   |     |                                                                                                                                                          |     |       |     |    |
|-------------------|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------|-----|----|
| COMM              | FR2 | Provide means of visual indication of the orders and responses in the bridge and machinery space control stations.                                       | All | Class | ABS | No |
| COMM              | FR3 | Provide a general alarm that is audible throughout all accommodation and normal crew working areas for summoning passengers and crew to muster stations. | All | Class | ABS | No |
| COMM              | FR4 | Provide means to initiate alarm from the centralized propulsion machinery control stations to alert the engineers not on duty.                           | All | Class | ABS | No |
| Safety Management |     |                                                                                                                                                          |     |       |     |    |
| MGMT              | FR1 | Provide accessibility to all the parts of the equipment requiring inspection or adjustment or replacement.                                               | All | Class | ABS | No |
| MGMT              | FR2 | Provide means of disconnecting the electrical equipment from power source for maintenance.                                                               | All | Class | ABS | No |
| MGMT              | FR3 | Cables are to be constructed to withstand marine environment , support connected loads and their overload protection.                                    | All | Class | ABS | No |
| MGMT              | FR4 | Electrical equipment installations are to be well supported and provided with adequate clearance for ease of operation and maintenance.                  | All | Class | ABS | No |
| MGMT              | FR5 | Provide suitable marking for high voltage cables, equipment and spaces containing them for warning.                                                      | All | Class | ABS | No |

### 3.4 GBS APPLICATION TO ENERGY STORAGE SYSTEMS' MARINE ARRANGEMENTS

The ESS arrangements below are considered **Conventional** due to Classification Societies having detailed prescriptive requirements. Accordingly, applicable **Prescriptive Requirements** and International Standards are provided in this section, supporting the Functional Requirements listed in this section and the overall Goals of IMO International Conventions or Codes, listed previously.

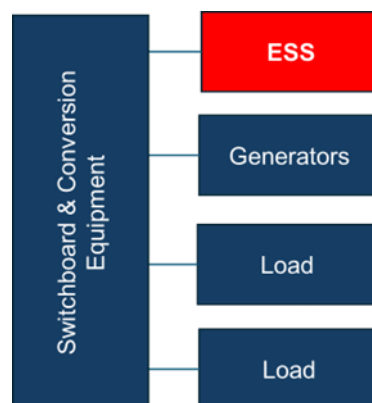


Figure 4 - Hybrid Electric power System (HES)

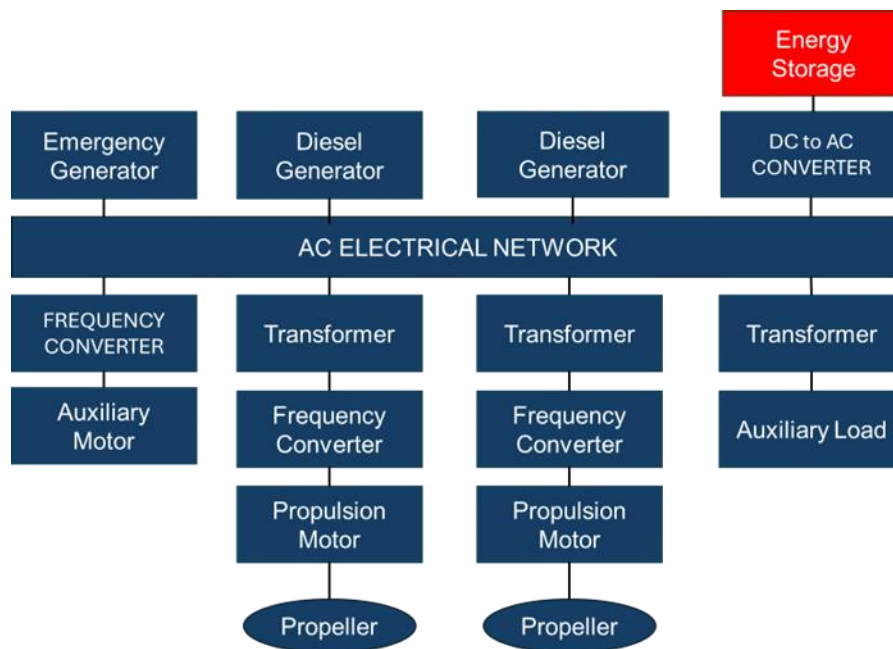


Figure 5 - Hybrid Electric Propulsion (HEP)

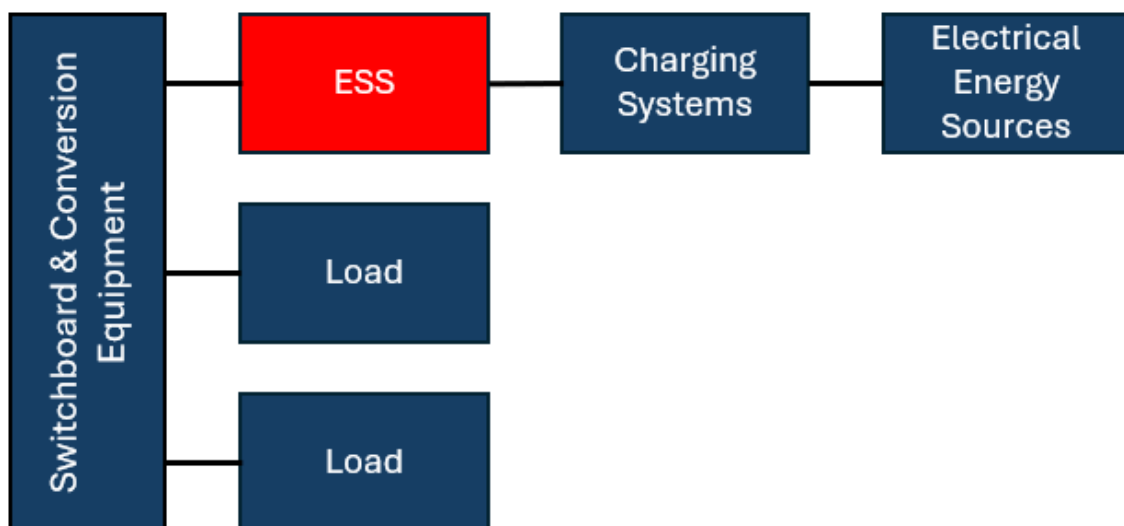


Figure 6 - All Electric power System (AES)

