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Project Abstract

The goal of the SEABAT project is to develop a full-electric maritime hybrid battery concept that is based on:

- Modularly combining high-energy batteries and high-power batteries,
- novel converter concepts and
- production technology solutions derived from the automotive sector.

The modular approach will reduce component costs (battery cells, convertors) so that unique ship designs can profit from economies of scale by using standardised low-cost components. The concept will be suitable for ships requiring up to 1 MWh of storage or more

Public summary

This document is part of **Work Package 2**, **Specifications and Requirements**, which main objective is to draw the scope of the project by identifying and defining the different maritime applications that are currently being electrified by using batteries and which maritime applications will be using batteries in the near future and in what way they will be suitable for the application of a hybrid battery system.

Tasks 2.1, 2.2 and 2.3 of this WP2 are the objective of this document. There are currently no international standards for marine battery installations. However, the International Electrotechnical Commission (IEC) is working on standards 62619 and 62620. Some additional requirements are available for transportation of batteries (e.g., UN 38.3 Recommendations on the Transport of Dangerous Goods – Manual of Tests and Criteria). These provisions are referenced as baseline. Classification societies, upon their experience, may have developed specific Rules and/or Additional Class notation supplementing these international regulations. The scope of this task is to draft some interim guidelines aimed at expanding the international requirements and promoting the adoption of a single set of regulations and/or standards. It is acknowledged that parallel activities may be part of the work plan of the international regulatory bodies. It is noted that so far, the range of available cell chemistries and technology made it unfeasible to define a prescriptive set of rules for batteries. Although lithium-ion is currently the most used type of cell, there is no standard cell. A preliminary version of the guidelines will be made available to develop the activities in the other WPs and Tasks and foster developments in cell chemistry. Towards the end of the project, the final revised version of the draft interim guidelines may be proposed to IACS (e.g., to become Unified Interpretations) and forwarded to the IMO, seeking support of Member States and/or NGO to promote their adoption.

Contents

1 Introduction

The overall objective of **SEABAT** is to develop a full-electric maritime hybrid concept based on combining modular high-energy batteries and high-power batteries, novel converter concepts and production technology solutions derived from the automotive sector. A modular approach will reduce component costs (battery, convertor) so that unique ship designs can profit from economies of scale by using standardised low-cost modular components. The concept is suitable for future battery generations and high-power components that may have higher power densities or are based on different chemistries.

This document is part of **Work Package 2**, **Specifications and Requirements**, which main objective is to draw the scope of the project by identifying and defining the different maritime applications that are currently being electrified by using batteries and which maritime applications will be using batteries in the near future and in what way they will be suitable for the application of a hybrid battery system. The battery system requirements for the different applications will be defined based on operational performance, safety requirements, regulations, and integration by standardization. The results of this WP 2 will have a direct impact on components and system design (WP3. WP4). The requirements from this WP 2 will be used to determine the KPIs for the concept selection in WP 3 and will be used for the validation of the results.

Tasks 2.2, 2.3 and 2.4, of this WP2, are the objective of this document. There are currently no international standards for marine battery installations. However, the International Electrotechnical Commission (IEC) is working on standards 62619 and 62620. Some additional requirements are available for transportation of batteries (e.g., UN 38.3 Recommendations on the Transport of Dangerous Goods – Manual of Tests and Criteria). These provisions are referenced as baseline. Classification societies, upon their experience, may have developed specific Rules and/or Additional Class notation supplementing these international regulations. The scope of this task is to draft some interim guidelines aimed at expanding the international requirements and promoting the adoption of a single set of regulations and/or standards. It is acknowledged that parallel activities may be part of the work plan of the international regulatory bodies. It is noted that so far, the range of available cell chemistries and technology made it unfeasible to define a prescriptive set of rules for batteries. Although lithium-ion is currently the most used type of cell, there is no standard cell. A preliminary version of the guidelines will be made available to develop the activities in the other WPs and Tasks and foster developments in cell chemistry. Towards the end of the project, the final revised version of the draft interim guidelines may be proposed to IACS (e.g., to become Unified Interpretations) and forwarded to the IMO, seeking support of Member States and/or NGO to promote their adoption.

As a summary, this document presents the current situation on ship battery regulation, focusing its content in the following aspects:

- analyse the requirements and limitations of the existing battery regulations in different classification societies.
- identify the current framework - regulations, rules, guidelines, codes and standards - applicable to battery installations in vessel design, construction and operation.
- provide references for the correct and safe design, testing and certification of battery installations in the relevant WPs and Tasks of the project,
- evidence regulatory gaps or barriers which may limit the full potential of battery installations on board.

Based upon the lessons learnt in the project, in due course, this regulatory baseline will be further updated as revised draft interim guidelines applicable to the functional design and certification of battery installations on a life-cycle perspective. The results may be proposed to IACS as Unified Interpretations, or be forwarded to the IMO, or to Standard organizations (e.g. ISO), as appropriate.

To achieve this objective, a variety of mandatory and voluntary rules and regulations are considered, issued by different national and international bodies, primarily focused on:

- system design
- constructional requirements
- electrical protection
- charging
- fire and explosion safety
- control, monitoring, alarm and safety systems
- battery management
- energy management
- location
- testing and inspection
- certification

It is very complex to consider systematically the current regulatory framework, due to the number, variety and some fragmentation of the existing provisions. In this review, reference is made to the most used and known rules, regulations, standards issued by the major Classification Societies and Authorities.

Where appropriate, reference is also made to battery installations used by other means of transport or industrial fields.

The editorial structure selected for this review is a set of spreadsheets, clustered in the Annexes according to a logic thematic breakdown, supplemented by specific comments and considerations. This solution is preferred to evidence the regulatory gaps in contrast with well-regulated (or even over-regulated and too prescriptive) requirements.

This editorial structure is also suitable to progress with the activities scheduled in other Tasks, using the spreadsheets as a baseline in the project. Based upon the gaps and lessons learnt in the project, this baseline will be updated in due course with performance criteria and project guidelines for future functional design and certification of battery installations on a life-cycle perspective.

2 Regulatory Analysis

The following breakdown structure is adopted for the regulatory review in this task. The relevant spreadsheets are attached in Annex 1 to this document.

The analysis of the Class requirements for battery installations shows that the terminology used is not always identical, but in general the following key sections are covered:

- General – Application
- Design and construction
- Definitions and acronyms
- System design (safety) requirements
- Location
- Installation
- Battery spaces
- Battery chargers
- Battery Management Systems (BMS)
- Availability of power
- Control, monitoring, alarm and safety systems
- Risk assessment
- Thermal management and ventilation
- Testing, surveys, and inspections
- Certification process
- Operation and maintenance

The following aspects are mostly covered by Class rules:

- Electrical network
- Electrical Installations
- Power availability to ship essential systems – Machinery, Auxiliary Systems, Directional Control Systems
- Remote Control, Alarm and Safety Systems
- Use as UPS for Shipborne Navigational Systems and Equipment
- Operational conditions and requirements

Most of the battery requirements set out by Classification Societies are based on international standards developed by the International Electrotechnical Commission (IEC).

In the following sections, the situation of the battery requirements of the following Classification Societies and international standards will be analysed:

- BUREAU VERITAS
- DNV-GL
- RINA
- LLOYD'S
- ABS
- IEC Standards

The objective is to compare each one of them and obtain an overview of the existing regulations to comply with when building a battery-powered ship.

2.1 Considerations of the regulatory analysis

As a general comment on Classification activities, it is worth recalling that: "The objective of ship classification is to verify the structural strength and integrity of essential parts of the ship's hull and its appendages, and the reliability and function of the propulsion and steering systems, power generation and those other features and auxiliary systems which have been built into the ship in order to maintain essential services on board.

Classification Societies aim to achieve this objective through the development and application of their own Rules and by verifying compliance with international and/or national statutory regulations on behalf of flag Administrations".

Moreover: "In developing its Rules, a Classification Society typically relies on empirical experience gained from classing a wide variety of ship types over many years, coupled with appropriate research that contributes towards the on-going development of relevant, advanced technical requirements."

Further insight on the terms and definitions used throughout this document, relevant to Classification, Surveys and their language and definitions can be found in:
http://www.iacs.org.uk/media/3785/iacs-class-what-why-how.pdf

Regulation 5 of the SOLAS Convention itself offers exemptions and provisions for "equivalents", applicable to any SOLAS regulation: "…for a particular fitting, material, appliance or apparatus, or type thereof, fitted or carried in a ship, or for which a particular provision shall be made, the Administration may allow any other fitting, material, appliance or apparatus, or type thereof, to be fitted or carried, or any other provision to be made in that ship, if it is satisfied by trial thereof or otherwise, that such fitting, material, appliance or apparatus, or type thereof, is at least as effective as that required by the [SOLAS] regulations".

Although this is a broad and strong alternative to SOLAS prescriptive provisions, there are some underlying conditions which need always be considered:

- National authorities (e.g. flag Administrations) have the discretion to permit the use of alternative design and arrangements.
- This discretion is to be based on experimental or other evidence, to be provided to the authority.
- Such evidence must satisfy the general condition that the equivalence is "at least as effective as" SOLAS' express provisions.

These provisions assign the responsibility to the Authority, as well as the discretion of the methodology to demonstrate and accept the equivalence - generally a risk-based assessment. When supporting data, experience, acceptance criteria and safety factors are not clearly established, the authority may have to follow a discretional one-off approach to address the uncertainties and this may take time, sometimes critical for a specific vessel design.

The principle of equivalence supported by a risk-based approach may be applied to novel design principles/features, supplemented by a Technology Qualification Process, based upon experiments, calculations, models, or other supporting information. Any specific limitations resulting from the assessment is to be indicated on the Certificate of Classification. On specific issues, there may be guidelines supporting this process, as applicable, complied with (or based upon) the best information and experience available at the time.
This approach raises the same problems of responsibility and discretion evidenced on SOLAS Reg.5 in terms of methodology to demonstrate and accept the proof of "equivalent level of safety". Once again,

significant discretion is left to national authorities, which can be reliant upon relevant Classification Society rules and/or the guidance stemming from other applicable national standards.

3 Overview of Rules for the Classification of ships with battery installations

3.1 Introduction

The purpose of this section is to make a first assessment of the existing Classification Society rules, to be used for prompt reference.

Five Classification Societies are considered:

- American Bureau of Shipping (ABS),
- Bureau Veritas (BV),
- Det Norske Veritas (DNV),
- Lloyd's Register (LR),
- Registro Italiano Navale (RINA).

of It should be mentioned that most of these classification societies do not have extensive regulations or requirements applicable to lithium ion battery systems, referring for the most part to acid and alkaline battery systems.

In this sense and given that the objective of this deliverable is to analyze and collect the regulations and useful and applicable requirements in SEABAT, which allow to carry out a correct development of the project and the consequent work packages, this document presents the status of the art of each classification society, identifying the existing regulations applicable to battery systems, including Lithium ion batteries, and the gaps present in each one them.

For a best comprehension, all of this is summarized and identified in Annex 1.

3.2 General methodology for approval of battery installations

Different certification schemes are usually used by Classification Societies to assess materials and equipment fitted on classed ships.

These global schemes are based upon the following steps of assessment:

- General design,
- System / component assessment,
- Specimen tests,
- Manufacturing and testing at works,
- Final testing, inspection, commissioning

The assessment requires the definition of:

- Type testing program and standard to be used for the assessment methodology;
- Validation criteria of test results and assessment,
- Body in charge of tests and assessments, and responsibilities (manufacturer / independent laboratory / Classification Society),
- Type of certificates granted to certify the assessment process, and body in charge to issue these certificates.

The activities at the manufacturer premises are aimed at assessing compliance of the materials and components manufactured in mass production and may include a verification of:

- The quality system of the manufacturer including the organization of production, the personal qualification, the quality controls and testing during mass production, the work instructions, the traceability of the production (inspection recording during production, handling of non-conformities), internal audit carried out by the manufacturer, etc.

- Audits and periodical visits carried out by the Classification Society.

To complete a satisfactory assessment of battery installations and issue the appropriate certification, the flag Administration is to be involved and experience shows that the submission of the following documents is usually required:

- System schematics of power generation / power distribution of the ship, with indication of the battery connections in the network,
- Data sheets of battery installations, supplied by the manufacturer, including the Factory Acceptance safety Tests,
- Risk assessment report,
- Approved drawings of battery installations, with specific focus on:
    - Battery Management System functionalities
    - Interface with EMS/PMS
- Approved drawings of safety-related systems of the battery room(s):
    - Ventilation of- exhaust from battery cells
    - Fire extinction, cooling
    - Fire detection and monitoring
- Evidence that notes to approved drawings and actions / risk control options identified in the risk assessment are properly implemented.

Next, the regulations established by each classification society are explained.

4 Bureau Veritas (BV)

In 2017, the Bureau Veritas S.A (BV hereinafter), announced that, in response to a growing number of hybrid vessels entering service, the certification agency has launched a new series of notations and rules addressing the requirements of energy storage systems (ESS) to support ship operations in reducing emissions.

The new rules and notations are said to provide a framework for electric and hybrid power solutions, with the notations covering power management (PM), power back-up (PB) and zero emission (ZE) standards.

This new regulation launched by Bureau Veritas is included in the following regulations, that will be analysed in the following sections of this document:

- NR467 STEEL SHIPS – January 2021 edition (entry into force 1 January 2021)
- NR566 SHIPS LESS THAN 500GT – July 2018 edition (entry into force 1 July 2018)
- NR217 INLAND NAVIGATION VESSELS – February 2019 edition (entry into force 1 February 2019)
- NR500 YACHTS – January 2016 edition (entry into force 1 January 2016)

4.1 BV Rules: NR467 for steel ships

BV Rules for the classification of steel ships are applied to seagoing steel ships. They provide detailed requirements for the assignment and the maintenance of BV classed ships.

The classification notations give the scope according to which the class of the ship has been based and refer to the specific rule requirements which are to be complied with for their assignment. In particular, the classification notations are assigned according to the type, service and navigation of the ship and other criteria which have been provided by the Interested Party, when applying for classification. The classification notations assigned to a ship are indicated on the Certificate of Classification, as well as in the Register of Ships published by the Society.

The requirements presented in this publication regarding the design, storage, location, and maintenance of batteries will be described below in the next paragraph of this document. All of them are included in **Pt C (MACHINERY, ELECTRICITY, AUTOMATION AND FIRE PROTECTION)** of the BV rules NR467 for Steel Ships.

In this regard, to cover the ships that carry battery propulsion, BV has issued the class notation **BATTERY SYSTEM** described below, presented on the **Part F (class notation)** of the BV Rules NR467 for Steel Ships. In addition, about battery subjects, in Bureau Veritas rules, another two classes notation were added: **ELECTRIC HYBRID** and **ELECTRIC HYBRID PREPARED**, Both, also described below in this document.

4.1.1 Electrical installation requirement

The requirements about design, installation, and storage of batteries, relative to all steel ships, regardless of whether they belong to any specific batteries class notation, are included on the Pt C Machinery, Electricity, Automation and Fire Protection on the BV Rules NR467. In particular, the general design requirements are described in Ch.2, Sec. 3, 7, 11 and 12, edition January 2021.

4.1.2 System design

The system design is described in the section 3 and the electrical protection is appeared in the Article 7 of this section. Referred to the protection of storage batteries (refer to NR467 Pt C, Ch.2, Sec.3, Article 7.11, edition January 2021), batteries are to be protected against overload and short-circuit by means of fuses or multipole circuit-breakers at a position adjacent to the battery compartment.

Overcurrent protection may be omitted for the circuit to the starter motors when the current drawn is so large that is impracticable to obtain short-circuit protection. When conductors from the batteries are not protected against short-circuiting and overload, they are to be installed to be adequately protected against short-circuits and earth faults and as short as possible, e.g., starting batteries for emergency generator or fire pumps engines in the same skid or very near.

4.1.3 Storage batteries and chargers

The general requirements for storage batteries and chargers are described on section 7 (refer to NR467 Pt C, Ch.2, Sec.7, edition January 2021). The requirements of this section are applied to permanently installed storage batteries (not to portable batteries).

Vented batteries are those in which the electrolyte can be replaced and freely releases gas during periods of charge and overcharge and are to be constructed to withstand the movement of the ship and the atmosphere (salt mist, oil etc.) to which they may be exposed.