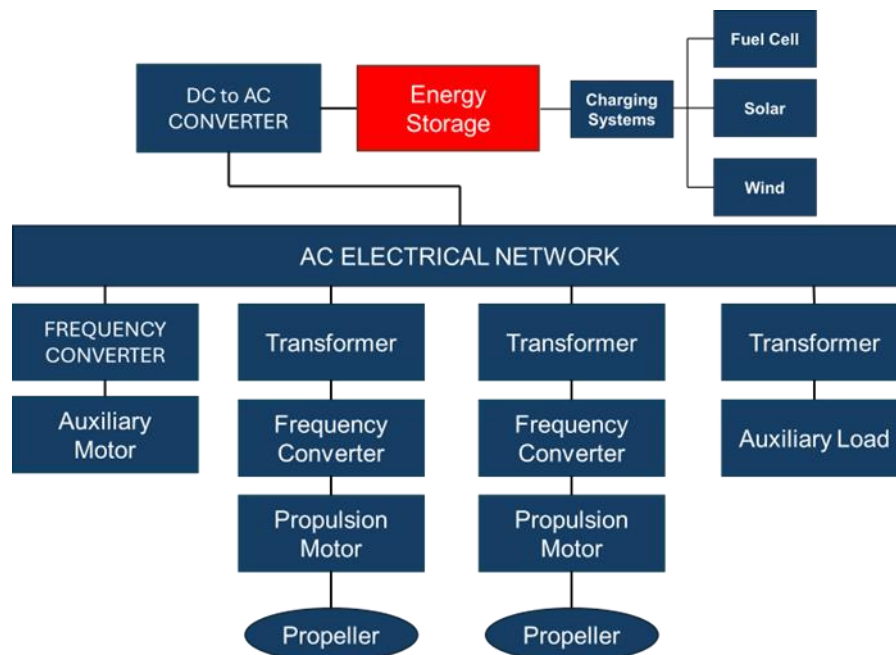


Figure 7 - All Electric Propulsion (AEP)

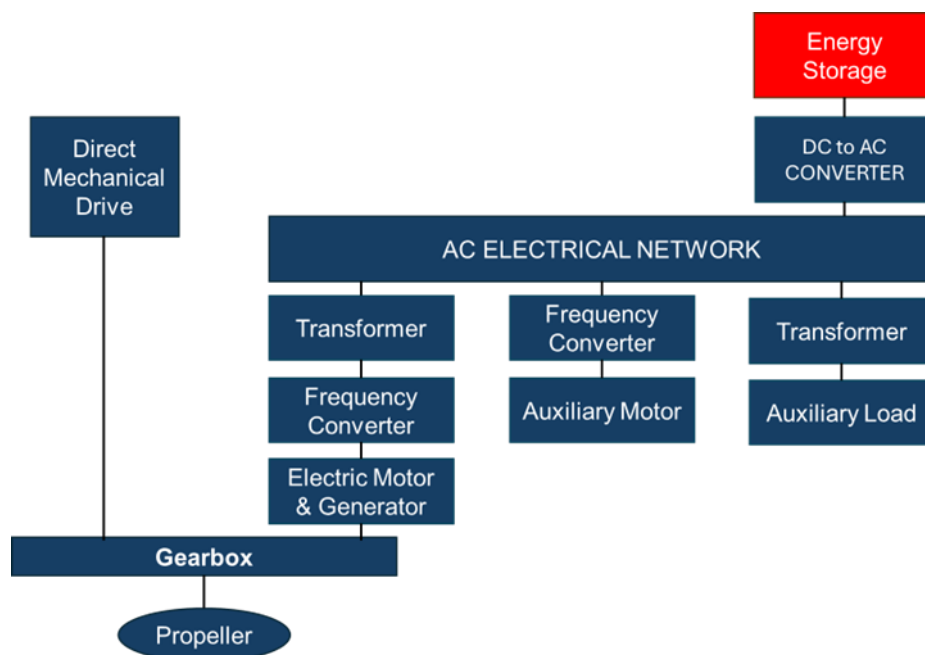


Figure 8 - Hybrid Propulsion-Hybrid Electric power System (HPEHS)

Table 4 - GBS of ESS at Marine Arrangements level [7, 8]

| TOPIC                                           | Number | Functional Requirements (Tier II)                                                            | ESS Arrangements  | Class/ Statutory/ Other | Reference | ESS Regulatory Gap |
|-------------------------------------------------|--------|----------------------------------------------------------------------------------------------|-------------------|-------------------------|-----------|--------------------|
| Propulsion, Maneuvering, station Keeping (PROP) |        |                                                                                              |                   |                         |           |                    |
| PROP                                            | FR1    | vessel is to have capability to maintain the vessel's station safely during charging from an | HEP, AEP and HPHS | Class                   | ABS       | No                 |

|                                                                  |            |                                                                                                                                                                                                    |                   |       |     |    |
|------------------------------------------------------------------|------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------|-----|----|
|                                                                  |            | offshore charging connection (OCC).                                                                                                                                                                |                   |       |     |    |
| PROP                                                             | FR2        | provide designs/arrangements that enable propulsion and steering to be available after a defined failure scenario.                                                                                 | HEP, AEP and HPHS | Class | ABS | No |
| <b>Power Generation and Distribution</b>                         |            |                                                                                                                                                                                                    |                   |       |     |    |
| POW                                                              | FR1        | provide sufficient power capacity and quantity to achieve continuity of power with at least one source of power in standby.                                                                        | All               | Class | ABS | No |
| POW                                                              | FR2        | provide starting arrangement for the restoration of propulsion.                                                                                                                                    | HEP, AEP and HPHS | Class | ABS | No |
| POW                                                              | FR3 (AUTO) | provide protection against overload, short circuit, earth-fault and overvoltage conditions and other hazards to prevent damage to equipment and maintain continuity of power to remaining circuits | All               | Class | ABS | No |
| POW                                                              | FR4        | provide means to manage loads such that blackouts are avoided, and power is always maintained to essential services and propulsion loads.                                                          | HEP, AEP and HPHS | Class | ABS | No |
| POW                                                              | FR5        | electric equipment connected to the power system is to be capable of operating in the power quality envelope of the system without damage.                                                         | All               | Class | ABS | No |
| POW                                                              | FR6        | provide safe and stable electrical distribution scheme for Alternating Current (AC) and Direct Current (DC) systems                                                                                | All               | Class | ABS | No |
| POW                                                              | FR7        | design and size the ESS to operate without damage throughout its service life.                                                                                                                     | All               | Class | ABS | No |
| POW                                                              | FR8        | electrical equipment is to be designed and constructed to withstand the marine environment and maximum design ambient temperature and stresses without any deterioration.                          | All               | Class | ABS | No |
| POW                                                              | FR9        | provide enclosure with suitable degrees of protection against ingress of foreign objects and liquids based on the location of installation.                                                        | All               | Class | ABS | No |
| POW                                                              | FR10       | apply fail-safe design for the electrical power system, control and safety systems to prevent a dangerous situation due to a single point failure.                                                 | All               | Class | ABS | No |
| <b>Automation: Control, Monitoring and Safety Systems (AUTO)</b> |            |                                                                                                                                                                                                    |                   |       |     |    |