A new paragraph about Li Ion batteries became effective on 1st January 2021. For Li Ion batteries of capacity above 20kWh, the requirements are specified in the additional notation **BATTERY SYSTEM** (refer to Pt F, Ch.11, Sec.21, edition January 2021) who is described in chapter 3.1.2 of this document. Likewise, for Li Ion batteries used as emergency source or transitional source or of capacity above 20kWh, the requirements specified in the additional notation **BATTERY SYSTEM**.

Also, in this section the battery maintenance is described. Where batteries are fitted for use for essential and emergency services, a schedule of such batteries is to be compiled and maintained. The schedule, which is to be reviewed by the Society, is to include at least the following information regarding the batteries:

- Maintenance/replacement cycle dates.
- Date of last maintenance and/or replacement.
- For replacement batteries in storage, the date of manufacture and shelf life.

4.1.4 Location

The requirements of batteries location are described in the section 11 of NR467 Pt C, Ch.2, edition January 2021. The first 5 articles of this session describe general aspects, the main electrical system, the emergency electrical system, the distribution boards and the cable runs.

Article 6 is called storage batteries and it is the part that contains more aspects on location requirements applied to batteries.

Batteries are to be located where they are not exposed to excessive heat, extreme cold, spray, steam or other conditions which would impair performance or accelerate deterioration. They are to be installed in such a way that no damage may be caused to surrounding appliances by the vapours generated.

Storage batteries are to be suitably housed, and compartments (rooms, lockers, or boxes) used primarily for their accommodation are to be properly constructed and efficiently ventilated to prevent accumulation of flammable gas.

Starter batteries are to be located as close as practicable to the engine or engines served.

Accumulator batteries shall not be in sleeping quarters except where hermetically sealed to the satisfaction of the Society.

It is important to consider the BV classification of battery types based on power:

- **Large vented batteries**: there are the batteries connected to a charging device of power exceeding 2 kW, calculated from the maximum obtainable charging current and the nominal voltage of the battery are to be installed in a room assigned to batteries only. Where this is not possible, they may be arranged in a suitable locker on deck. Rooms assigned to large batteries are to be provided with mechanical exhaust ventilation. Natural ventilation may be employed for boxes located on open deck.
- **Moderate vented batteries**: there are the batteries connected to a charging device of power between 0,2 kW and 2 kW. There are to be arranged in the same manner as large batteries or placed in a box or locker in suitable locations such as machinery spaces, storerooms, or similar spaces. In machinery spaces and similar well-ventilated compartments, these batteries may be installed without a box or locker provided they are protected from falling objects, dripping water and condensation where necessary.

  Rooms, lockers, or boxes assigned to moderate batteries are to be provided with natural ventilation or mechanical exhaust ventilation, except for batteries installed without a box or locker (located open) in well-ventilated spaces.

- **Small vented batteries**: there are the batteries connected to a charging device of power less than 0,2 kW. There are to be arranged in the same manner as moderate or large batteries, or without a box or locker, provided they are protected from falling objects, or in a box in a ventilated area. Boxes for small batteries may be ventilated only by means of openings near the top to permit escape of gas.

This part of the Rules (refer to NR467 Pt C, Ch.2, Sec.11, Article 6.5 Ventilation, edition January 2021) proposes three ways of ventilating the batteries:

- Exhaust ducts of **natural ventilation systems**:
  a) are to be run directly from the top of the compartment to the open air above (they may terminate in the open or in well-ventilated spaces).
  b) are to terminate not less than 90 cm above the top of the battery compartment.
  c) are to have no part more than 45° from the vertical.
  d) are not to contain appliances (for example for barring flames) which may impede the free passage of air or gas mixtures.

- In **mechanical exhaust ventilation systems**:
  a) electric motors are to be outside the exhaust ducts and battery compartment and are to be of safe type if installed within 3 m from the exhaust of the ventilation duct.
  b) fans are to be so constructed and of a material such as to render sparking impossible in the event of the impeller touching the fan casing.
  c) steel or aluminium impellers are not to be used.
  d) the system is to be interlocked with the charging device so that the battery cannot be charged without ventilation (trickle charge may be maintained).
  e) a temperature sensor is to be in the battery compartment to monitor the correct behaviour of the battery in cases where the battery element is sensitive to temperature.

- For **natural ventilation systems for deck boxes**:
  a) holes for air inlet are to be provided on at least two opposite sides of the box.
  b) the exhaust duct is to be of ample dimensions.
  c) the duct is to terminate at least 1,25 m above the box in a gooseneck or mushroom-head or the equivalent.

4.1.5 Installation

In the Article 5 of this section (refer to NR467 Pt C, Ch.2, Sec.12, Article 5.1 and Article 5.2, edition January 2021) vented type storage batteries, the protection against corrosion is to be described.

The interior of battery compartments (rooms, lockers, boxes) including all metal parts subject to the electrolyte is to be protected against the deteriorating effect of the latter by electrolyte-resistant coating or other equivalent means, unless corrosion-resistant materials are used.

Interior surfaces of metal shelves for battery cells, whether grouped in crates or trays, are to be protected by a lining of electrolyte-resistant material, watertight and carried up to at least 75 mm on all sides. Alternatively, the floor of the room or locker is to be lined as specified above to a height of at least 150 mm

For more details of electrical installation requirement related to batteries, please refer to NR467 Pt C, Ch.2, Sec.3 & Sec.7 & Sec.11 & Sec.12 (edition January 2021).

4.1.6 Battery system class notation

Based on BV Rules NR467 Pt F, Ch.11, Sec.21, edition January 2021, the additional class notation **BATTERY SYSTEM** may be assigned to ships when batteries are used for propulsion and/or electric power supply purpose during ship operation. This notation is mandatory when the ship is relying only on batteries for propulsion and/or electrical power supply for main sources. When an emergency source of power is required on board the ship, it is to remain independent from the battery source considered for propulsion and/or main source of power. Batteries may be of the lead-acid type, nickel alkaline type or lithium type, due consideration being given to the suitability for any specific application. Other types of batteries may be considered.

To develop this class notation, BV consider the following definition:

- **Battery management system (BMS):** A battery management system is an electronic system associated with a battery pack which monitors and/or manages in a safe manner its electric and thermal state by controlling its environment, and which provides communication between the battery system and other macro-system controllers, such as a power management system (PMS).
- **Battery pack:** Battery pack means one or more sub-packs that can work or the intended purpose as a standalone unit.
- **Battery support system (BSS):** A battery support system is a group of interconnected and interactive parts that performs an essential task as a component of a battery system.
- **Battery system:** A battery system is an energy storage device that includes cells, cell assemblies or battery pack(s), as well as electrical circuits and electronics (example of electronics: BMS, BSS, cell electronics).
- **Cell:** Cell means the smallest unit of a battery.
- **Cell electronics:** Cell electronics means the electronic device that collects and possibly monitors thermal and electric data of cells or cell assemblies and contains electronics for cell balancing, if necessary, as well as over-current protection devices (e.g., fuse).
- **Module:** A module is an assembly of cells including some levels of electronic control.
- **Rated capacity:** Rated capacity means Supplier's specification of the total amount of ampere hours that can be withdrawn from a fully charged battery pack or system for a specified set of test conditions, such as discharge rate, temperature, and discharge cut-off voltage.
- **State of charge (SOC):** State of charge means the available capacity in a battery pack or system, used to estimate the current charge level of a battery in use.
- **State of health (SOH):** State of health means the available capacity in a battery pack or system as a function of the battery lifetime.
- **Sub-pack:** Sub-pack means the assembly of one or more modules. This is the smallest unit that can be electrically isolated.

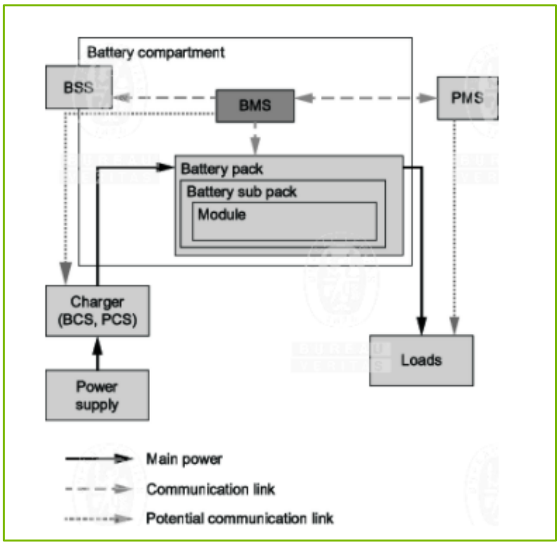


Figure 1 BV battery system considered

In the Article 3 of this section (refer to NR467 Pt F, Ch.11, Sec.21, Articles 3, edition January 2021), the safety and design issues are described. On the one hand, security measures are considered for a battery compartment and on the other hand the security requirement for battery pack are presented.

Refer to battery compartment, to complete the requirements of BV Rules Pt C, Ch.2 mentioned above, requirements on the following three aspects became effective on 1st July 2020:

- Ventilation
- Protection against water entry and/or liquid leakage in battery compartment
- Fire protection

Refer to the battery pack cooling, it is to be ensured either by the ventilation of the battery compartment or by direct cooling (dedicated cooling circuit). When a direct cooling is installed, the following alarms are to be provided, where applicable:

- High temperature of the cooling air of battery pack provided with forced ventilation.
- Reduced flow of primary and secondary coolants of Battery packs having a closed cooling system with a heat exchanger.

Based on the new paragraph (entry into force 1st July 2020) of the battery pack, as for the lithium type batteries, a risk analysis covering together battery packs, battery compartment and BMS is to be conducted and submitted to the Society for review.

The following items, at least, are to be covered: risk of thermal runaway, risk of emission of combustion gases, risk of internal short-circuit, risk of external short-circuit, risk of sensor failure (voltage, temperature, gas sensor), risk of high impedance (cell, connectors,), risk of loss of cooling, risk of leakage (electrolyte, cooling system), risk of failure of BMS (error on manoeuvring breakers, overloading, over discharge) and risk for external ingress (fire, fluid leakage, fire-fighting water).

For more details of the battery system class notation, please refer to NR467 Pt F, Ch.11, Sec.21, Articles 1 to 5 (edition January 2021).

4.1.7 Electrical hybrid class notation

Based on BV Rules NR467 Pt F, Ch.11, Sec.22, edition January 2021, the additional class notation **ELECTRIC HYBRID** may be assigned in accordance with Pt A, Ch.1, Sec.2, to ships provided with an Energy Storage System (ESS) used to supply the electric propulsion and/or the main electrical power distribution system of the ship.

The notation **ELECTRIC HYBRID** is to be completed, between brackets, by at least one of the following complementary notations:

- PM when at least one of the following Power Management mode is available:
  - load smoothing mode
  - peak shaving mode
  - enhanced dynamic mode,
- PB when Power Backup mode, is available.
- ZE when Zero Emission mode, is available.

Referring to the ESS (Energy Storage System) charging, in the Article 3 of this section, after partial or full discharge, the charging current of the batteries will be limited due to the high temperature of the battery cells.

Therefore, in PB and ZE mode, the charging current and the time to charge completely the batteries is to be evaluated during a charging test, just after the ESS has been discharged in the conditions of load balance for PB or ZE mode.

For more details of the Electrical Hybrid Class Notation, please refer to NR467 Pt F, Ch.11, Sec. 22, Articles 1 to 5 (edition January 2021).

4.1.8 Electrical hybrid prepared class notation

Based on BV Rules NR467, Pt F, Ch.11, Sec.29, edition January 2021, the additional class notation **ELECTRIC HYBRID PREPARED** may be assigned, in accordance with Pt A, Ch.1, Sec.2, to new ships that are designed with specific arrangements intended to accommodate an Electric Hybrid installation in the future.

The additional class notation **ELECTRIC HYBRID PREPARED** gives the opportunity to the ship owner to delay the installation on board of the batteries and their associated equipment to anticipate new developments in battery technologies and therefore, to take benefit of their last improvements in terms of discharge rates, power density, safety, life cycle, cost, in view of future conversion to electric hybrid.

The pieces of equipment intended for conversion to electric hybrid need not be provided onboard at newbuilding stage. The additional class notation **ELECTRIC HYBRID PREPARED** aims at controlling the impact of the conversion to electric hybrid on the existing installation by considering the corresponding main design requirements.

This class notation is to be complemented by one or by a combination of the following complementary notations:

- PM when at least one of the following Power Management mode is intended to be available:
    - load smoothing mode
    - peak shaving mode
    - enhanced dynamic mode,
- PB when Power Backup mode is intended to be available.
- ZE when Zero Emission mode is intended to be available.

Referring to the ESS (Electric Energy Storage System), in the Article 3 of this section, the following design parameters of the batteries intended to be installed at conversion to electric hybrid stage are to be specified in the dimensioning analysis: technology, nominal voltage, nominal capacity, discharging rates (C rate) and autonomy in the different modes (PB, ZE).

For more details of the electrical hybrid prepared class notation, please refer to NR467 Pt F, Ch.11, Sec.29, Articles 1 to 5 (edition January 2021).

4.2 BV Rules: NR566 for ships less than 500GT

Requirements of these rules are specific to ships and non-propelled units of less than 500 GT without restriction in hull construction material.

However, the following types of ships are not covered by these rules:

- Passenger ships with unrestricted navigation
- Ro-ro passenger ships with unrestricted navigation
- Fishing vessels
- High speed craft
- Yachts
- Chemical tankers
- Liquefied gas carrier

Relaxations on requirements referred to in this rule are applied on the following ships:

- Ships with navigation notation **SHELTERED AREA** or **COASTAL AREA**
- Ships with service notation **LAUNCH** or **SEAGOING LAUNCH**
- Ships with service notation **LIGHT SHIP** or **CREW BOAT** and navigation **notation SEA AREA 1**, **SEA AREA 2** and **SEA AREA 3**.

The requirements related to batteries (design, equipment, location, and installation), in this Rule, are set out in chapter 3 electricity and automation (refer to NR566, Ch.3, Sec.1 to Sec.4, edition July 2018).

In this chapter 3 (Electricity and Automation), it is defined:

- **Vented battery**: a vented battery is one in which the cells allow products of electrolysis and evaporation to escape freely to the atmosphere and can receive additions to the electrolyte.
- **Valve regulated sealed battery**: a valve regulated sealed battery is one in which the cells are closed but have a valve which allows the escape of gas if the internal pressure exceeds a predetermined value. The electrolyte cannot normally be replaced.

4.2.1 System design

In section 2 of the chapter 3 (refer to NR566, Ch.3, Sec.2, Article 3-Article 6 to 8, edition July 2018) different aspects of the system design are described. Battery related subjects described in this section are as follows:

- D.C distribution system supplied from batteries (refer to NR566, Ch.3, Sec.2, Article 3.4, edition July 2018). Each battery or group of batteries is to be capable of being isolated from the d.c. system, which is supplied, normally by a switch. Isolation switches are to be placed in a readily accessible location as closed as practical to the battery or group of batteries, but outside the battery compartment or container.
- Protection of storage batteries (refer to NR566, Ch.3, Sec.2, Article 6.6, edition July 2018). Batteries are to be protected against overload and short-circuit by means of fuses or multipole circuit-breakers placed as closed as practicable to the batteries but outside the battery compartment or container. Emergency batteries supplying essential services are to have short-circuit protection only.
- Choice of cables (refer to NR566, Ch.3, Sec.2, Article 7.8, edition July 2018)

Electrical installations in battery rooms (refer to NR566, Ch.3, Sec.2, Article 8.2, edition July 2018). Only lighting fittings may be installed in compartments assigned solely to large vented storage batteries.

4.2.2 Equipment

In the equipment section, section 3, of chapter 3 (refer to NR566, Ch.3, Sec.3, Article 6, edition July 2018), the constructional requirements for batteries and chargers are described. There are applied to permanently installed storage batteries (not to portable batteries).

Storage batteries may be of the lead-acid or nickel-alkaline type, due consideration being given to the suitability for any specific application.

Other types of storage batteries of satisfactorily proven design (e.g., silver/zinc) may be accepted provided they are suitable for shipboard use to the satisfaction of the Society.

Cells are to be assembled in suitable crates or trays equipped with handles for convenient lifting Battery terminal connectors which depend on tension for mechanical connection to the terminal are not to be used.

Requirements for valve-regulated sealed batteries and chargers at the same than exposed on the Rules for Steel Ships, please for more information refer to NR566, Ch.3, Sec.3, Article 6.3, 6.4 and 6.5, edition July 2018.

4.2.3 Location and installation

In article 5 of the section 4 is where the requirements of the batteries related to the location, their storage and installation are described (refer to NR566, Ch.3, Sec.4, Article 5, edition July 2018).

As it was mentioned already in the steel ship rule chapter, batteries are to be located where they are not exposed to excessive heat, extreme cold, spray, steam or other conditions which would impair performance or accelerate deterioration. They are to be installed in such a way that no damage may be caused to surrounding appliances by the vapours generated. Storage batteries are to be suitably housed, and compartments (rooms, lockers, or boxes) used primarily for their accommodation are to be properly constructed and efficiently ventilated so as to prevent accumulation of flammable gas.

BV classification of battery types based on power, ways of ventilating the batteries and requirements are mentioned in this section. These definition and classification being the same as already described in steel ship rules.

For classification batteries:

- Large vented batteries
- Moderate vented batteries
- Small vented batteries

For proposal ways of ventilating the batteries:

- Natural ventilation systems
- Mechanical exhaust ventilation systems
- Natural ventilation systems for deck boxes

4.3 BV Rules: NR217 for inland navigation vessels

These BV Rules give the requirements for the assignment and the maintenance of class for inland navigation vessels as well as vessels operated in restricted maritime stretches of water.

As steel ships, the type and service notation may be also completed by the additional service depending upon vessel mode of propulsion, hull structural configuration and hull materials.

In this regards, these inland navigation vessels may be completed by the additional class notation **BATTERY SYSTEM** when batteries are used for propulsion and / or electric power supply purpose during operation of the vessel. This additional service feature is mandatory when the vessel is only relying on batteries for propulsion and / or electrical power supply for main sources. The requirements for the assignment of this additional class notation are given in the Rules for the Classification of Steel Ships (refer to NR467, Pt F, Ch.11, Sec 21, edition January 2021).

It is important to know that when a vessel is assigned the additional class notation **ELECTRIC HYBRID**, it is not necessary to assign the additional class notation **BATTERY SYSTEM** (refer to NR467, Pt F, Ch.11, Sec 22, edition January 2021).

4.3.1 Storage batteries

The BV Rules for inland navigation vessels are applied to permanently installed storage batteries. Only storage batteries suitable for vessels usage can be used. Storage batteries must follow and tested according to recognised standards, e.g.:

- IEC 60896-11 or IEC 60896-21,22, for Lead-acid batteries
- IEC 60622, IEC 60623 or IEC 62259, for Nickel-Cadmium batteries.

For more details, refer to NR217, Pt C, Ch.2, Sec.5, edition February 2019.

4.3.2 Installation and location

The following general requirements are listed in this Rule to describe the installation and location of the batteries installed on board (refer to NR217, Pt C, Ch.2, Sec.5, Article 4, edition February 2019):

- Storage batteries are to be installed in such a way that they are accessible for cell replacement, inspection, testing, topping-up and cleaning. The installation of batteries in the accommodation area, in cargo holds and wheelhouses is not permissible. Gastight batteries be an exception, e.g., in case of internal power source of emergency lighting fittings.
- Storage batteries are not to be installed in locations where they are exposed to unacceptably high or low temperatures, spray, or other effects liable to impair their serviceability or reduce their life essentially. They are to be installed in such a way, that adjacent equipment is not damaged by the effects of escaping electrolyte vapours.
- Measures are to be taken to prevent storage batteries from shifting. The braces used shall not impede ventilation.
- For the installation of storage batteries, the total power of associated charger must be considered. The charging power is to be calculated from the maximum current of the battery charger and the rated voltage of the battery.

4.3.3 Ventilation

The general requirements about battery ventilation described that all battery installations in rooms, cabinets and containers shall be constructed and ventilated in such a way as to prevent the accumulation of ignitable gas mixtures. However, Gastight NiCd-, NiMH- or Li- batteries may not be ventilated.

Ventilation subjects described in this section are as follows:

- Batteries installed in switchboards charging power up to 0,2 kW. Lead batteries with charging power up to 0,2 kW may be installed without separation to the switchgear, if: the batteries are of valve regulated type (VRL), provided with solid electrolyte, and the switchboards are not closed completely (IP 2X will be suitable), and the charger is an automatic IU-charger with a maximum continuous charging voltage of 2,3 V/cell and rated power is limited on 0,2 kW.
- Ventilation spaces, battery charging power up to 2 kW.
- Ventilated room, battery charging power more than 2 kW. If the charging power of batteries exceeds 2 kW, it must be installed either in closed cabinets, containers, or a battery room to be ventilated to the open deck. Lead batteries up to 3 kW still may be ventilated by natural ventilation. Battery rooms are to exhaust to open deck area. It should be used forced ventilation. Doors to battery rooms must be gastight with self-closing devices without holding back means.
- Forced ventilation.

For more details about ventilation aspect, refer to NR217, Pt C, Ch.2, Sec.5, Article 6, edition February 2019)

4.3.4 Starter batteries

The general requirements of starter batteries described in this section (refer to NR217, Pt C, Ch.2, Sec.5, Article 8, edition February 2019) are:

- Storage batteries for starting internal combustion engines shall be designed to have sufficient capacity for at least six starting operations in 30 minutes without intermediate recharging.
- Starter batteries shall be capable of being recharged with the means available on board and may only be used to start engines and supply energy to the monitoring systems allocated to them.
- Starting internal combustion engines with the vessel's supply battery is permitted only in emergencies.
- Wherever possible storage batteries used for starting and preheating internal combustion engines are to be located close to the machines.

For more details about ventilation aspect, refer to NR217, Pt C, Ch.2, Sec.5, Article 8, edition February 2019)

4.3.5 Rating of storage battery chargers

In this section is described that charging equipment shall be so rated that discharged storage batteries can be charged to 80% of their rated capacity within a period not greater than 15 hours without exceeding the maximum permissible charging currents.

Only automatic chargers shall be used with charging characteristic adapted to the type of batteries. If consumers are simultaneously supplied during charging, the maximum charging voltage shall not exceed 120% of the rated voltage. The power demand of the consumers shall be considered for the selection of the chargers.

The mentioned above are the general requirements for battery chargers but for more details, refer to NR217, Pt C, Ch.2, Sec 5, Article 9, edition February 2019.

4.3.6 Test onboard

Related to the battery tests, for the storage batteries, the following shall be tested:

- Installation of storage batteries.
- ventilation of battery rooms, cupboards/containers, and cross-sections of ventilation ducts.
- storage-battery charging equipment.
- the required caution labels and information plates.

For more details about the tests to carry out on board, please refer to NR217, Pt C, Ch.2, Sec.17, Article 3, edition February 2019.

4.4 BV Rules: NR500 for yachts

The requirements of these Rules are specific to yachts intended for pleasure cruising and not exceeding 100 m in length. Yachts exceeding 100 m in waterline length are considered by the Society on a case-by-case basis of NR467 Rules for the Classification of Steel Ships and these Rules.

Yachts covered by these Rules are designated with the following service notations:

- **YACHT** when the ship is not engaged in trade.
- **CHARTER YACHT** when the ship is engaged in trade.

It is in part C of these Rules, chapter 2 electrical installation, where the main aspects related to the installation of batteries in yachts are described (refer to NR500, Pt C, Ch.2, Sec.1 to 4, edition January 2016).

4.4.1 General requirements

Two important definitions are outlined in this general requirement section (refer to NR500, Pt C, Ch.2, Sec.1, Article 3, edition January 2016):

- **Vented battery**: a vented battery is one in which the cells allow products of electrolysis and evaporation to escape freely to the atmosphere and can receive additions to the electrolyte.
- **Valve regulated sealed battery**: a valve regulated sealed battery is one in which the cells are closed but have a valve which allows the escape of gas if the internal pressure exceeds a predetermined value. The electrolyte cannot normally be replaced.

Electrical apparatus, batteries, generators, electrical cables are not to be located, as far as practicable near magnetic compass, or other navigational aids and instruments likely to be sensitive to electromagnetic disturbances.

Finally, for yachts greater than 24 m, the international Rules IEC60533 and IEC60945 may be used for guidance.

4.4.2 System design

In section 2 of the chapter 2 different aspects of the system design are described. Battery related subjects described in this section are as follows:

- Sources of electrical power (refer to NR500, Pt C, Ch.2, Sec.2, Article 2.1, edition January 2016). For yachts whose length is less than 24 m, it is to be fitted with a source of electrical power of sufficient capacity to supply all essential services necessary for their normal operation. The source of power may consist of batteries and d.c. or a.c. generator(s). Where d.c. generator(s) are provided, they are to be capable of supplying the total load and simultaneously be capable of charging the batteries to 80% charge within 10 hours.
- D.C distribution system supplied from batteries (refer to NR500, Pt C, Ch.2, Sec.2, Article 3.5, edition January 2016). Each battery or group of batteries is to be capable of being isolated from the d.c. system, which is supplied, normally by a switch in the positive conductor. Isolation switches are to be placed in a readily accessible location as closed as practical to the battery or group of batteries, but outside the battery compartment or container.
- Protection of storage batteries (refer to NR500, Pt C, Ch.2, Sec.2, Article 6.6, edition January 2016). Batteries are to be protected against overload and short-circuit by means of fuses or multipole circuit-breakers placed as closed as practicable to the batteries but outside the battery compartment or container.
- Choice of cables (refer to NR500, Pt C, Ch.2, Sec.2, Article 7.8, edition January 2016).

- Electrical installation in battery rooms (refer to NR500, Pt C, Ch.2, Sec.2, Article 8.2, edition January 2016). Only lighting fittings may be installed in compartment assigned solely to large vented storage batteries. Standard marine electrical equipment may be installed in compartments assigned solely to valve-regulated sealed storage batteries.

For more details about system design for yachts regulation, refer to NR500, Pt C, Ch.2, Sec.2, edition January 2016.

4.4.3 Equipment

In the equipment section, section 3, of chapter 2, the constructional requirements for batteries and chargers are described:

- Constructional requirements for batteries apply to permanently installed storage batteries. Vented batteries are to be constructed to withstand the movement of the yacht and the atmosphere (e.g., salt mist) to which they may be exposed. No spillage of electrolyte is to occur at any inclination angle up to 45° from the vertical.
- Constructional requirements for chargers. Chargers are to incorporate a voltage regulator and a charge indicator. The charging facilities for batteries are to be such that the completely discharged battery may be charged to 80% charge within a period of 10 hours without exceeding the maximum permissible charging current and having due regard for service requirements.

For more details of equipment subjects on yacht Rules, refer to NR500, Pt C, Ch.2, Sec.3, Article 6, edition January 2016.

4.4.4 Installation

In the article 4 of the section 4 is where the requirements of the batteries related to the location and the installation are described (refer to NR500, Pt C, Ch.2, Sec.4, Article 4, edition January 2016).

As it was mentioned already in the steel ship rule chapter, batteries are to be located where they are not exposed to excessive heat, extreme cold, spray, steam or other conditions which would impair performance or accelerate deterioration. They are to be installed in such a way that no damage may be caused to surrounding appliances by the vapours generated. Batteries are to be secured against movements and inclinations occurring during yacht operation. On sailing yachts, and small motor yachts, batteries are to be secured sufficiently to prevent them from breaking free in the event of a complete capsize (i.e., inversion).

Where vented batteries are fitted in machinery spaces, drip trays or containers resistant to the effects of the electrolyte are to be provided.

Batteries are not to be installed directly above or below a fuel tank or fuel filter and any other metallic component of the fuel system within 300 mm above the battery top, as installed is to be electrically insulated. Batteries are not to be in sleeping quarters except where hermetically sealed to the satisfaction of the Society.

BV classification of battery types based on power, ways of ventilating the batteries and requirements are mentioned in this section. These definition and classification being the same as already described in steel ship rules.

For classification batteries:

- Large vented batteries
- Moderate vented batteries
- Small vented batteries

For proposal ways of ventilating the batteries:

- Natural ventilation systems
- Mechanical exhaust ventilation systems
- Natural ventilation systems for deck boxes

5 DNV-GL

5.1 Electrical installation

The requirements about battery system design, battery protection and battery installation, relative to all ships, regardless of whether they belong to any specific batteries class notation, are included on the Part 4 (System and Components), Chapter 8 (Electrical Installation) on DNV-GL Rules, edition July 2020.

5.1.1 Battery definition

The DNV-GL Rules in Part 4, Ch.8, Sec.13, Article 1.10 (edition July 2020), give the following definitions about battery installed onboard:

- **Vented batteries** are of the type of where individual cells have covers, which are provided with an opening, through which products of electrolysis and evaporation are allowed to escape freely from the cells to atmosphere.
- **Valve-regulated batteries** are of the type in which the cells are closed but have an arrangement (valve) that allows the escape of gas if the internal pressure exceeds a predetermined value.
- **Sealed batteries** are of the type in which cells are hermetically sealed. For abuse conditions a safety vent or venting mechanism shall exist.

5.1.2 Battery system

The battery system design is described in DNV-GL Rules, Part 4, Ch.8, Sec.2, article 4, edition July 2020. The general requirement listed in this Rule are as follow:

- Batteries shall be used for power supply required by these Rules shall be dimensioned for the time required for the intended function at an ambient temperature of 0°C unless heating is provided.
- Every battery system shall have its own dedicated charging device (i.e., to constitute a battery system).
- Battery systems shall be so rated that they can supply the consumers for the required period, in accordance with the energy balance, when charged to 80% of their rated capacity.
- Each charging device is, at least, to have sufficient rating for recharging to 80% of rated battery capacity, within 10 hours, while the system has normal load.
- The battery charger shall be suitable to keep the battery in full charged condition, (float charge), taking into account battery characteristics, temperature, and load variations. If the battery requires special voltage regulation to obtain effective recharging, then this shall be automatic. If manual boost charge is provided, then the charger shall revert to normal charge automatically.

5.1.3 Protection

The battery protection, in particular the battery circuits protection, is described in DNV-GL Rules, Part 4, Ch.8, Sec.2, article 7.6, edition July 2020. The general requirement listed in this Rule are as follow:

- Circuits connected to batteries above 12 V or above 1 Ah capacity shall have short circuit and overcurrent protection. Protection may also be required for smaller batteries capable of posing a fire risk. Short circuit protection shall be located as close as is practical to the batteries, but not inside battery rooms, lockers, boxes or close to ventilation holes. The connection between the battery and the charger is also to have short circuit protection.
- Connections between cells and from poles to first short circuit protection shall be short circuit proof.
- The main circuit from a battery to a starter motor may be carried out without protection. In such cases, the circuit shall be installed short circuit proof, and with a switch for isolating purposes.

5.1.4 Battery installation

The requirements of battery installation are applicable to all type of rechargeable NiCd and lead acid batteries, based on DNV-GL Rules, Part 4, Ch.8, Sec.2, article 9.4, edition July 2020.

The general requirements about the arrangement of the battery room are as follow:

- Accumulator batteries shall be suitably housed, and compartments shall be properly constructed and efficiently ventilated.
- Batteries shall be so located that their ambient temperature always remains within the manufacturer's specification.
- Battery cells shall be placed so that they are accessible for maintenance and replacement.
- Batteries shall be so installed that battery poles are covered/protected such that a short circuit is prevented in case of falling objects or other incidents.
- Batteries shall not be in sleeping quarters. Exemptions shall be justified and will be specially considered.
- Batteries shall not be located in a battery box at open deck exposed to sun and frost. Batteries may exceptionally be accepted located at open deck on the conditions that the box is white in colour, are provided with ventilation and heating, and that the charger is provide with temperature compensation capability.