|             |      |                                                                                                                                                                       |     |       |     |    |
|-------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------|-----|----|
| <b>AUTO</b> | FR7  | Provide protection against overload, undervoltage and short circuit conditions to prevent damage to equipment and maintain continuity of power to remaining circuits. | All | Class | ABS | No |
| <b>AUTO</b> | FR8  | The circuit protection devices are to be able to withstand the prospective short circuit current values at the point of installation.                                 | All | Class | ABS | No |
| <b>AUTO</b> | FR9  | control systems are to be designed to achieve safe and effective operation.                                                                                           | All | Class | ABS | No |
| <b>AUTO</b> | FR10 | apply fail-safe design for all control systems, monitoring systems and safety systems to prevent dangerous situations due to a single point failure.                  | All | Class | ABS | No |
| <b>AUTO</b> | FR11 | circuit protection devices are to be able to withstand the prospective short circuit current values at the point of installation.                                     | All | Class | ABS | No |

| TOPIC                | Regulations and Class Requirements (Tier IV)                         | ESS Arrangements | Class/Statutory/ Other | Reference | ESS Regulatory Gap |
|----------------------|----------------------------------------------------------------------|------------------|------------------------|-----------|--------------------|
| <b>PROP-FR1</b>      | Hybrid rules 3/25, 3/35<br>Single Point Moorings 4-5                 | All              | Class                  | ABS       | No                 |
| <b>PROP-FR2</b>      | MVR 4-8-2/3, 4-8-2/5                                                 | All              | Class                  | ABS       | No                 |
| <b>POW-FR1</b>       | MVR 4-8-2/3, 4-8-2/5, 4-8-2/7, 4-8-2/9                               | All              | Class                  | ABS       | No                 |
| <b>POW-FR2</b>       | MVR 4-1-1/7.7                                                        | All              | Class                  | ABS       | No                 |
| <b>POW-FR3(AUTO)</b> | MVR 4-8-2/9                                                          | All              | Class                  | ABS       | No                 |
| <b>POW-FR4</b>       | MVR 4-8-2/3.11, 4-8-5/5.3.3                                          | All              | Class                  | ABS       | No                 |
| <b>POW-FR5</b>       | MVR 4-8-2/9                                                          | All              | Class                  | ABS       | No                 |
| <b>POW-FR6</b>       | MVR 4-3-7/9.9, 4-8-2/7                                               | All              | Class                  | ABS       | No                 |
| <b>POW-FR7</b>       | MVR 4-8-2/9                                                          | All              | Class                  | ABS       | No                 |
| <b>POW-FR8</b>       | MVR 4-1-1/7                                                          | All              | Class                  | ABS       | No                 |
| <b>POW-FR9</b>       | MVR 4-8-3/Table 1a, 1b & 2, 4-9-9/15.7                               | All              | Class                  | ABS       | No                 |
| <b>POW-FR10</b>      | MVR 4-9-3/5                                                          | All              | Class                  | ABS       | No                 |
| <b>PROP-FR2</b>      | MVR 4-8-1/7.3.3,                                                     | All              | Class                  | ABS       | No                 |
| <b>AUTO-FR1</b>      | MVR 4-9-2/3, 4-9-2/5, 4-9-2/7, 4-9-2/9, 4-9-2/11, 4-9-2/13, 4-9-2/15 | All              | Class                  | ABS       | No                 |
| <b>AUTO-FR2</b>      | MVR 4-9-2/9                                                          | All              | Class                  | ABS       | No                 |
| <b>AUTO-FR4</b>      | MVR 4-9-3/5                                                          | All              | Class                  | ABS       | No                 |
| <b>AUTO-FR5</b>      | MVR 4-9-3/5                                                          | All              | Class                  | ABS       | No                 |

| AUTO-FR6                   | MVR 4-8-2/9.3                                                                                                                                                                                                           | All              | Class                  | ABS                   | No                                             |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|------------------------|-----------------------|------------------------------------------------|
| TOPIC                      | Industry Standards and Practices (Tier V)                                                                                                                                                                               | ESS Arrangements | Class/Statutory/ Other | Reference             | ESS Regulatory Gap                             |
| FIR, SAFE, MGMT            | <i>Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres</i>                                                                                                                           | All              | Other                  | IEC 60079-10-1        | No<br>(Directly reference d in ABS Rules))     |
| POW, FIR, SAFE, AUTO, MGMT | <i>Electrical Installations in Ships</i>                                                                                                                                                                                | All              | Other                  | IEC 60092 - 502       | No<br>(Directly reference d in ABS Rules))     |
| POW, FIR, SAFE, AUTO, MGMT | <i>Low-voltage electrical installations</i>                                                                                                                                                                             | All              | Other                  | IEC 60634 (All parts) | No<br>(Not Directly reference d in ABS Rules)) |
| POW, FIR, SAFE, AUTO, MGMT | <i>Semiconductor converters – General requirements and line commutated converters – Specification of basic requirements All</i>                                                                                         | All              | Other                  | IEC 60146-1-1         | No<br>(Directly reference d in ABS Rules))     |
| POW, FIR, SAFE, AUTO, MGMT | <i>Safety requirements for power electronic converter systems and equipment – Part 1: General</i>                                                                                                                       | All              | Other                  | IEC 62477-1-2012      | No<br>(Not Directly reference d in ABS Rules)) |
| POW, FIR, SAFE, AUTO, MGMT | <i>Electrical energy storage (EES) systems – Part 5-1: Safety considerations for grid integrated EES systems – General specification</i>                                                                                | All              | Other                  | IEC TS 62933-5-1:2017 | No<br>(Not Directly reference d in ABS Rules)) |
| POW, FIR, SAFE, AUTO, MGMT | <i>Electromagnetic compatibility (EMC) – Part 1-2: General – Methodology for the achievement of functional safety of electrical and electronic systems including equipment with regard to electromagnetic phenomena</i> | All              | Other                  | IEC 61000-1-2         | No<br>(Not Directly reference d in ABS Rules)) |
| POW, FIR, SAFE, AUTO, MGMT | <i>Electromagnetic compatibility (EMC) – Part 6-7: Generic standards – Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations</i>     | All              | Other                  | IEC 61000-6-7         | No<br>(Not Directly reference d in ABS Rules)) |
| POW, FIR, SAFE, AUTO, MGMT | Environmental testing - Part 2-6: Tests - Test Fc: Vibration (sinusoidal)                                                                                                                                               | All              | Other                  | IEC 60068-2-6         | No<br>(Directly reference                      |

|                            |                                                                       |     |       |                |                                                |
|----------------------------|-----------------------------------------------------------------------|-----|-------|----------------|------------------------------------------------|
|                            |                                                                       |     |       |                | d in ABS Rules))                               |
| POW, FIR, SAFE, AUTO, MGMT | Environmental testing - Part 2-52: Tests - Test Kb: Salt mist, cyclic | All | Other | IEC 60068-2-52 | No<br><br>(Directly reference d in ABS Rules)) |

### 3.5 GBS APPLICATION TO ENERGY STORAGE SYSTEMS' MARINE FUNCTIONS

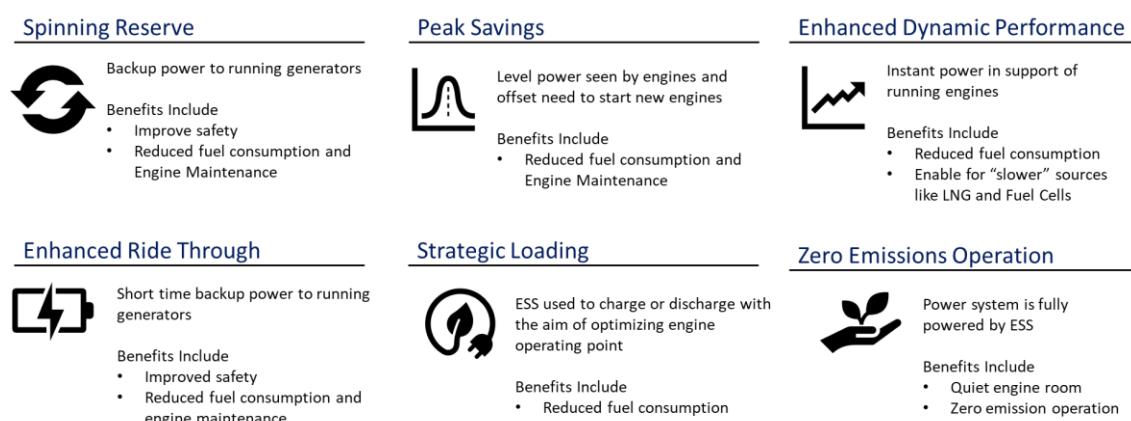


Figure 9 - ESS Marine Functions

The above ESS Marine Functions are applicable to all ESS arrangements except for the Zero emissions Operation where it is applicable only to HEP and HPHS.

Table 5 - GBS of ESS at System Functions Level

| TOPI C                                                           | Number | Functional Requirements (Tier II)                                                                                                                              | ESS Arrangements | Class/Statutory/Other | Reference | ESS Regulatory Gap |
|------------------------------------------------------------------|--------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------|-----------|--------------------|
| <b>Automation: Control, Monitoring and Safety Systems (AUTO)</b> |        |                                                                                                                                                                |                  |                       |           |                    |
| AUTO                                                             | FR12   | power and energy management systems are to be designed so that their failure does not affect the availability of power sources.                                | All              | Class                 | ABS       | No                 |
| AUTO                                                             | FR13   | system independence is to be applied to safety systems performing different functions. Failure of one function should not lead to the loss of other functions. | All              | Class                 | ABS       | No                 |

### 3.6 GBS APPLICATION TO INDIVIDUAL EQUIPMENT OR COMPONENTS OF MARINE ENERGY STORAGE SYSTEMS

To facilitate any potential *New Technology Qualification* process for KESS and SMES, the following section provides an overview of the systems' components.

KESS systems consist of the key components below:

1. The Rotating flywheel
2. Bearings
3. The Electric machine
4. The Power electronics and control

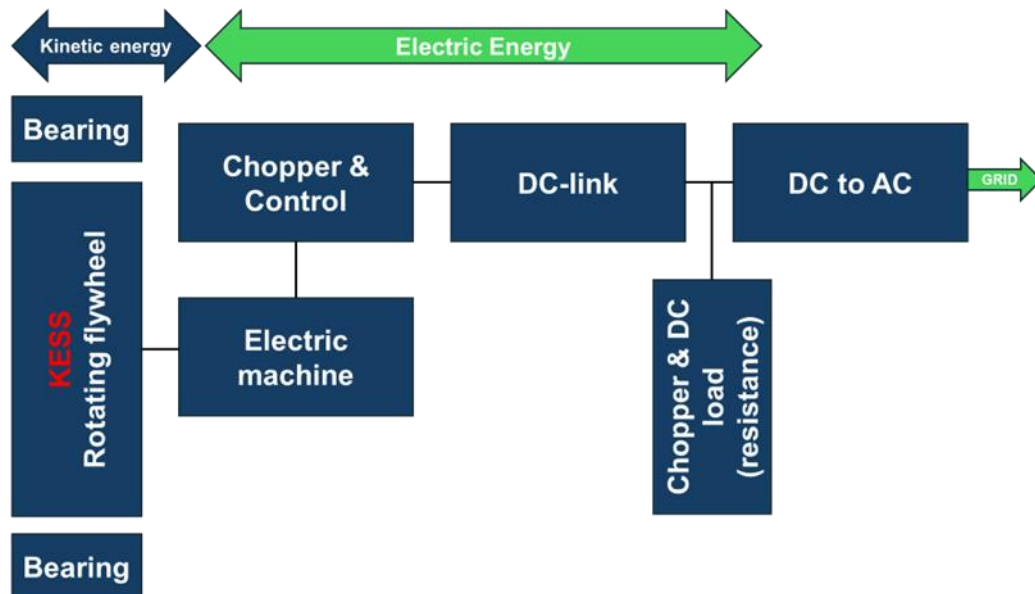


Figure 10 - KESS components

As outlined through work conducted by the Danish Maritime Fund [9], the following KESS operational and environmental conditions were defined:

- List: +/- 15 degrees
- Trim: +/- 5 degrees
- F/A Deck Angle +/- 15 degrees (assumed)
- Roll +/- 45 deg; 12 sec
- Pitch +/- 12 deg; 9 sec
- Heave 0.4 g
- Surge 0.25 g
- Ship length 600 ft
- Ship Beam 80.7 ft
- MIL-S-901 Grade A Shock
- MIL-STD-461 EMI (electromagnetic compatibility)
- MIL-STD-167 Vibration

As KESS may be designed based on different materials, the applicable GBS are provided in Table 6 below.