5.1.5 Equipment batteries

The requirements exposed on DNV-GL Rules, Part 4, Ch.8, Sec.10, article 2.3 (edition July 2020) are apply to all stationary accumulator batteries:

- Battery stands, boxes and lockers shall be fixed to the vessel's structure. The batteries shall be fixed or supported on the shelves. Shelves and fixings shall be constructed to withstand the forces imparted from the batteries, during heavy sea.
- All materials used for the construction, including ventilation ducts and fans, shall be corrosion resistant or shall be protected against corrosion by suitable painting, with consideration given to the type of electrolyte actually used.
- Except when corrosion resistant materials are used, the shelves in battery rooms and lockers and the bottom of battery boxes shall be covered with a lining of corrosion resistant material, having a minimum thickness of 1.5 mm and being carried up not less than 75 mm on all sides (e.g., lead sheath for lead and acid batteries, steel for alkaline batteries).

5.2 Class notation BATTERY

Since the October 2015 edition, the DNV classification society has been developing a class notation for the use of batteries in ship propulsion. The additional class notation **BATTERY** facilitates the use of electrical energy storage (EES) installations on electric and hybrid vessels.

The additional class notation **BATTERY** sets requirement for safety and availability of EES installations onboard vessels.

The requirements of batteries are presented in the Part 6 of the Rules, Additional Class Notation, in the chapter 2: Propulsion, Power generation and Auxiliary system, in the section 1, electrical energy storage. These Rules cover design, installation and certification requirements for lithium-ion battery systems and electrochemical capacitor systems.

As specified in the following table, the addition class notation **BATTERY (SAFETY)** or **BATTERY (POWER)** must be given to vessels that meet the requirements described in the Rules Part 6, Ch.2, Sec.1 Electrical Energy Storage (edition July 2020).

Class notation	*Qualifier*	*Purpose*	*Application*
Battery Mandatory: Yes Design requirements: [2] and [3] Survey requirements for fleet in service: Pt.7 Ch.1 Sec.2 and Pt.7 Ch.1 Sec.4	**Power**	For vessels where the EES power is used for electrical propulsion of the vessel.	— All-electric vessel, i.e. all main sources of power are based on EES. — Hybrid vessel where one of the main sources of power is based on EES. — Hybrid vessel having an operational mode where the vessel is operating on EES power only, with the other main source of power in standby. — Hybrid vessel using the EES system as a redundant source of power for main and/ or additional class notations, e.g. dynamic positioning.
	Safety	For vessels where the aggregated EES installation in one EES space has an rated capacity of 20 kWh or above and not having the **Battery(Power)** notation.	— Hybrid vessels not using the EES power as a main source of power. — Hybrid vessels using the EES power for only peak shaving and/or load levelling. — Vessels using EES power solely when moored.

Table 1 DNV-GL battery class notation application

Likewise, the following table shows the definitions related to the batteries that the DNV-GL considers developing the battery requirements.

Term	*Definition*
battery cell	smallest building block in a battery, a chemical unit
battery cell block	group of cells connected together in parallel configuration
battery module	assembly of cells including electronic control
battery pack	one or more modules including complete BMS and can be used as a standalone unit
battery string	battery string comprises a number of cells or modules connected in series with the same voltage level as the battery system
battery system	whole battery installation including battery modules, electrical interconnections, BMS and other safety features
C-Rate	current (A) used to charge/discharge the EES system divided by the rated ampèr-hours (Ah)
capacitor cell	single capacitor
capacitor cell block	group of capacitors connected together in parallel configuration
capacitor module	assembly of capacitors including electronic control
capacitor pack	one or more modules including complete CMS and can be used as a standalone unit
capacitor string	capacitor string comprises a number of cells or modules connected in series with the same voltage level as the capacitor system
capacitor system	whole capacitor installation including capacitor modules, electrical interconnections, CMS and other safety features
CP-Rate	power (W) used to charge/discharge the EES system divided by the rated Watt-hours (Wh)
EES converter	equipment controlling the charging and discharging of the EES system.
EES space	electrical energy storage space for lithium-ion batteries and/or electrochemical capacitors
EES system	whole EES installation including modules, electrical interconnections, control management system and other safety features
electrochemical capacitor	electric double layer capacitor that stores electrical energy in an electrochemical cell, covering also supercapacitors, ultracapacitors, asymmetric capacitors and Li-ion capacitors.
off-gas	gasses released from EES cell(s) during an abnormal incident (vaporised electrolyte, thermal runaway exhaust gas)
sealed battery	battery that remains closed and does not release either gas or liquid when operated within the limits specified by the manufacturer

Table 2 DNV-GL battery definition

5.2.1 Class notation BATTERY (safety)

All requirements develop for DNV-GL related to this additional class notation **BATTERY (SAFETY)** can be found on the article 2 of DNV-GL Rules Part 6, Ch.2, Sec.1, edition July 2020. Battery related subjects described in this article are as follows:

- Design principle.
- Arrangement. EES spaces shall be positioned aft of collision bulkhead. Boundaries of EES spaces shall be part of vessels structure or enclosures with equivalent structural integrity. Only equipment associated with the EES system shall be placed within the EES space. All equipment located at ceiling level in the EES space shall be suitable for zone 2 installation. The temperature class and gas group for the ex-rated zone 2 equipment shall as minimum be T2 and IIC.
- Ventilation. A mechanical ventilation system is required for the EES space. The EES space ventilation system shall be activated upon off-gas incidents from the EES system. EES space ventilators shall be fitted with means of closing whenever:
  - the EES space does not open directly onto an exposed deck
  - the ventilation opening for the EES space is required to be fitted with a closing device according to the
  - Load Line Convention, or

- the EES space is fitted with a fixed gas fire-extinguishing system.

All ventilation inlet and exhaust evacuated directly to open air shall be to suitable areas to make sure possible toxic gases will not endanger crew or passengers. Areas on open deck within 1.5 m of inlet or exhaust openings

- Fire Safety for EES spaces.
- Safety philosophy on the onboard installation. The arrangement of the EES spaces shall be such that the safety of passengers, crew and vessel is ensured. The safety philosophy for the EES space shall be documented. The safety philosophy should cover all potential hazards represented by the type of EES system and cover at least:
  - gas development hazard (toxic, flammable, corrosive)
  - fire hazard
  - explosion hazard
  - necessary detection, monitoring and alarm systems (off-gas detection, fire detection etc.) and ventilation
  - ventilation handling in case of off-gas release and/or fire
  - external hazards (fire, water ingress, etc.).
- System design.
- Testing.
- Operation and maintenance. Instructions for emergency operation shall be kept on board.

For more details of class notation **BATTERY (SAFETY)**, refer to DNV-GL Rules, Pt 6, Ch.2, Sec.1, Article 2, edition July 2020.

5.2.2 Class notation BATTERY (power)

All requirements develop for DNV-GL related to this additional class notation **BATTERY (POWER)** can be found on the article 3 of DNV-GL Rules Part 6, Ch.2, Sec.1, edition July 2020. Battery related subjects described in this article are as follows:

- General. The requirements given for **BATTERY (SAFETY)** in last paragraph shall be fulfilled.
- System design. When all the main sources of power are based on EES only, the main sources of power shall consist of at least two independent EES systems located in two separate EES spaces. Energy management system (EMS) shall be installed.
- Testing.
- Operation and maintenance. Operating instruction shall be kept on board.

For more details of class notation **BATTERY (POWER)**, refer to DNV-GL Rules, Pt 6, Ch.2, Sec.1, Article 3, edition July 2020.

5.2.3 Battery system

The battery system is described in the article 4 of DNV-GL Rules Part 6, Ch.2, Sec.1 and the requirements given in this article are related to lithium-ion battery systems.

About the safety requirements of battery system, entry into force 1st July 2020, all hazards shall be described in a battery system safety description and safety precautions mitigating the identified risks shall be included.

The safety description shall cover all potential hazards represented by the type (chemistry) of battery and including:

- safety philosophy
- potential gas development (toxic, flammable, corrosive)
- fire risk
- explosion risk, including a description of the gas that can be released from the cell(s) during venting and thermal runaway (gas volume, release rate and gas composition).
- necessary detection, monitoring and alarm systems (gas detection, fire detection etc.) and ventilation rates for the battery space.
- a suitable fire extinguish method shall be given.
- internal cell failure/thermal runaway.
- internal and external short circuit and earth faults.
- electrical protections (over current, over voltage and under voltage)
- protection against creeping current, electrical arcing, and electrolysis due to external leakage or pollution.
- flooding of battery modules due to cooling liquid leakage.
- external heating/fire.
- safe charging/discharging characteristics.

Battery modules shall be designed such that the risk of a cooling liquid leakage inside the module is minimized and do not lead to hazardous creepage currents, electrolysis, short circuit, electric arcing, earth faults or other hazards. Leakage detection inside the module shall be arranged if there is liquid cooling inside the module.

Battery systems shall be designed such that the risk of cooling liquid leakage in the battery system is minimized and do not lead to hazardous creeping currents, electrolysis, short circuit, electric arcing, earth faults or other hazards.

About battery alarm, any abnormal condition in the battery system shall initiate an alarm in the vessel's main alarm system with individual or group-wise indication. For vessels without a centralized main alarm system, battery alarms shall be presented at the bridge.

For the material used on the batteries, the battery system shall be made of a flame-retardant material according to international Rules IEC 60092-101.

Finally, a test program for functional and safety tests at manufacturer shall be submitted for approval before testing. The tests to be done on a system battery are the following:

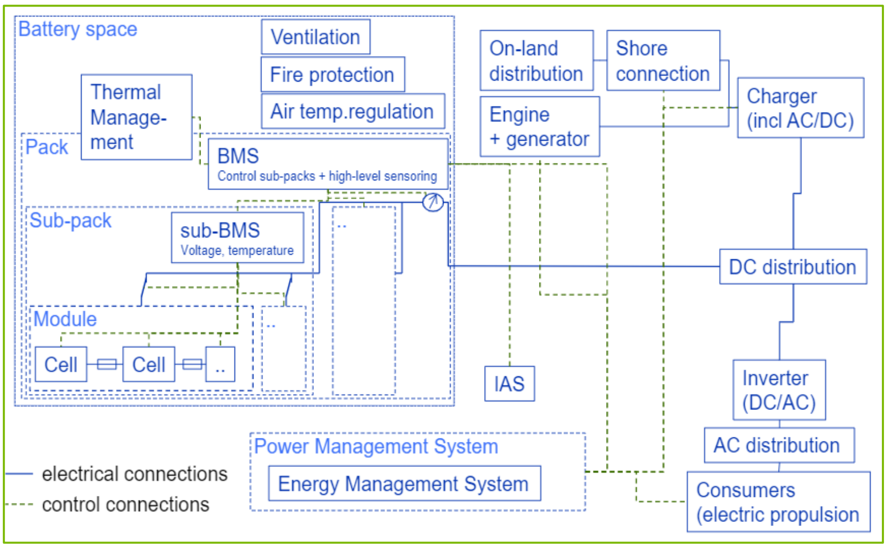
- Propagation testing
- Lithium-ion cell tests
- Lithium-ion battery system tests

For more details of battery system, refer to DNV-GL Rules, Pt 6, Ch.2, Sec. 1, Article 4, edition July 2020.

5.3 GUIDELINE FOR LARGE MARITIME BATTERY SYSTEMS

Apart from current regulations, DNV-GL has a guide applicable to large marine battery systems. The aim of this guideline is to help ship owners, designers, yards, system and battery vendors and third parties in the process of feasibility study, outline specification, design, procurement, fabrication, installation, operation and maintenance of large Li ion-based battery systems. These guidelines are consistent with the DNV rules for battery power.

In these guidelines DNV establishes a generic scheme of how a large battery system should be installed on board a ship, including modules and sub-modules. The block diagram is presented in the following illustration.



5.3.1 Installation and commissioning

Issues often occur in the interface between systems. The interfaces between the battery system and the other ship systems therefore need special focus.

The Battery Management System communicates with the ships Power Management System and key battery information is displayed at the ships bridge. The BMS must have an override function to prevent the Power Management System to perform tasks outside its safe boundaries.

Proper installation documentation must be provided by the battery system supplier.

All interfaces must be tested before the installation can be signed out and a proper test and commissioning plan must be made for the testing to be done at the yard before final sign out. This task should not be underestimated and needs a close cooperation between the battery system supplier, the supplier of the other power plant components and the yard.

5.3.2 Recommendations for operational strategy

The normal use of the batteries should be fully automatic. There should be no need for manual interaction. The following table gives recommendations towards a generic operational strategy.

Generic	Only Battery Power	Hybrid Battery/ICE System
• Vessel operation should be as simple and as similar to conventional system as possible, requiring an (automated) energy management system in addition to power management. The BMS keeps battery usage within allowed limits. • Emergency operation procedures necessary (fire, abandonment, etc.).	• Energy management becomes critical. • Charging procedure necessary.	• Energy management becomes critical if battery used as main power source. • Charging procedure if shore power option.

Even though they do not require manual interaction, DNV establishes some recommendations in case it is necessary to operate manually with the battery system, the recommendations being the following:

- Load profiles.
- Charging procedure.
- Normal operation procedures of the battery system included minimum levels of battery capacity.
- Emergency operation procedures of the battery system.
- Estimated battery deterioration (ageing) rate curves.
- Operating instructions for normal and degraded operating modes.
- Details of the user interface.
- Transfer of control (if more than one control station, or local control are implemented).
- Test facilities.
- Failure detection and identification facilities, automatic and manual.
- Data security.
- Access restrictions.
- Special areas requiring user attention.
- Procedures for start-up.
- Procedures for restoration of functions.
- Procedures for data back-up where applicable.

5.3.3 Maintenance strategy

The maintenance recommendations are covered in the following table.

Generic	Only Battery Power	Hybrid Battery/ICE System
• Internal diagnostics wherever feasible	• A plan including how and how often the state of charge/health of the batteries is checked/validated shall exist.	• When used as main power: A plan including how and how often the state of charge/health of the batteries is checked/validated shall exist.

5.3.4 Battery space assessment

DNV recommends undertaking a safety assessment of the battery space and if it possible in the design phase. The safety assessment should include the following steps:

- Identification of all potential hazards with a list of all relevant accident scenarios with potential causes and outcomes, including that Li-Ion battery fires have extinguishing challenges.
- Assessment of risks including evaluation of risk factors.
- Risk control options.
- Actions to be implemented.

5.3.5 Strategy for ventilation and fire protection

It is recommended to develop a strategy for ventilation and fire protection when temperatures above warning levels are detected. Flammable off-gases will be generated from the battery electrolyte solvents if cell temperatures go above certain values. Such hazards need to be considered as a cell can continue to function despite a building off-gas hazard. Adequate ventilation in the enclosed spaces affected can contribute to manage this risk.

DNV stablishes an example of a ventilation and fire protection strategy:

- Reduce or cut battery load.
- Increase battery cooling as much as possible.
- Ventilate battery off-gases to outside theship, as long as there is no fire.
- If fire breaks out, shut down ventilation and activate fire extinguishing system

Así mismo, hay que destacar que en este apartado sólo se han recogido las recomendaciones más significativas, pero las guidelines de DNV proporcionan recomendaciones a todos los niveles, tanto desde el punto de vista del fabricante como del usuario del sistema de baterías, incluyendo su instalación a bordo. Por ello, for more detailed information, refer to "DNV GUIDELINE FOR LARGE MARITIME BATTERY SYSTEMS".

6 RINA

The "go-to-green" race has been going on since a few years, but today, the "more tech-ecological" ship award is even more desired. Low emission, global warming and energy efficiency are the main issues that ship owners and shipyards have to face regardless the purpose of the ship (luxury yacht, ferry boat, taxi boat, vessel, etc.).

New lithium-ion solutions allow the storage of much more energy, saving weight and volume. High technology control systems, the Battery Management System, ensure batteries work properly and safety. Also, improvements at a chemical level and control tools for charge and discharge, contribute to overcome explosion and fire risks. Last but not least, more lasting battery life.

In the marine sector, RINA, as a classification society, has developed guidelines for electric propulsion plant and hybrid propulsion and has been part of the Rules for many years, having extensive experience in the installation of hybrid propulsion on yachts for many years. In addition, RINA is one of the trusted partners to provide analysis, verification, validation and approval services as well as other training courses on battery system for ship propulsion and power generation.

Therefore, in RINA Rules, in particular in Part C (Machinery, system and fire protection), requirements and characteristics about propulsion with batteries are present in the following items:

- General requirements of electrical installation (system design, protection, storage, location and installation). Refer to RINA Rules, Pt C, Ch.2, Sec.3, 7, 11 and 12, edition January 2021.
- Battery powered ships. Refer to RINA Rules, Pt C, Ch.2, App.2, edition January 2021.
- Additional class notation HYB-… Refer to RINA Rules, Pt F, Ch.13, Sec.28, edition January 2021.