SMES systems consist of the key components below:

1. Superconducting Coil: The core element of an SMES, typically made of high-temperature superconducting (HTS) materials.
2. Cryogenic Cooling System: Maintains the superconducting state of the coil.
3. Power Conditioning System: Interfaces the SMES with the electrical grid.
4. Control and Protection System: Manages the operation and ensures safety.

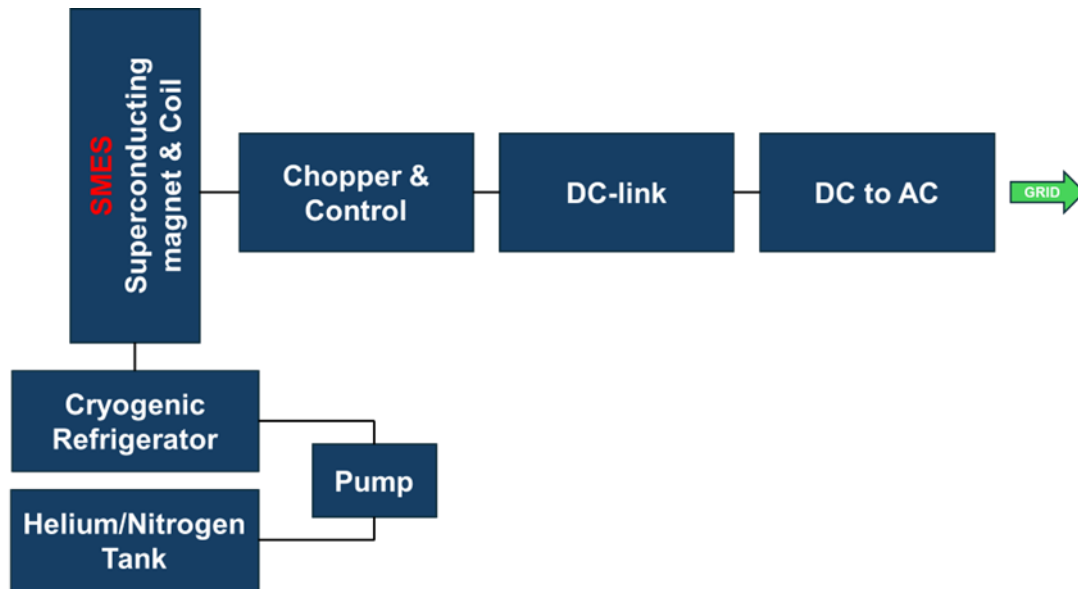


Figure 11 - SMES Components

As SMES systems may be designed based on different materials, the applicable GBS are provided in the following tables.

Individual equipment or components may be approved based on the overall system meeting the goals and functional requirements. However, individual equipment or components that do not comply with the prescriptive Class Rules, Guides or other recognized standards will typically not be eligible for Class Type Approval.

Table 6 - GBS of ESS at Individual Equipment or Component Level

**MATERIALS** - are to be suitable for the intended application in accordance with the following goals and support the Tier 1 Goals listed elsewhere in the Rules.

| TOPIC | Number | Goal (Tier I)                                                                                                                                                                   | ESS Onboard Arrangements | Class/Statutory/ Other | Reference               | ESS Regulatory Gap |
|-------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|------------------------|-------------------------|--------------------|
| MAT   | 1      | The selected materials' physical, mechanical and chemical properties are to meet the design requirements appropriate for the application, operating conditions and environment. | All                      | Class/Other            | ABS Marine Vessel Rules | No                 |

|     |   |                                                                                                                                       |     |             |                         |    |
|-----|---|---------------------------------------------------------------------------------------------------------------------------------------|-----|-------------|-------------------------|----|
| MAT | 2 | The manufacturing process is to be capable of producing products to meet the specified quality and property requirements.             | All | Class/Other | ABS Marine Vessel Rules | No |
| MAT | 3 | The fabrication and welding process is to be capable of producing products that meet the specified quality and property requirements. | All | Class/Other | ABS Marine Vessel Rules | No |

| TOPIC         | Regulations and Class Requirements (Tier IV)                                                | ESS Arrangements | Class/Statutory/Other | Reference | ESS Regulatory Gap              |
|---------------|---------------------------------------------------------------------------------------------|------------------|-----------------------|-----------|---------------------------------|
| POW,FIR,S AFE | Requirements for Hybrid and All-Electric Power Systems for Marine and Offshore Applications | All              | Class                 | ABS       | Yes (No KESS, SMES reference)   |
| POW,FIR,S AFE | Requirements for Use of Supercapacitors in the Marine and Offshore Industries               | All              | Class                 | ABS       | No                              |
| POW,FIR,S AFE | Requirements for Use of KESS in the Marine and Offshore Industries                          | All              | Class                 | All       | Yes (No Class Requirements yet) |
| POW,FIR,S AFE | Requirements for Use of SMES in the Marine and Offshore Industries                          | All              | Class                 | All       | Yes (No Class Requirements yet) |

| TOPIC                      | Industry Standards and Practices (Tier V)                                                                                                                                                    | ESS Arrangements | Class/Statutory/Other | Reference          | ESS Regulatory Gap                         |
|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------|--------------------|--------------------------------------------|
| FIR, SAFE, MGMT            | Fixed electric double-layer capacitors for use in electric and electronic equipment – Part 1: Generic specification                                                                          | All              | Other                 | IEC 62391-1        | No (Directly referenced in ABS Rules)      |
| POW, FIR, SAFE, AUTO, MGMT | Fixed electric double-layer capacitors for use in electronic equipment – Part 2: Sectional specification – Electric double layer capacitors for power application                            | All              | Other                 | IEC 62391-2        | No (Directly referenced in ABS Rules)      |
| POW, FIR, SAFE, AUTO, MGMT | 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 | All              | Other                 | IEC 62391-2        | No (Directly referenced in ABS Rules)      |
| POW, FIR, SAFE, AUTO, MGMT | Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design Part 2: Validation                                                                     | All              | Other                 | EN ISO 13849-1 & 2 | Yes (Not directly referenced in ABS Rules) |

|                                     |                                                                                                                                   |      |       |                       |                                                                                                                                               |
|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|------|-------|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Safety requirements for power electronic converter systems and equipment – Part 1: General                                        | All  | Other | IEC 62477-1-2012      | Yes (Not directly referenced in ABS Rules)                                                                                                    |
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | <i>Semiconductor devices-Discrete devices-Part 9 Insulated-gate bipolar transistors (IGBTs)</i>                                   | All  | Other | IEC 600747-9          | Yes (Not directly referenced in ABS Rules)                                                                                                    |
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Electrical energy storage (EES) systems – Part 5-1: Safety considerations for grid integrated EES systems – General specification | All  | Other | IEC TS 62933-5-1:2017 | Yes (Not directly referenced in ABS Rules)                                                                                                    |
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Cryogenic vessels-Valves for cryogenic service                                                                                    | SMES | Other | ISO 21011             | Applicable to helium/storage tanks and associated valves, of the cryogenic refrigerator System.<br><br>(Not directly referenced in ABS Rules) |
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Valves—Flanged, Threaded, and Welding End ASME B16.34-2004 (Revision of ASME B16.34-1996)                                         | SMES | Other | ASME B16.34           | Applicable to valves associated with the helium/nitrogen of the cryogenic refrigerator System.<br><br>(Not directly referenced in ABS Rules)  |
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Storage tanks                                                                                                                     | SMES | Other | API 620,650           | Applicable to helium/nitrogen storage tank of the cryogenic refrigerator System.<br>(Not directly referenced in ABS Rules)                    |
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Safe Design and Operation of Cryogenic Enclosures - 3rd Edition                                                                   | SMES | Other | CGA P-8.8-2021        | Applicable to the cryogenic refrigerator System.<br><br>(Not directly referenced in ABS Rules)                                                |
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Valves for Cryogenic Service Including Requirements for Body/Bonnet Extensions                                                    | SMES | Other | MSS SP-134-2012       | Applicable to cryogenic refrigerator System.<br>(Not directly referenced in ABS Rules)                                                        |
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Specification for Valves for cryogenic service                                                                                    | SMES | Other | BS 6364:1984          | Applicable to refrigerator cryogenic System.<br><br>(Not directly referenced in ABS Rules)                                                    |

|                                     |                                                          |      |       |                                                                                                                                            |                                                                                                                                                      |
|-------------------------------------|----------------------------------------------------------|------|-------|--------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Methods for evaluating<br>cryogenic filters              | SMES | Other | SAE ARP<br>900C-2019                                                                                                                       | Applicable to<br>cryogenic<br>refrigerator System.<br><br>(Not directly<br>referenced in ABS<br>Rules)                                               |
| POW, FIR,<br>SAFE,<br>AUTO,<br>MGMT | Electrical Standards and<br>Magnetic Conductor Standards | SMES | Other | ASTM<br>standards<br><br>Applicable<br>according<br>to material<br>of<br>supercond<br>ucting coil<br>and<br>supercond<br>ucting<br>magnet. | Applicable to<br>superconducting<br>coil and<br>superconducting<br>magnet of the SMES<br>System.<br><br>(Not directly<br>referenced in ABS<br>Rules) |

## 4 CONCLUSION

Deliverable D6.1 provided a Goal Based Standards (GBS) approach, effectively documenting the State of the Art for the regulatory compliance of marine Energy Storage Systems (ESS), incorporating Supercapacitors, KESS and SMESS technologies.

Applicable Tier I Goals have been identified in tabular format, to assist the initial design exploration stage, and to clarify the responsibilities that the ESS design needs to address without extending its scope to the scope of other systems onboard.

Applicable, Tier II Functional Requirements have been defined in tabular format, as a result of applicable Tier I Goals. Functional Requirements provided in this deliverable, better clarify the boundaries and interfaces of the marine ESS with other systems onboard.

Also In this deliverable, a clear correlation between Functional Requirements and ABS prescriptive Rules requirements was provided, to assist with the Tier III Verification of Conformity of detailed design decisions of ESS based on KESS and SMESS technologies.

In addition, Tier IV Regulation and Class Requirements have been identified to provide detailed criteria that specify how the Functional Requirements are to be met for the **Conventional** part of the ESS design, based on KESS and SMESS technologies.

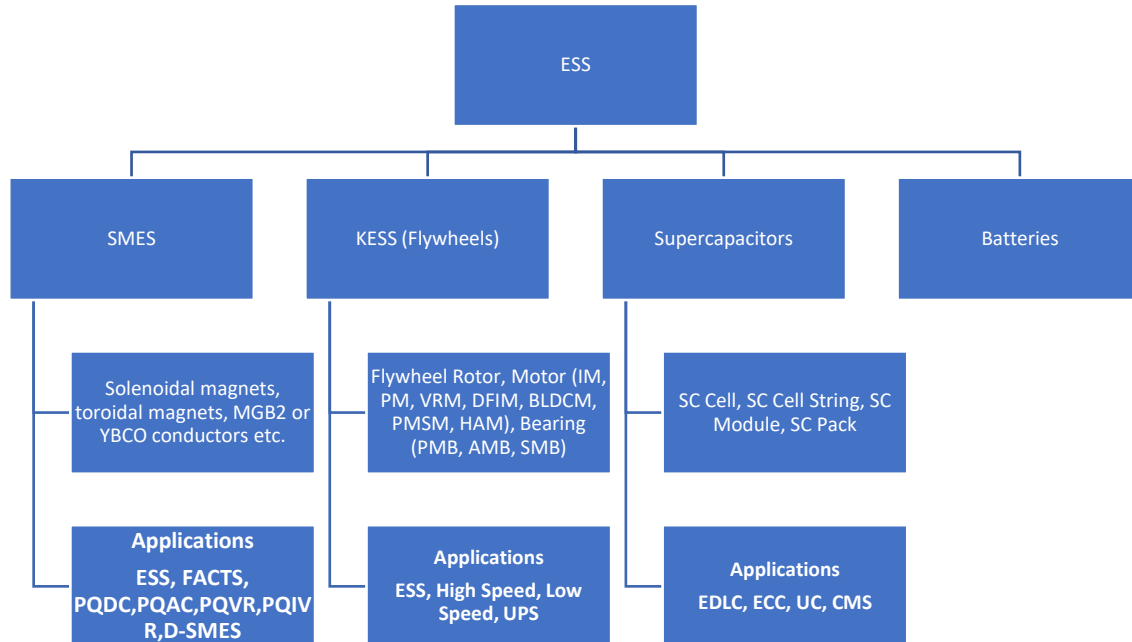
Finally, Tier V Industry Standards and Practices have been researched extensively and documented in tabular format, to provide detailed test criteria and conditions that need to be considered for the **Alternative part and Alternative Arrangements** of the ESS based on KESS and SMESS technologies, in addition to Tier IV detailed criteria for the **Conventional** part of the ESS design.