6.1 Battery powered ships

The importance of batteries in ships is reflected in appendix 2 of the chapter 2, Pt C which is dedicated to the battery powered ships.

The provisions of this Appendix apply to ships where batteries, other than Lead and Nickel-Cadmium batteries, are installed to supply essential or not-essential services and emergency services, except batteries embedded in consumer products like computers and similar appliances.

6.1.1 System design

In the paragraph 2 of the Appendix 2, the general requirements of the system design with batteries are described. The most important guidelines to keep in mind are the following:

- Battery installations may replace generator sets in the main source of electrical power on condition that the capacity of the battery installation is sufficient for the intended operation of the ship and such design capacity is stated in the class certificate as an operational limitation.
- In ships or units where the main source of electrical power is based on battery installations only, the battery installation is to be divided into at least two independent battery systems located in two separate battery spaces, each having a capacity sufficient for the intended operation of the ship.

- When batteries are used as storage of power for the propulsion or dynamic positioning system or as part of the mains source of electrical power, an Energy Management System (EMS) is to be provided.
- A Risk Assessment, to be initiated in the design phase, is to be carried out to cover, but not limited to: evaluation of the risk factors, measures to control and reduce the identified risk, including potential gas development (e.g., toxic, corrosive), fire and explosion risk and action to be implemented.

About construction requirements, in the Rules, is listed that battery enclosure covering modules and cells are to be made of flame-retardant materials and a thermal protection device, capable to disconnect the battery in case of high temperature, is to be provided in the battery.

About electrical protection, each battery is to be protected against overload and short circuit in each separate circuit by means of fuses or multi pole circuit breakers having isolating capabilities.

Also, the alarm system and safety system requirements are described in this part; and for more information refer to the paragraph 3.3 and 3.4 of the Appendix 2, Pt C, Ch.2, edition January 2021.

Finally, this Rules described that an energy management system (EMS) is to be provided complying with the requirements of Pt C, Chapter 3 consisting of several levels of controls and alarm functions, such as:

- monitoring and alarm functions of all power sources, inverters and disconnectors
- voltage and power control for DC distribution system
- available power and charge/discharge status of the storage energy source
- interface with Power Management System (PMS) for combinations of AC and DC distribution systems
- inverter control for the overall system

6.1.2 Location

The most relevant requirements about battery location are presented in the paragraph 4 of the appendix and there are the followings:

- Battery spaces are to be arranged aft of collision bulkhead and in such a way that danger to persons and damage to vessel due to failure of the batteries (e.g., caused by gassing, explosion, and fire) is minimized.
- Batteries are not to be located in a battery box on the open deck exposed to sun and frost. They are to be located where they are not exposed to excessive heat, extreme cold, spray, steam, shocks or vibration or other conditions which would impair their safety, performance or accelerate deterioration.
- Batteries are to be suitably housed by means of compartments (rooms, lockers or boxes) used primarily for their accommodation which are to be properly constructed and efficiently ventilated and cooled (as necessary).
- The battery space is not to contain other systems supporting essential or emergency services.

6.1.2.1 Battery space

When required, based on the risk assessment, a space assigned to batteries only is to be foreseen. Access to this space is to be through self-closing doors and as an alternative normally closed doors with alarm may be considered.

The battery space ventilation system is to be:

- independent from any other ventilation system serving other ship's spaces.
- provided with local manual stop, still available in case of failure of the automatic and or remote-control system.
- provided with indication of ventilation running and of battery space ambient temperature.

6.1.3 Testing and inspection

Battery systems are to be tested by the Manufacturer and if the battery systems having a capacity of 50 kWh or above are to be tested at the presence of a RINA surveyor.

Performance tests are to be carried out on the battery system according to a test program which is to be submitted for approval and which is to include functional tests (alarm system, safety system, control system, etc.) and further tests, if any, resulting from the Risk Assessment.

When battery installation is used as storage of power for the propulsion or dynamic positioning systems or as part of the main source of electrical power, tests for the verification of the battery SOH are to be carried out.

6.1.3.1 Testing and inspection after installation on board

After installation, and after any important repair or alteration which may affect the safety of the arrangement, following a check of compliance with the plans, the battery system is to be subjected at least to the following tests and inspections, to the satisfaction of the Surveyor in charge:

- visual inspection
- operational tests
- tests of all the alarms and safety functions
- charging and discharging capacities
- emergency shutdown operation
- checking of operation of sensors, including simulation of changes in parameters and simulation of sensor failure
- simulation of communication failure
- insulation resistance test
- correct operation of ventilation, cooling, gas detection system, fire detection system and fire extinguishing system, etc., where provided.

For more details and information about the battery powered ships (system design, location and testing and inspection), refer to RINA Rules, Pt C, Ch.2, Appendix 2, edition January 2021.

6.2 Hybrid propulsion ship (HYB-…)

Rina Rules develops in Part F (Additional Class Notation), chapter 13, section 28 the additional class notation **HYBRID PROPULSION SHIP (HYB-…),** edition January 2021. This additional class notation is assigned to ships equipped with a hybrid propulsion system.

The requirements of this section are additional to those applicable in other parts of the Rules; in particular:

- where batteries other than Lead and Nickel-Cadmium batteries are provided as energy storage, the requirements in Pt C, Ch 2, App 2 "**BATTERY POWERED SHIPS**" apply;
- where fuel cells are provided as energy generation sources, the "**Rules for fuel cells installation in ships (FC SHIPS)**" apply.

This section implemented in January 2019, defines hybrid propulsion system as a propulsion system having two or more different sources of power such as mechanically transmitted power from internal combustion engines, electrical power or hydraulic power so arranged that the ship may be propelled by using the different power sources both separately and in combination.

Also, the Rules defines failure mode and effects analysis (FMEA) as systematic analysis of systems and sub-system to identify all potential failure modes down to the appropriate sub-system level and their consequence.

The additional class notation **HYB-…** is to be completed by an additional symbol according to the type of hybrid system:

- E x/y: ship having a hybrid propulsion system driven by combustion engine(s) and electric motor(s)
- H x/y: ship having a hybrid propulsion system driven by combustion engine(s) and hydraulic motor(s)

Where x represents the total classification power in MW of the combustion propulsion engines and y represent the total rated power in MW of the electric or hydraulic propulsion motors.

For this Rules, the hybrid propulsion system comprises the following systems:

- energy generation sources (such as fixed or variable speed generators, fuel cells, hydraulic power units);
- power distribution system;
- propulsion system;
- control system.

For systems assigned the HYB-E notation, the primary electrical power distribution system can be AC or DC as follows:

- DC switchboard: a primary DC distribution system connected to AC systems by means of inverter units, feeding power in both directions; DC power sources, such as fuel cells or batteries, may be connected to the DC distribution system through a controlled DC/DC converter or directly,
- AC switchboard: a primary AC distribution system either at fixed frequency and voltage or variable frequency.

Finally, this section described the tests shall be carried on board and it’s are as follow:

- functional test of the hybrid system in the different configurations
- verification of active load sharing between different power sources
- verification of reactive load sharing between different power sources
- sudden load disconnection and load ramp-up to verify battery system capability
- test of max charging capabilities of batteries
- test of start and stop of engines
- test of system stability during faults
- testing of pre-charge system in inverters when re-connected
- proper working of alarms
- quality of power in different operational modes

For more details and information about class notation HYB-…, refer to RINA Rules, Pt F, Ch.13, Sec.28, edition January 2021.

7 Lloyd's register (LR)

The development of battery and hybrid technology is helping the maritime industry overcome the challenges of emission regulations and shipowners' desire to maximize efficiency. But battery technology is also helping shipowners address more stringent emissions regulations, with recent technological developments leading to an increasingly efficient alternative to traditional power sources. Advances in battery technology and energy management capability have rightly seen increasing interest in battery and hybrid power in the maritime industry.

Lloyd's Register (LR) is involved in a wide range of projects which aim to make batteries efficient, stable and commercially viable. LR is excited to be playing a part in developing battery technology for a future generation of hybrid or potentially even single source vessels.

Regarding batteries, the Lloyd's Register (LR) has been developed requirement about the use presented in the Pat 6 of the Rules for Classification of Ships, the additional class notation **HYBRID POWER** and **HYBRID POWER (+)** and it developed in 2015 the **GUIDANCE FOR LARGE BATTERY INSTALLATIONS.**

Below, the most relevant definitions that the Lloyds Rules is considered, at the beginning of the part 6 Control, Electrical, Refrigeration and Fire considers to develop its battery regulation.

- **Secondary lithium cell:** is a cell where electrical energy is derived from the insertion/extraction reactions of lithium ions or oxidation/reduction of lithium between the negative electrode and the positive electrode. These may be combined in cell blocks consisting of a group of cells connected together in a parallel configuration.
- **Battery module:** is an energy storage device comprising one or more electrically connected cells or cell blocks. The battery module can include protective and monitoring devices.
- **Battery pack:** is an energy storage device comprising one or more electrically connected cells, cell blocks or modules. The battery pack can include protective devices and control and monitoring systems which communicate with the battery management system.
- **Battery management system (BMS):** is an electronic system which monitors and manages the state of a cell, battery module or battery pack in order to maintain the battery system in a safe operating state and protect against overcharging, Overcurrent and overheating and communicates with an external charge/discharger controller.
- **Lithium battery system:** is a system comprising one or more lithium battery modules or packs incorporated in a fixed installation together with means of isolation, a cooling system (if provided) and has an associated BMS.

7.1 Batteries

The part 6, chapter 2, in the section 12, of the Lloyd's Rules (edition July 2020) are dedicated to the requirements that must be applied in case of installing batteries on board.

The requirements batteries apply to aqueous and non-aqueous permanently installed secondary batteries of the vented and valve-regulated sealed type such that the following goal and functional requirements are achieved.

Also, it is defined:

- A vented battery is one in which the cells have a cover provided with an opening through which the products of electrolysis and evaporation are allowed to escape freely from the cells to the atmosphere.
- The following requirements apply to lead acid, nickel cadmium and lithium cell chemistries.
- Where the lithium battery total system installation is less than 20 kWh then it is to be housed in a gastight steel enclosure with a gastight ventilation duct leading to a safe space on open

deck and is to be suitable for withstanding the temperatures and pressures generated in the worst case thermal runaway condition

7.1.1 Design and construction

Based on Lloyd's Register Rules, Pt 6, Ch.2, Sec. 12 (edition July 2020), the requirements about design and construction about batteries are the following:

- Batteries are to be constructed so as to prevent spilling of the electrolyte due to motion and to minimise the emission of electrolyte spray.
- A Failure Mode and Effects Analysis (FMEA) is to be carried out for the lithium battery system installation and is to consider the effects of failure upon safety and dependability of the lithium battery system installation, taking account of reasonably foreseeable internal and external failures such that the goal.
- The casing of a lithium cell and/or battery module is to incorporate a pressure relief function(s) that will prevent overpressure, rupture or explosion of the battery module enclosure.
- A fully independent hard-wired means to disconnect the battery system in an emergency from power distribution is to be provided. This emergency trip is to be located outside of the battery space and situated such that it will remain accessible in the event of an emergency inside the battery space and is to initiate an audible and visual alarm at the relevant control stations to advise duty personnel of the emergency condition.

7.1.2 Location

Based on Lloyd's Register Rules, Pt 6, Ch.2, Sec. 12(edition July 2020), the requirements about location of the batteries on board are the following:

- Vented batteries connected to a charging device with a power output of more than 2 kW, calculated from the maximum obtainable charging current and the nominal voltage of the battery, are to be housed in an adequately ventilated compartment assigned to batteries only, or in an adequately ventilated suitable box on open deck.
- Vented batteries connected to a charging device with a power output within the range 0,2 kW to 2 kW, calculated from the maximum obtainable charging current and the nominal voltage of the battery, or may be installed within a well-ventilated machinery or similar space.
- Vented batteries connected to a charging device with a power output of less than 0,2 kW, calculated from the maximum obtainable charging current and the nominal voltage of the battery, may be installed in an open position or in a battery box in any suitable space.
- Where lead-acid and nickel-cadmium batteries are installed in the same compartment precautions are to be taken, such as the provision of screens, to prevent possible contamination of electrolytes.
- Where batteries may be exposed to the risk of mechanical damage, or falling objects, they are to be suitably protected.
- Batteries installed in crew and passenger cabins, together with their associated corridors, are to be of the hermetically sealed type.
- A permanent notice prohibiting smoking and the use of naked lights or equipment capable of creating a source of ignition is to be prominently displayed adjacent to the entrances of all compartments containing batteries.
- The lithium battery space is to be separate from other spaces and compartments, is not to be located forward of the collision bulkhead and is not to be contiguous to the boundaries of machinery spaces of Category A or those spaces containing the main source of electrical power, associated transforming equipment (if any) or the main switchboard. The boundaries of the lithium battery space are to be part of a vessel structure or enclosures and provided with 'A60' insulation of the bulkhead unless the space is adjacent to spaces of negligible fire risk such as cofferdams, void spaces or similar, in which case consideration may be given to reducing the insulation to 'A-0'.

7.1.3 Installation

Based on Lloyd's Register Rules, Pt 6, Ch.2, Sec. 12 (edition July 2020), the requirements about batteries installation on board are the following:

- Batteries are to be arranged such that each cell or crate of cells is accessible from the top and at least one side and it is to be ensured that they are suitably secured to move with the ship's motion.
- Measures are to be taken to minimise the effect of any electrolyte spillage and leakage.
- The interiors of all compartments for batteries, including crates, trays, boxes, shelves and other structural parts therein, are to be of an electrolyte-resistant material or suitably protected, for example with paint or a coating.
- The lithium battery space and the crates, trays, boxes, shelves and other structural parts therein are to be designed and constructed such that the structural integrity of the battery space will not be compromised in the event of a lithium fire.
- The lithium battery space is to be fitted with suitable fixed detectors in accordance with manufacturer's recommendations and which are capable of providing early identification of a fire or thermal runaway condition.
- The fixed fire-fighting control system is to be located outside the battery space, be activated automatically and be capable of manual activation. In addition to the fixed fire-fighting system, the battery space is to be provided with a minimum of two (2) portable and suitable fire-extinguishers located outside the space at or near the entrance(s).
- The lithium battery space is to be provided with two means of escape, at least one independent of any watertight door and leading to a safe position outside the space. One of the escapes is to be suitable for the passage of a stretcher. At each entrance/exit an emergency escape breathing device (EEBD) is to be provided. Where the maximum travel distance to the door within the lithium battery space is less than 5 m, a single means of escape is acceptable. The lithium battery space is not to be considered as part of an escape route (primary or secondary) from any other accommodation, control, service space, machinery space of Category 'A' and high fire risk area such as a garage, paint store, etc.

7.1.4 Thermal management and ventilation

Based on Lloyd's Register Rules, Pt 6, Ch.2, Sec. 12 (edition July 2020), the requirements about batteries ventilation on board are the following:

- Battery compartments and boxes are to be ventilated to avoid accumulation of dangerous concentrations of flammable gas.
- Ducted natural ventilation may be employed for battery installations connected to a charging device with a power output of 2 kW or less, provided the exhaust duct can be run directly from the top of the compartment or box to the open air above, with no part of the duct more than 45° from the vertical. A suitable opening is also to be provided below the level of the top of the batteries, so as to ensure a free ventilation air flow. The ventilation duct is to have an area not less than 50 cm2 for every 1 m3 of battery compartment or box volume.
- Where natural ventilation is impracticable or insufficient, mechanical ventilation is to be provided, with the air inlet located near the floor and the exhaust at the top of the compartment.
- Mechanical exhausted ventilation is to be provided for battery installations connected to a charging device with a total maximum power output of more than 2 kW. Also, to minimise the possibility of oxygen enrichment, compartments and spaces containing batteries with boost charging facilities are to be provided with mechanical exhaust ventilation irrespective of the charging device power output.
- The ventilation system for battery compartments and boxes is to be separate from other ventilation systems.

- Battery boxes are to be provided with sufficient ventilation openings located so as to avoid accumulation of flammable gas whilst preventing the entrance of rain or spray.

7.1.5 Charging facilities

Based on Lloyd's Register Rules, Pt 6, Ch.2, Sec. 12 (edition July 2020), the requirements about charging facilities on board are the following:

- Charging facilities are to be provided for all secondary batteries such that they may be completely charged from the completely discharged state in a reasonable time having regard to the service requirements.
- For floating circuits or any other conditions where the load is connected to the battery whilst it is on charge, the maximum battery voltage is not to exceed the safe value for any connected apparatus.
- Where valve-regulated sealed batteries are installed, the charging facilities are to incorporate independent means such as overvoltage protection to prevent gas evolution in excess of the manufacturer's design quantity.

7.1.6 Recording of batteries for emergency and essential service

Based on Lloyd's Register Rules, Pt 6, Ch.2, Sec. 12 (edition July 2020), the requirements about recording batteries for emergency or essential service are the following:

- A schedule of batteries fitted for use for essential and emergency services is to be compiled and maintained.
- The schedule and replacement procedure documentation are to be made available to the LR Surveyor on request.

7.2 Hybrid electrical power systems

Based on Lloyd's Register Rules, Pt 6, Ch.2, Sec. 24 (edition July 2020), the requirements of the section 24 are applicable to ships having a main source of electrical power which is provided by hybrid electrical power generation and distribution systems within which the main electrical power demand is supplied by two or more different types of power source or by stored electrical energy.

These requirements apply to hybrid electrical power systems which provide the main source of electrical power and exceptionally, where permitted by the National Administration, the emergency source of electrical power.

In this section, the additional class notation **HYBRID POWER** and **HYBRID POWER (+)** are defined as follow:

- The additional class notation **HYBRID POWER** is assigned to ships with an electrical power system including a combination of two or more different types of power source or utilizing stored electrical energy to satisfy the ship's main power demand.
- The additional class notation **HYBRID POWER (+)** assigned to ships meeting the requirements for **HYBRID POWER** and the additional optional requirements for **HYBRID POWER (+)** specified within Pt 6, Ch 2, 24 Hybrid electrical power systems. The additional optional requirements aim to provide for enhanced performance of the electrical power system achieved through the consideration of system simulation, system integration and dependability of the electrical power system during normal or reasonably foreseeable abnormal operation.

Hybrid electrical power system is a ship's electrical power system comprising sources, stores, consumers and distribution of electrical power together with their associated controls within which electrical power is provided by two or more different types of power source or utilizing stored electrical energy to satisfy the ship's main power demand.

For these additional class notations, different combinations of energy sources and storage are described, which fall within the combinations so that the ship is considered as a hybrid. The source and combination described are the following:

- Source of electrical power.
- Store of electrical energy.
- Consumer of electrical power.
- Combined source and consumer of electrical power.
- Combined source of electrical power and store of electrical energy.
- Combined store of electrical energy and consumer of electrical power.
- Combined store of electrical energy and source and consumer of electrical power.

All the previous combinations and sources, are summarized in the following figure.

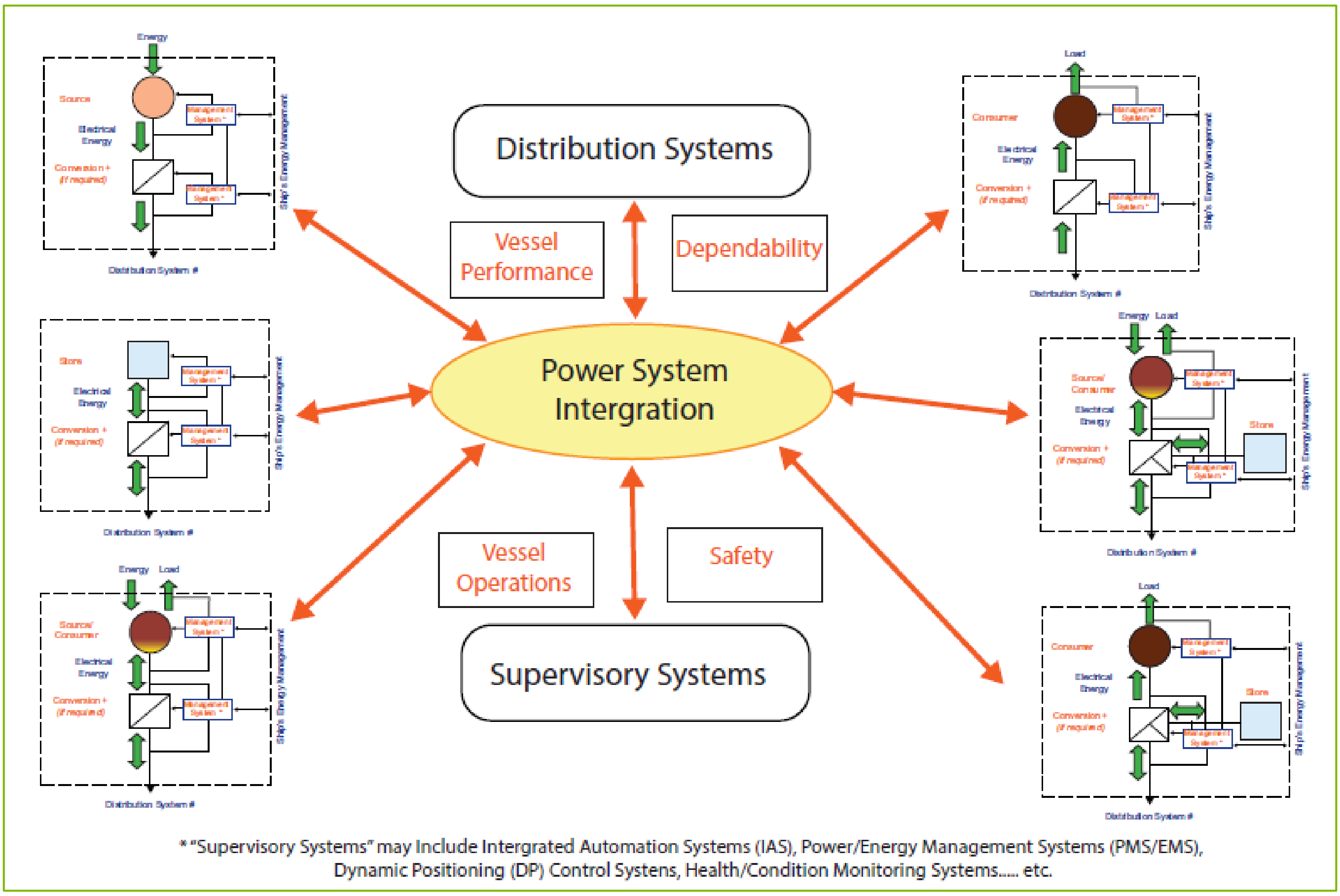


Figure 2 Role of system integration activities

For more details and information about the additional class notation **HYBRID POWER** and **HYBRID POWER (+)**, refer to Lloyd's Register Rules, Pt 6, Ch.2, Sec. 24, edition July 2020.

7.3 Guidance for large battery installations

LR's experience with large battery installations is captured in this guidance document aimed at facilitating a risk-based approach to battery use. The guidance describes the key hazards to consider when installing battery technology, and gives an overview of our non-prescriptive approach to approval. The guidance also covers battery chemistry and industry standards.

The guidance starts at the beginning of a battery system's life cycle when the cells are being manufactured, and goes on to consider how an installation affects or is affected by a vessel's power system, placement on board, ventilation, fire-fighting, electrical protection and maintenance. The guidance aims to help industry consider the hazards associated with large battery installations but is not specific to a particular cell chemistry.

Also, this guidance provides guidance to clients on the hazards associated with large battery installations, and gives an overview of Lloyd's Register's (LR's) approach to approving them. It is based on our extensive experience of large battery installations on board ships and yachts.

To understand the battery world, it is interesting the overview of cell chemistries that is described in the guidance and presented in the following table. Mass-produced cells can be categorized as aqueous and non-aqueous. Aqueous batteries include lead-acid batteries and alkaline batteries with an aqueous electrolyte such as nickel-cadmium, nickel-zinc or zinc/silver-oxide. Lithium-ion batteries, which are also a type of alkaline battery, are non-aqueous and therefore present different challenges to aqueous batteries.

Cell type	Cell name	Advantages	Disadvantages	Failure mechanisms
Aqueous (Lead-Acid)	Lead-acid	Low cost	Low energy density	Short circuit, loss of electrolyte
Aqueous (Alkaline)	Nickel cadmium	Durable, good low-temperature performance	Low energy density	Gas barrier failure, short circuit, loss of electrolyte
	Nickel-metal hydride	High energy density	Poor charge retention	Thermal imbalance
	Nickel-zinc	Low cost	Low energy density	Zincate deposits on nickel electrode
	Silver-oxide	High energy density, low self-discharge	High cost, poor performance at low temperatures, poor lifecycle	Shape change and dendrites
Non-aqueous	Lithium-ion	High energy density, low self-discharge	Cannot withstand overcharge, degrade when over-discharged, safety concerns	Under/over-voltage, thermal runaway

Table 3 LR overview of cell chemistries

Likewise, this guidance lists a series of risks that must be mitigated, to the point that the residual risk is acceptable compared to conventional power generation systems. Those that must be taken into account are the following:

- Mechanical.
- Electrical.
- Chemical.
- Fire.
- Environmental.

For more details and information, refer to GUIDANCE FOR LARGE BATTERY INSTALLATIONS, edition 2015.

8 American bureau of shipping (ABS)

The Classification Society American Bureau of Shipping (ABS) started developing regulations regarding ship batteries a few years ago and started developing the requirements in the **Rules for Building and Classing Marine Vessel in the Part 4 Vessel System and Machinery**, in particular in chapter 8 Electrical System.

In 2017, due to the growing demand for this technology, ABS developed a specific class notation for ships using lithium batteries as propulsion. This Rule is the **GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES** and the class notation developed is the **ESS-LiBATTERY** class notation. Thus, in June 2018, the conversion of first OSV (offshore support vessel), SEACOR MAYA, to a hybrid diesel-electric solution (lithium-ion battery) was developed. The vessel was to ABS class and awarded the classification society’s first Battery-Li notation.

The hybrid solution has the potential to cut the ship’s fuel consumption, reduce emission and support the company’s compliance with the ever-tightening environmental regulations in the US and abroad. So, in order to comply this, ABS also develop in 2020 the **GUIDE FOR HYBRID ELECTRIC POWER SYSTEMS FOR MARINE AND OFFSHORE APPLICATION**. The guidelines focus on systems integrating electric power generation and storage technologies with conventional power generation. The guide also introduces a new class notation **HYBRID IEPS** because ABS noted that hybrid power systems have significant potential to contribute to the marine and offshore industries decarbonization targets

8.1 Electrical system – vessel system and machinery (part 4 marine vessel)

8.1.1 Battery system and uninterruptible power system (UPS)

In the section 3 of the chapter 8 the requirement of the equipment for essential (emergency and transitional) sources of power is presented. Such equipment would include:

- Battery charging and discharging units of 25 kW and over and the associated distribution boards.
- Uninterruptible power supply (UPS) units of 50 kVA and over and the associated distribution boards.

Uninterruptible Power System (UPS) is A combination of converters, switches and energy storage means, for example batteries, constituting a power system for maintaining continuity of load power in case of input power failure.

About design and construction, battery charger units and uninterruptible power system (UPS) units are to be constructed in accordance with the IEC 62040 Series, or an acceptable and relevant national or international standard. The UPS unit is to be suitably located for use in an emergency. The UPS unit is to be located as near as practical to the equipment being supplied.

Finally, for ventilation, UPS units utilizing valve regulated sealed batteries may be located in compartments with normal electrical equipment, provided the ventilation arrangements are in accordance with the requirements of 4-8-4/5.3 and 4-8-4/5.5.

For more details about this item, refer to ABS Rules for Building and Classing Marine Vessels, Part 4, Ch.8, Sec.3 Electrical Equipment, edition January 2021.

8.2 Guide for use of lithium batteries in the marine and offshore industries

The American Bureau of Shipping (ABS), in its edition of February 2020, has produced this Guide to provide requirements and reference standards to facilitate effective installation and operation of lithium battery systems.

The purpose is to establish safety guidelines for owners, operators, shipyards, designers, and manufacturers. The lithium battery types covered by this Guide include lithium-ion, lithium alloy, lithium metal, and lithium polymer types. For requirements applicable to conventional battery types (such as lead acid, alkaline, etc.).

This Guide is applicable to marine and offshore assets designed, constructed, or retrofitted with a lithium battery system used as an additional source of power with a capacity greater than 25 kWh. An optional class notation **ESS-LiBATTERY** may be granted to those assets once the battery installation has complied with the requirements of this Guide.

The mot used terminology in this Guide is the following:

- **Battery Management System**. Electronic system associated with a battery module/pack that has functions to cut off in case of overcharge, overcurrent, over-discharge, and overheating. It monitors and/or manages its state, calculates secondary data, reports that data, and/or controls its environment to influence the battery's safety, performance, and/or service life.
- **Battery Cell**. The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, and terminals that is a source of electrical energy by insertion/extraction reactions of lithium ions or oxidation/reduction reaction of lithium between the negative electrode and the positive electrode. It is not ready for use in an application since it is not yet fitted with its final housing, terminal arrangement, and electronic control device(s).
- **Battery Module**. A group of cells connected together in a series and/or parallel configuration with or without protective devices and monitoring circuitry.
- **Battery Pack**. Energy storage device that is comprised of one or more cells or modules electrically connected. It has a monitoring circuitry that provides information to a battery system.
- **Battery System (Array).** System comprised of one or more cells, modules, or battery packs. It has a battery management system to cut off in case of overcharge, overcurrent, over-discharge, and overheating.

8.2.1 Battery system design and construction

The exposed battery casing (for cells and modules) is to be constructed of durable, flame retardant, moisture resistant materials, which are not subject to deterioration in the marine environment and at the temperature to which it is likely to be exposed.

The casing of a cell, module, battery pack, and battery systems are to be provided with a pressure relief mechanism/arrangement to prevent rupture or explosion. The individual modules are also to have arrangements to prevent spilling of electrolyte.

The battery system is to have a Battery Management System (BMS). The BMS is to, at a minimum, monitor the battery cell voltage, cell temperature, and battery string current. The BMS is to be continuously powered and an alarm is to be given in the event of failure of the normal power supply. The safety system is to be activated automatically in the event of identified conditions that could lead to damage of the lithium battery system.

For more details about this subject, refer to the Guide ABS GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES, Section 2, edition February 2020.

8.2.2 Battery system installation

In the section 3 of the Guide, which was implemented in February 2020, the requirements of battery space are presented:

- Battery spaces are not to be located forward of the collision bulkhead of the vessel. Special cases may be considered for powering loads located forward of collision bulkhead.
- Battery spaces are not to contain any heat sources or high fire risk objects external to that of the battery system.
- High ambient temperature in the battery space is to be monitored and alarmed at a continuously manned location.
- The battery space is to be installed with appropriate means to vent gases, which may be generated during an abnormal situation, from the battery space to open deck.
- Battery spaces are to be mechanically ventilated and discharges from the exhaust fans are to be led to a place on the open deck where such discharges will not cause a fire or explosion hazard or toxic hazard to nearby personnel. Inlet and exhaust ventilation duct(s) for the battery space are to be from and to a safe location on open deck. The ventilation of the battery space is to have sufficient capacity to minimize the possibility of accumulation of flammable vapours, especially during an abnormal condition. The fan is to be of the non-sparking type and shall provide six (6) air changes per hour. The ventilation ducting for the battery space is to be separate from the HVAC systems used to ventilate other spaces on the vessel.

Accompanied by the space requirements mentioned above, in the section 3 the fire safety requirements are also described. The requirements implemented in the last edition of this Guide (February 2020) are as follow:

- The battery space is to be considered an Auxiliary Machinery Space or a Machinery Space other than category.
- The battery space is to be fitted with a suitable Fixed Fire Extinguishing System (FFES) recommended by the vendor and appropriate to the battery chemistry used.