## 5 REFERENCES

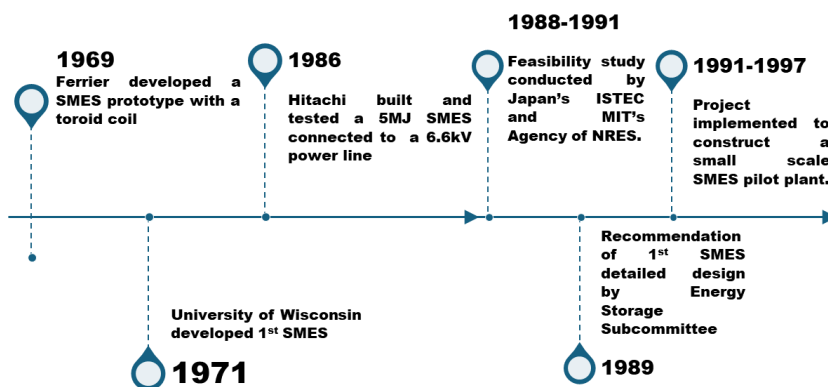
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# 1 APPENDIX I: ENERGY STORAGE TECHNOLOGY TECHNICAL STATE OF THE INDUSTRY

## 1.1 OVERVIEW OF ENERGY STORAGE TECHNOLOGIES

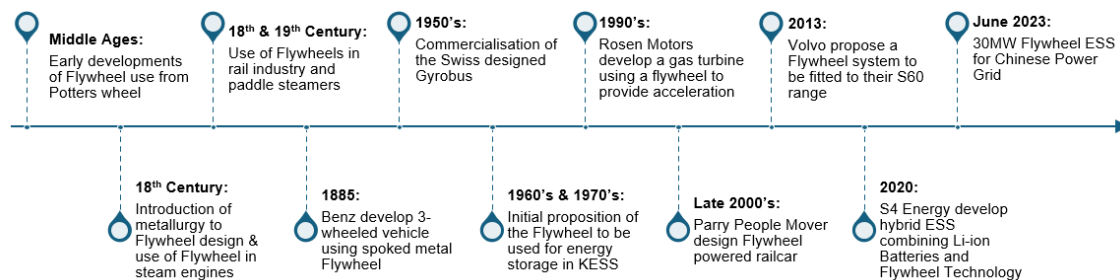


### 1.1.1 SUPERCONDUCTING MAGNETIC ENERGY STORAGE (SMES)



Superconducting magnetic energy storage (SMES) systems store energy in a magnetic field. This magnetic field is generated by a DC current traveling through a superconducting coil. In a normal wire, as electric current passes through the wire, some energy is lost as heat due to electric resistance. However, in a SMES system, the wire is made from a superconducting material that has been cryogenically cooled below its critical temperature. As a result, electric current can pass through the wire with almost no resistance, allowing energy to be stored in a SMES system for a longer period of time. Common superconducting materials include mercury, vanadium, and niobium-titanium. The energy stored in an SMES system is discharged by connecting an AC power converter to the conductive coil.

### 1.1.2 KINETIC ENERGY STORAGE SYSTEMS (KESS)



Recent improvements in materials, magnetic bearings, power electronics, and the introduction of high-speed electric machines, Kinetic Energy Storage Systems (FESS) has been established as a solid option for energy storage applications. A flywheel stores energy that is based on the rotating mass principle. It is a mechanical storage device which emulates the storage of electrical energy by converting it to mechanical energy. The energy in a flywheel is stored in the form of rotational kinetic energy. The input energy to the FESS is usually drawn from an electrical source coming from the grid or any other source of electrical energy. The flywheel speeds up as it stores energy and slows down when it is discharged, to deliver the accumulated energy. The rotating flywheel is driven by an electrical motor-generator (MG) performing the interchange of electrical energy to mechanical energy, and vice versa. The flywheel and MG are coaxially connected, indicating that controlling the MG enables control of the flywheel.

The commercialization and design of the KESS has seen interest among various industrial sectors in engineering. From automotive to land based grid systems, the KESS offers a high degree of potential for green energy. Therefore, due to the vast possibilities surrounding KESS, the maritime industry has begun to take an interest in such technologies. One study, funded by the Danish maritime fund, made significant developments towards the marinization of KESS, yet found that a substantial number of functionalities were required prior to the commercialization of such technologies. Moreover, further discussions in the maritime industry for KESS have seen the system being conceptually designed to be utilized as a potential power source for fast ferries using only green energy [10].

### 1.1.3 SUPERCAPACITORS

A supercapacitor is a device that stores energy electrochemically using a polarized electrolyte, which emerged back in the 1970s and 1980s. It operates distinctly from traditional power supplies, positioning itself between conventional capacitors and batteries in terms of energy storage. The classification of supercapacitors as pseudo-capacitors is based on the redox reactions occurring at the electrical power storage interfaces (EDLCs) and the non-Faradic double-layer charge that builds at the electrode-electrolyte interface, which relies on redox pseudo-capacity.

### 1.1.4 LITHIUM-ION BATTERIES

The first lithium-ion batteries were introduced in the mid-1990s. These batteries exhibited low internal resistance and low parasitic losses, and were used for low energy, low power and long-life applications.

However, advances in Li-ion chemistries have led to increased energy and power density along with a terminal voltage vs. state of charge that is superior to traditional battery chemistries such as Nickel Metal Hydride (NiMH), Nickel Cadmium (NiCd), lead acid, etc.