Where battery space is located adjacent to and within machinery space of category A, the following additional requirements are to be met:

- A-60 Fire integrity between the battery space and machinery space of category A.
- The ventilation duct(s) are to be of fully welded construction and duct materials are to be compatible with the gases produced in a thermal runaway condition. Where ventilation duct(s) from the battery space is passing through high fire risk areas, A-60 insulation is to be provided for the duct(s).
- Ventilation is to be such that with the battery room door open, air flow is from the Machinery Space into the Battery Room with over-pressure. Loss of ventilation overpressure is to be alarmed at a normally manned location.
- Access to the space is to be through normally closed gas-tight doors with alarm at a normally manned location or self-closing gas-tight doors with no holdback arrangement.

- Means to disconnect the battery system in the event of a fire in the machinery space of Category A or within the lithium battery space are required to be provided and located outside of the protected space.
- The risk assessment document discussed in Subsection 3/5 shall address the following:
  - ✓ Chemical composition of the lithium batteries.
  - ✓ Indicate if flammable gas is or is not released during normal operations, including charging mode. If flammable gas release is possible in normal operations, then the ventilation system is to be interlocked with the battery chargers to prevent battery charging when the ventilation is not operating.
  - ✓ Means of escape from the battery space.

About operation and maintenance, the Battery System Operations and Maintenance manual submitted for review is to address normal and emergency operating procedures and maintenance procedures for the use of the battery system.

For more details about these subjects (battery space, fire safety and operation and maintenance), refer to the Guide ABS GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES, Section 3, edition February 2020

8.2.3 Battery system used as main source of electric power

This Section covers battery systems used as the main source of electrical (i.e., ship service loads) and propulsion power.

About redundancy of the batteries and equipment, at a minimum, two independent battery systems are to be provided and located in separate spaces.

For more details of protective system, monitoring, fire protection and trials, refer to the Guide ABS GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES, Section 4, edition February 2020.

8.2.4 Battery system surveys

The section 5 of the Guide pertains to surveys carried out on lithium battery system(s) with ESS-LiBATTERY class notation during construction, installation, and testing of the asset at the builder’s yard/facility, including required onboard testing and trials.

The following items are to be verified by the attending Surveyor:

- Location and arrangements
- Testing
- Ventilation and environmental control
- Maintenance and replacement
- Installation of the battery system

8.3 Guide for hybrid electric power system for marine and offshore application

For the last 60 years, the primary form of ship propulsion consisted of diesel engines delivering thrust directly to the water via a shaft and propeller.

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 electric propulsion motors. These propulsion motors are powered by a set of generators which supply both the vessel's essential and non-essential service loads.

Hybrid electric power systems offer the opportunity to improve safety, reliability, operational efficiency, and reduce the fuel consumption, environmental footprint, and equipment maintenance when compared to traditional electrical power systems.

ABS develops in this Guide the requirements for the design, construction, testing and survey of vessels utilizing electric power systems.

The requirements of this Guide are intended for installations of a variety of hybrid electric power systems (HEPS) such as combination of conventional power generation (generator, shaft-generator), energy storage system (battery, supercapacitor), fuel cell power system, and future technologies {e.g., solar and wind (electric) power} on marine and offshore installations.

The integrated electric power system is utilized for powering the vessels' or units' essential and non-essential service loads as well as the electric motor driven propulsion system loads.

8.3.1 Hybrid notation of marine and offshore vessels

The American Bureau of Shipping (ABS), through these guides, develops the optional class notation **HYBRID IEPS** for vessels installed with a hybrid electric power system.

Where a vessel is arranged to use one or more sources of power e.g., energy storage system (ESS) such as lithium battery, supercapacitor, fuel cell system and conventional generation (including shaft generator), a system designed, constructed and tested in accordance with this Guide will be assigned the Class Notation HYBRID IEPS.

Hybrid Electric Power System (HEPS) is a hybrid-electric power system who combines internal combustion engine driven generators and/or shaft generator/motor driven by main engine with an ESS consisting of batteries, supercapacitors, fuel cells, or other technologies to form the power generation and propulsion system of the vessel. The architecture of a hybrid system can be designed specifically for the requirements of each vessel and thus optimize the use of each component for maximum efficiency. The combination of two or more new technologies when conventional generation is not installed on board also constitutes a HEPS.

In this Guide, the following items are presented and developed in the different sections:

- **System design**: generation and energy storage system capacity, operating modes, power distribution system, control and instrumentation, electrical protection system, HEPS risk assessment and emergency source of power. Refer to the Guide ABS GUIDE FOR HYBRID ELECTRIC POWER SYSTEM FOR MARINE AND OFFSHORE APPLICATION, Section 3, edition October 2020.
- **Equipment and installation**: electrical equipment and hazardous area installation. Refer to the Guide ABS GUIDE FOR HYBRID ELECTRIC POWER SYSTEM FOR MARINE AND OFFSHORE APPLICATION, Section 4, edition October 2020.
- **Test and trials**: surveys during construction, onboard testing and survey after construction. Refer to the Guide ABS GUIDE FOR HYBRID ELECTRIC POWER SYSTEM FOR MARINE AND OFFSHORE APPLICATION, Section 5, edition October 2020.

9 International electrotechnical commission (IEC)

The **International Electrotechnical Commission** (**IEC**) is an international standards organization that prepares and publishes international standards for all electrical, electronic and related technologies – collectively known as "electrotechnology". IEC standards cover a vast range of technologies from power generation, transmission and distribution to home appliances and office equipment, semiconductors, fibre optics, batteries, solar energy, nanotechnology and marine energy as well as many others.

The IEC also manages fourhttps://en.wikipedia.org/wiki/International_Electrotechnical_Commission - cite_note-6global conformity assessment systems that certify whether equipment, system or components conform to its international standards.

The IEC has developed in recent years, due to the increasing market of batteries and their increasingly frequent use in hybrid vehicles, a series of standards about the lead acid batteries and nickel-cadmium batteries. In these standards the requirements, characteristics and methods of testing are developed.

As we have seen in the previous sections, the different classification societies, to develop their battery standards, rely on some standards developed by the IEC. A summary of these standards is presented as follow.

9.1 Lead acid batteries

The lead–acid battery is the earliest type of rechargeable battery. Despite having a very low energy-to-weight ratio and a low energy-to-volume ratio, its ability to supply high surge currents means that the cells have a relatively large power-to-weight ratio. These features, along with their low cost, make them attractive for use in hybrid vehicles to provide the high current required by starter motors.

They generate electricity through a double sulphate chemical reaction. Lead and lead dioxide, the active materials on the battery's plates, react with sulfuric acid in the electrolyte to form leadsulphate. Sulfation occurs in lead–acid batteries when they are subjected to insufficient charging during normal operation.

Large-format lead–acid designs are widely used for storage in backup power supplies in cell phone towers, high-availability settings like hospitals, and stand-alone power systems. For these roles, modified versions of the standard cell may be used to improve storage times and reduce maintenance requirements. Gel-cellsand absorbed glass-mat batteries are common in these roles, collectively known as VRLA (valve-regulated lead–acid) batteries.

The lead acid battery used on board a ship consists of a series of cells, with each cell containing a lead peroxide positive plate and a lead negative plate immersed in a dilute sulphuric acid solution. This sulphuric acid solution is known as electrolyte.

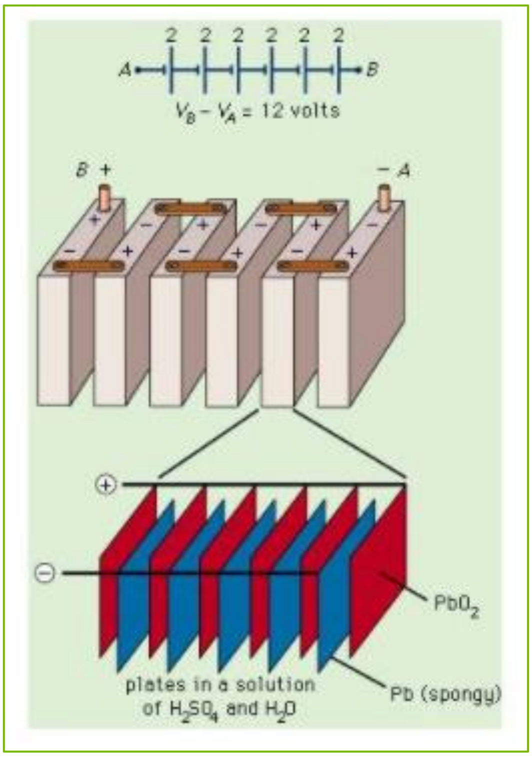


Figure 3 Lead acid battery

9.1.1 Vented types – general requirements and methods of tests

This part of IEC 60896 is applicable to lead-acid cells and batteries which are designed for service in fixed locations (i.e., not habitually to be moved from place to place) and which are permanently connected to the load and to the d.c. power supply. Batteries operating in such applications are called "stationary batteries". Any type or construction of lead-acid battery may be used for stationary battery applications. This part 11 of the standard is applicable to vented types only.

For more details, refer to IEC 60896-11, first edition published in 1987 as amendments (edition 2, 1990).

9.1.2 Valve regulated types – methods of test

This part of IEC 60896 applies to all stationary lead-acid cells and monobloc batteries of the valve regulated type for float charge applications, (i.e., permanently connected to a load and to a d.c. power supply), in a static location (i.e., not generally intended to be moved from place to place) and incorporated into stationary equipment or installed in battery rooms for use in telecom, uninterruptible power supply (UPS), utility switching, emergency power or similar applications. The objective of this part of IEC 60896 is to specify the methods of test for all types and construction of valve regulated stationary lead acid cells and monobloc batteries used in standby power applications

For more details, refer to IEC 60896-21, edition 2004 as amendment.

9.1.3 Valve regulated types – requirements

This part of IEC 60896 applies to all stationary lead-acid cells and monobloc batteries of the valve regulated type for float charge applications, (i.e., permanently connected to a load and to a d.c. power supply), in a static location (i.e., not generally intended to be moved from place to place) and incorporated into stationary equipment or installed in battery rooms for use in telecom, uninterruptible power supply (UPS), utility switching, emergency power or similar applications. The objective of this part of IEC 60896 is to assist the specifier in the understanding of the purpose of each test contained within IEC 60896-21 and provide guidance on a suitable requirement that will result in the battery meeting the needs of a particular industry application and operational condition. This standard is used in conjunction with the common test methods described in IEC 60896-21 and is associated with all types and construction of valve regulated stationary lead-acid cells and monoblocs used in standby power applications.

For more details, refer to IEC 60896-22, edition 2004 as amendment.

9.2 Nickel-cadmium batteries

The nickel–cadmium battery (Ni-Cd battery or NiCad battery) is a type of rechargeable battery using nickel oxide hydroxide and metallic cadmium as electrodes.

A Ni-Cd battery has a terminal voltage during discharge of around 1.2 volts which decreases little until nearly the end of discharge. The maximum electromotive force offered by a Ni-Cd cell is 1.3V. Ni-Cd batteries are made in a wide range of sizes and capacities, from portable sealed types interchangeable with carbon-zinc dry cells, to large ventilated cells used for standby power and motive power. Compared with other types of rechargeable cells they offer good cycle life and performance at low temperatures with a fair capacity, but their significant advantage is the ability to deliver practically their full rated capacity at high discharge rates (discharging in one hour or less). However, the materials are more costly than that of the lead–acid battery, and the cells have high self-discharge rates.

Sealed Ni-Cd cells were at one time widely used in portable power tools, photography equipment, flashlights, emergency lighting, hobby R/C, and portable electronic devices. The superior capacity of Nickel-metal hydride batteries, and recent lower cost, has largely supplanted Ni-Cd use.

Sealed Ni–Cd cells may be used individually or assembled into battery packs containing two or more cells. Small cells are used for portable electronics and toys (such as solar garden lights), often using cells manufactured in the same sizes as primary cells. When Ni–Cd batteries are substituted for primary cells, the lower terminal voltage and smaller ampere-hour capacity may reduce performance as compared to primary cells.

Larger flooded cells are used for aircraft starting batteries, electric and hybrid vehicles, and standby power.

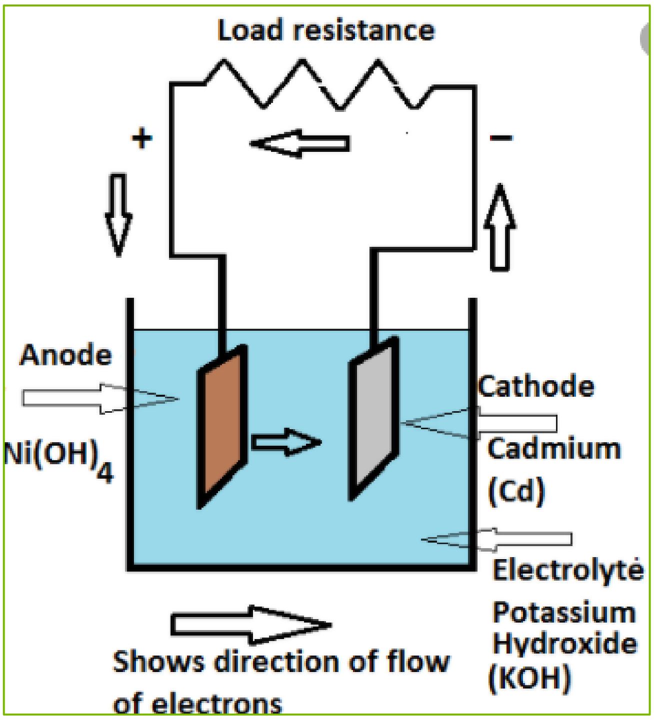


Figure 4 Nickel-cadmium battery

The IEC is developing three standards related to the use and requirements of nickel-cadmium batteries:

- IEC 60622: secondary cells and batteries containing alkaline or other non-acid electrolytes – sealed nickel-cadmium prismatic rechargeable single cells (edition 2002 as amendment).
- IEC 60623: secondary cells and batteries containing alkaline or other non-acid electrolytes – vented nickel-cadmium prismatic rechargeable single cells. This standard specifies marking, designation, dimensions, tests, and requirements for vented nickel-cadmium prismatic secondary single cells (edition 2017 as amendment).
- IEC 62259: secondary cells and batteries containing alkaline or other non-acid electrolytes – nickel-cadmium prismatic secondary single cells with partial gas recombination (edition 2003 as amendment). This standard specifies marking, designation, dimensions, tests, and requirements for vented nickel-cadmium prismatic secondary single cells where special provisions have been made in order to have partial or, under very specific conditions, full gas recombination.

9.3 Lithium ion batteries

Regarding lithium ion batteries, the IEC has standard 62281, which specifically addresses the safety of primary and secondary lithium batteries during transport as well as the safety of the packaging used. El alcance de este standard reside en specifie test methods and requirements for primary and secondary (rechargeable) lithium cells and batteries to ensure their safety during transport other than for recycling or disposal.

Así mismo, este standard utiliza otros standards como referencia, los cuales se nombran a continuación:

- IEC 61960, Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for portable applications.

- IEC 62133, Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications.
- IEC 62660-1, Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 1: Performance testing

This International Standard applies to primary and secondary (rechargeable) lithium cells and batteries containing lithium in any chemical form: lithium metal, lithium alloy or lithium-ion. Lithium-metal and lithium alloy primary electrochemical systems use metallic lithium and lithium alloy, respectively, as the negative electrode.