These favorable characteristics have facilitated the use of lithium-ion batteries in applications that were previously impractical for traditional battery chemistry. Large scalable lithium-ion battery packs have found applications in defense systems, electric vehicles, satellites and marine and offshore installations.

Despite the many advantages, lithium-ion battery technology requires operation within defined parameters including specific charge/discharge rates, voltages, currents and temperatures. Operation outside these values can lead to premature failure, loss of performance and unsafe operation.

## 2 APPENDIX II: ENERGY STORAGE SYSTEMS ASSESSMENT FOR MARINE APPLICATIONS (DESIGN OPTIMIZATION CONSIDERATIONS)

Currently the main characteristics of these 3 FRESS in terrestrial applications have been summarized in the following Table 7.

Table 7 - Comparison between the main features of the 3 FRESS in terrestrial applications reference [11]

|                                                                          |                                      | SMES                      | KESS                                | Supercapacitor            |
|--------------------------------------------------------------------------|--------------------------------------|---------------------------|-------------------------------------|---------------------------|
| Environmental Impact                                                     | Land and water impact                | Insignificant             | Insignificant                       | Insignificant             |
|                                                                          | Emissions produced during operation  | None                      | None                                | None                      |
|                                                                          | Hazardous materials                  | None                      | None                                | None                      |
|                                                                          | Hazardous emissions                  | None                      | None                                | None                      |
|                                                                          | Short-term safety concerns           | Several                   | Some                                | Minimal                   |
|                                                                          | Resource depletion                   | Somewhat significant      | Insignificant                       | Somewhat significant      |
|                                                                          | Geographic requirements              | None                      | None                                | None                      |
| Compatible Applications for Electrical/Mechanical Energy Storage Systems | Energy arbitrage                     | Incompatible              | Incompatible                        | Incompatible              |
|                                                                          | Frequency regulation                 | Compatible                | Compatible                          | Compatible                |
|                                                                          | Load following                       | Compatible                | Somewhat Compatible                 | Compatible                |
|                                                                          | Voltage support                      | Compatible                | Compatible                          | Compatible                |
|                                                                          | Spinning reserves*                   | -                         | Compatible                          | -                         |
|                                                                          | Nonspinning and supp reserves*       | -                         | Incompatible                        | -                         |
|                                                                          | Black start*                         | -                         | Incompatible                        | -                         |
|                                                                          | VSR integration*                     | -                         | Compatible                          | -                         |
|                                                                          | Seasonal storage*                    | -                         | Incompatible                        | -                         |
|                                                                          | Process heat applications*           | -                         | Incompatible                        | -                         |
| Performance Metrics for Electrical/Mechanical Energy Storage             | Energy Capacity (MWh)                | 0.001-0.015               | 0.0005 – 0.025 per unit, five total | 0.0005                    |
|                                                                          | Power Capacity (MW)                  | 0.1-10                    | 0.1 – 1.65 per unit, 20 total       | 0 – 0.3                   |
|                                                                          | Discharge Time                       | Milliseconds to seconds   | 0 – 0.25h                           | Milliseconds to 1h        |
|                                                                          | Response Time                        | Milliseconds, < 1/4 cycle | Seconds                             | Milliseconds, < 1/4 cycle |
|                                                                          | Storage Degradation Rate (%/Day)     | 10% – 15%                 | 20% per h                           | 20% – 40%                 |
|                                                                          | Energy Density (kWh/m <sup>3</sup> ) | 0.2 – 2.5                 | 20 – 80                             | 0.01 – 1                  |
|                                                                          | Power Density (kWh/m <sup>3</sup> )  | 1000 – 4000               | 1000-2000                           | 200 – 10,000              |
|                                                                          | Specific Energy (Wh/kg)              | 0.5 – 5                   | 10-30                               | 2.5 – 15                  |
|                                                                          | Specific Power (W/kg)                | 500 – 2000                | 400-1500                            | 500 – 5000                |
|                                                                          | Round-Trip Efficiency                | 95% – 98%                 | 90%-95%                             | 90% – 95%                 |
|                                                                          | Cycle Life (Cycles)                  | 100000+                   | 20000-100000                        | 100000+                   |
|                                                                          | Technology Lifetime (Years)          | 20-30                     | 15-20                               | 10-30                     |

Advantages of SMES technology are (reference [12]):

- SMES is environmentally friendly,
- Superconductivity does not produce chemical reaction,
- No toxins produced in process,
- High efficiency (90%),

- High capacity (it depends on magnet and load needs),
- Short charging time (minutes),
- Very fast response (tenths of milliseconds),
- Long lifetime of the system,
- Minimal need of maintenance,
- Low operational costs (actually only for the cryo system maintenance).

**On the other hand, the disadvantages of SMES technology are:**

- High investment costs because of superconducting magnet with cryo system and power conditioning system,
- Short carryover time (it depends on load),
- Need of permanent cooling,
- Size issues in the case of high-capacity system,
- Lorentz forces issue ("earth supported" coil could be the solution for large scale systems), possible health effects because of high magnetic field (in the case of large systems)

**Advantages of KESS technology are**(reference [13]):

- High energy-efficiency
- Almost immediate delivery
- Strong power
- Requires little maintenance
- Long service life
- Environmentally friendly
- Simple and safe
- Flexible in the rate of charging and/or discharging

**On the other hand, the disadvantages of KESS technology are:**

- The need for permanent magnets in the rotor
- May require costly cryogenic cooling devices
- Cryogenic cooling also reduces the overall energy storage efficiency
- Deep discharging cannot be achieved
- High capital cost, whether due to the materials' cost for the light rotational mass, i.e., at high rpm, or for the magnetic bearing using heavy rotational masses
- High self-discharge rate and low energy density

**Advantages of Supercapacitor are** (reference [14]):

- Provide Backup power and peak power.
- Enhance run time of battery and prolong its life.
- Helps to reduce size, weight and cost of battery.
- High range of temperature operation is possible.
- Parallel operation with battery improves load balancing.
- Energy storage with energy harvesters.
- Reduces pulse current noise.
- Less space requirement achieved.
- It eliminates DC/DC which reduces the RF noise.
- Environmental friendly

**On the other hand, the disadvantages of Supercapacitor are:**

- They have higher self discharge rate.
- Individual cells have low voltage.
- Amount of energy stored per unit weight is considerably lower comparable to electrochemical batteries.
- It offers low energy density compare to battery.
- It can't be used in AC and higher frequency circuit.