10 Fire safety of marine battery installations

10.1 IMO: SOLAS Regulations

Apart from the conventional lead battery installations for the emergency source of power, IMO and IACS provisions do not cover exhaustively with statutory requirements the following aspect for any type of battery installations:

- Structural Fire Protection of battery installations
- Active Fire Protection systems of battery installations
- Risk assessment criteria (e.g. safety margins, fire hazards, acceptability criteria, individual / societal risk of passengers / crew / firefighters, fire risk control options, etc.)
- Fire detection systems of battery installations
- Battery installation normal and emergency cooling systems
- Ventilation systems of battery cells and gas exhaust

To guide the risk assessment process or any alternative design, the identification and implementation of the equivalence principle is to be based upon the Fire Safety Objectives and Functional Requirements (equivalent to GBS Tiers I and II) listed in SOLAS chapter II-2 as applicable. The goals and functional requirements are explicitly mentioned in each of the 23 regulations of SOLAS chapter II-2:

- Regulation 1 – Application
- Regulation 2 – Fire safety objectives and functional requirements
- Regulation 3 – Definitions
- Regulation 4 – Probability of ignition
- Regulation 5 – Fire growth potential
- Regulation 6 – Smoke generation potential and toxicity
- Regulation 7 – Detection and alarm
- Regulation 8 – Control of smoke spread
- Regulation 9 – Containment of fire
- Regulation 10 – Firefighting
- Regulation 11 – Structural integrity
- Regulation 12 – Notification of crew and passengers
- Regulation 13 – Means of escape
- Regulation 14 – Operational readiness and maintenance
- Regulation 15 – Instructions, onboard training and drills
- Regulation 16 – Operations
- Regulation 17 – Alternative design and arrangements
- Regulation 18 – Helicopter facilities
- Regulation 19 – Carriage of dangerous goods
- Regulation 20 – Protection of vehicle, special category and ro-ro spaces
- Regulation 21 – Casualty threshold, safe return to port and safe areas

- Regulation 22 – Design criteria for systems to remain operational after a fire casualty
- Regulation 23 – Safety center on passenger ships

It is worthwhile recalling some SOLAS principles related to fire safety, i.e. fire protection, detection, and extinction.

Chapter II-2 Reg.2 outlines some broad “fire safety objectives”:

- Prevent the occurrence of fire and explosion
- Reduce the risk to life caused by fire
- Reduce the risk of damage caused by the fire to the ship, its cargo and its environment
- Contain, control and suppress fire and explosion to the compartment of origin
- Provide adequate and readily accessible means or escape for passengers and crew

This regulation further prescribes “functional requirements”, the most notable of which is the restricted use of combustible materials.

It is also well known that a performance-based approach is guaranteed by SOLAS Chapter II, Part F, Reg.17, whereby alternative design and arrangements for fire safety may deviate from the prescriptive requirements, provided that the design and safety arrangements meet the fire safety objectives and the functional requirements, set out in Regulation 2 of Part A, set out above.

The relevant maritime Administration is tasked to evaluate the submission, in accordance with the relevant IMO guidance:

- engineering analysis, including a determination of the required safety performance criteria;
- any deviation from prescriptive requirements;
- technical justification, demonstrating that the alternative design and arrangements meet the required fire safety criteria.

As already explained on SOLAS Reg.5, the final authorization by the Administration implies problems of responsibility and discretion based upon technical evidence, tests, experiments, models, calculations, simulations under the supervision of a Classification Society.

The Fire Test Procedures Code 2010 as amended (FTP Code) is applicable for products which are required to be tested, evaluated, and approved under SOLAS.

Chapter 7 of the FTP Code deals with the USE OF EQUIVALENTS AND MODERN TECHNOLOGY:

- *7.1 To allow modern technology and development of products, the Administration may approve products to be installed on board ships based on tests and verifications not specifically mentioned in this Code but considered by the Administration to be equivalent with the applicable fire safety requirements of the SOLAS Convention.*
- *7.2 The Administration shall inform the Organization of approvals referenced in paragraph 7.1 in accordance with regulation I/5 of the Convention and follow the documentation procedures as outlined below:*
    - *.1 in the case of new and unconventional products, a written analysis as to why the existing test method(s) cannot be used to test this specific product;*
    - *.2 a written analysis showing how the proposed alternative test procedure will prove performance as required by the Convention; and*
    - *.3 a written analysis comparing the proposed alternative test procedure to the required procedure in the Code.*

Chapter 6 of the FTP Code deals with PRODUCTS WHICH MAY BE INSTALLED WITHOUT TESTING AND/OR APPROVAL. Annex 2 to this Code specifies the groups of products, which are considered to comply with the specific fire safety regulations of the SOLAS Convention and which may be installed without testing and/or approval.

However, there is no mention whatsoever of battery installations in the FTP Code. Test methods are limited to (non-combustible) materials for bulkheads, decks, ceilings, doors, windows, etc. as well as other components e.g. thermal and acoustic insulation materials, fire dampers, cable and pipe penetrations, ventilation ducts etc., considered to be directly related to fire protection.

10.2 Further considerations on fire and explosion risk

Some aspects of fire and explosion risk would require further evaluation.

It is therefore important that the approach used to assess safety can properly describe the effects on fire safety posed by the battery installation design and arrangements. The difficult part is to identify and evaluate uncertainties, with sufficient confidence to establish appropriate safety margins.

Moreover, the focus on safety of human life in the fire safety objectives makes it topical to address not only the safety of passengers, but also the safety of firefighters and crew – which is a broad concept difficult to translate into prescriptive requirements.

Consideration of the functional requirements especially indicates that risks from adding battery systems on board (of which type/where/how much/for which functions) need to be accounted for.

Beside the combustibility assessment, it is nevertheless important to identify ignition sources and ensure that battery installations integrity is properly protected by fire insulation.

For the time that the construction is thermally protected, battery installations will not add to the generation or toxicity of the produced smoke. But, in the event of a fire lasting long enough to involve the structural divisions, an increased fire risk and toxicity of smoke could occur. This toxicity depends on the type of batteries. It is therefore crucial that fire hazards introduced in case of a long-lasting fire (i.e. lasting for more than 60 minutes) as well as the effects of fire extinguishing systems are carefully addressed in the SOLAS regulation II-2/17 assessment.

Even if not explicitly mentioned by prescriptive requirements, it may prove necessary to better address the fire functional requirement by a combination of passive and active measures, e.g. by an additional active fire-extinguishing system on exterior surfaces, or additional structural fire protection to mitigate the fire risks.

Additional safety measures may be needed on specific ship categories to address the SOLAS fire safety objectives. Typical examples are ships carrying dangerous goods, or ro-ro special category spaces, where more specific and stringent assessments may become necessary.

Furthermore, Safe Return to Port and Safe Areas provisions for the refuge of passengers in passenger ships (SOLAS regulation 21.5), are to be considered in case that battery installations support essential systems, or command and control activities necessary to manage an incident.

Direct fire safety assessments are usually based upon fire models and CFD computational tools. Critical aspects of such models include the verification of the effects fire extinguishing systems on a fire, and their possible contribution to prevent major consequences.

10.3 Some conclusions on fire safety

Generally, in the maritime sector, combustibility and fire protection are the key drivers of safety, since maritime regulatory provisions focus on the ability of a ship to be able to withstand fire at sea for a period of time - which is peculiar and not replicated in other regulations applied to other means of transport.

The way out to progress on fire safety of battery installations could be found in a new integrated performance-based methodology, following a fire safety engineering approach to meet SOLAS objectives and functional requirements - e.g. probability of ignition, risk by toxic product and smoke, smoke containment, structural integrity, etc.

Specific considerations would be required on:

- standards and acceptance criteria for fire resistance test procedures
- standards for fire protection effectiveness
- standards for fire detection and firefighting
- life-cycle performance criteria for fire safety

Other applicable industrial standards (ISO, IEC…) are reported in the Annex.

11 Considerations on the disposal and recycling of marine batteries

The following aspects would also require specific considerations:

- Sustainability - end-of-life waste handling, disposal, recycling of batteries
- Application of the Inventory of Hazardous Materials
- Application of the Hong Kong Convention and elements of the Nairobi Wreck Removal Convention (about the management of vessels or parts of vessels that are abandoned, wrecked, or are no longer usable)

Sustainability of ships at the end of their life cycle, waste handling, disposal, recycling policies are high priorities in the IMO agenda.

Current international legal instruments include:

- The Basel Convention (1989)
  Adopted on March 22nd,1989 (United Nations Environmental Programme) the Basel Convention provides a framework for minimisation and safe management of environmentally hazardous waste material.
- The Nairobi Convention (Adoption, 18th May 2007, entry into force 14th April, 2015)
  The Nairobi Convention (signed in Kenya, 2007) set in place a legal basis for states to remove wrecks.
- The Sound Recycling of Ships (Hong Kong) Convention, 2009.

11.1 Battery Lifecycle and Second Use Standards

In the scope of sustainable development, it is crucial to consider the batteries lifecycle and their end of life as well.

To this purpose, it is first necessary to define the lifetime or the durability of a battery system. However, this is still no uniformly agreed definition of durability of a battery system and many diverse definitions of battery performance degrading are still conflicting. In general, the existing standards prescribe tests based on cycling (charge and discharge, calendar ageing tests) and periodical evaluation of the battery performance. The termination criterion (end of life) is defined with respect to the initial battery performance.

The most relevant standards and regulations defining these aspects are listed in Table 7. As it emerges from this overview, most of the standards and regulations are oriented towards electric vehicles, being them the most sensitive to the definition of battery performance and battery end of life.

Table 4 Overview of relevant standards and regulations defining the performance of batteries for non-maritime applications.

Standard	Description
IEC 62660-1: Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 1: Performance testing	Testing of secondary lithium-ion cells for propulsion of electric and hybrid electric vehicles. How to obtain the capacity, power density, energy density, storage life and cycle life characteristics of cells.
ISO 12405: Electrically propelled road vehicles – Test specification for lithium-ion traction battery packs and systems Performance testing	Performance, reliability and electrical functionality for the battery packs and systems for high-power/high-energy applications.
IEC 61427: Secondary cells and batteries for renewable energy storage – General requirements and methods of test	Secondary batteries for on-grid and off-grid storage applications. Methods of test of endurance, properties and electrical performance. Tests do not depend on battery chemistry.
IEC 60896: Stationary lead-acid batteries	Methods of test for valve regulated stationary lead acid cells used in standby power applications.
SAE J2288: Life Cycle Testing of Electric Vehicle Battery Modules	Test method to determine the expected service life, in cycles, of electric vehicle battery modules. Test valid for different technologies. End of life condition evaluated based on module capacity and power rating. (Starts from USABC Baseline Life Cycle Test Procedure).
SAE J1798: Recommended Practice for Performance Rating of Electric Vehicle Battery Modules	Test and verification methods to determine battery module performance for electric vehicles. Definition of basic performance of battery modules and minimum performance compliance.
Battery Technology Life Verification Test Manual (TLVT)	Can be applied to batteries and other storage systems (e.g., supercapacitors). Based on automotive sector, but can be extended to others. Statistical-based test matrix designs and lifetime estimation methods.
U.S. Department of Energy (DoE) Battery Calendar Life Estimator Manual	Estimation of battery life using linear and non-linear models.
USABC Vehicle Battery Test Procedures Manual	Testing of cells, packs, modules. Estimation of battery life for electric vehicles based on accelerated performance and normal operation testing.
Program Battery Test Manual for Plug in Hybrid Electric Vehicles	Specific procedures for P-HEVs. Testing of full-size battery systems and also modules, cells.

The second step, after having defined the performance degradation of batteries, is to develop regulations related to the disposal/recycling of batteries (as already mentioned in 11) and possible second-use applications. In particular, second use of depleted maritime batteries can be considered for other applications, with less stressing utilization profiles (e.g., stationary grid applications), as it is currently proposed for exhausted electric vehicle batteries (i.e., capacity lower than 20-30% of the original one). Therefore, a review of the standards for second use has been included in this report. It must be pointed out that only one standard (UL 1974) is active at the present, while others are still under development, giving room for further modifications and advancements.

The key aspects of these standards are related to the battery management system and the thermal management, which are usually specific of the battery pack of the vehicle and cannot be easily refitted for other applications. Therefore, it is crucial to standardize the sizes, geometries and interfaces of battery systems, as well as simplify the disassembly process, to enable a second use applications. Moreover, second life applications could be further optimized in a complete lifetime perspective (both primary and second use), with a broader evaluation of the economic aspects during all the life cycle. With reference to [52], the following aspects are worth mentioning when developing second use standards:

- Definition of battery End of Life and second use applications with respect to the battery lifecycle.
- Criteria to evaluate the battery status: when and if it is suitable for a second life application.
- Standard practice to dismantle, move and store used batteries.

In table 6 the relevant standards regarding second life of batteries are listed.

Table 6 Standards for second use of batteries.

Standard	Description
SAE J2997: Standards for Battery secondary use (started 2012)	Testing and definition of batteries for safe reuse. Standard for transportation, labelling and state of health.
UL 1974: Standard for Evaluation for Repurposing Batteries (Active)	Sorting and grading process of batteries and electrochemical capacitors, originally configured and used for other purposes, and that are intended for a repurposed use application, such as energy storage systems. Application specific requirements for repurposed battery systems utilizing repurposed modules, cells and other components.

12 Overview of Provisions and Standards on Batteries Installations for Automotive and Stationary Applications (Non-Maritime)

In the outlook of providing guidelines to expand the international requirements and promoting the adoption of a single set of regulations and/or standards, it is useful to review the existing standards and prescriptions for non-maritime applications. In this overview, the considered non-maritime applications are automotive and stationary, intended as energy storage for grid applications.

These already existing standards represent a valid reference for safety, reliability, installation and operation of batteries in the maritime sector as well. In this analysis, the following standardizing committees are considered:

- ISO: International Organization for Standardization;
- IEC: International Electrotechnical Commission;
- SAE: Society of Automotive Engineers;
- UL: Underwriters Laboratories;
- ECE: Economic Commission for Europe.

12.1 Safety/Reliability Testing Standard Comparison

The first aspect considered in this overview compares the testing procedures for batteries in automotive and stationary applications. These tests are necessary to ensure the safety of the equipment and the users during the operation of these devices.

This overview highlights four fields of testing, which represent the possibilities of misuse that can be faced by batteries: mechanical, electrical, environmental and chemical. Each misuse class is further divided into more specific aspects and the most significant international standards are then compared in their requirements. The results, which are summarized in Table 7, highlight that the automotive standards are much more detailed in describing the spectrum of required mechanical tests, compared to stationary applications. This can be explained by the more stressful operating conditions of automotive batteries, compared to stationary applications and could be more suitable for maritime applications. Also, probably due to the difference of battery size for these two applications of fields, the propagation default inside the battery is much more assess for stationary application, e.g. propagation test for IEC62619 and internal fire exposure test for UL1973.

From the electrical point of view, the considered standards are uniform in prescribing a full spectrum of tests, covering the most common electrical failures: short circuit, overcharge and overdischarge. These tests are independent on the field of applications and could also be included in maritime standards.

From the environmental and chemical point of view, the SAE automotive standards are the most specific, as they prescribe a broader range of tests for batteries. These tests include not only the basic thermal and fire exposure tests, but also thermal stability tests (thermal runaway), overheating and low temperature exposure tests. Finally, it is of utmost importance that faulted batteries do not represent a source of chemical hazard in case of accidents. In particular, it is crucial to identify and quantify any toxic gases (e.g., carbon monoxide, carbon dioxide, methane, hydrogen, hydrofluoric acid, VOC…) that might be released by faulty batteries, to ensure the safety of both the operators and the emergency teams operating after any accidents.

Table 7 Overview of the abusive tests for batteries prescribed by significant international standards for automotive and stationary applications.

Field →		Automotive						Stationary
Test		**ISO 6469**	**IEC 62660**	**SAE J2464**	**SAE J2929**	**UL2580**	**ECE R100.02**	**UL 1973**
Mechanical	Vibration	•	•	-	•	•	•	-
	Mechanical shock	•	•	•	•	•	•	-
	Rollover	-	-	•	•	•	-	-
	Penetration	-	-	•	-	-	-	-
	Drop test	-	-	•	•	•	-	•
	Crush/Crash	•	•	•	•	•	•	-
	Immersion	•	-	•	•	•	-	•
Electrical	Short circuit	•	•	•	•	•	•	•
	Overcharge protection	•	•	•	•	•	•	•

	Over-discharge protection	•	•	•	•	•	•	•
Environmental	Thermal shock and cycling	•	•	•	•	•	•	•
	Fire	•	-	•	•	•	•	•
	Thermal Stability	-	•	•	-	•	•	•
	Low temperature test	-	-	-	-	•	-	-
	Overheat	-	-	•	•	-	-	-
Chemical	Emission	-	-	•	•	•	-	-
	Flammability	-	-	•	•	•	-	-

It is also of interest to discuss the classification of the outcome of these tests on batteries, according to the various standards. In most cases, the standards prescribe “pass” or “fail” outcomes for each of the reviewed tests. However, in the automotive field, a more detailed classification method, defined by the EUCAR Hazard level table (listed in Table 5), is often applied, requiring a performance level less of equal than 4.

Table 5 EUCAR hazard levels.

Hazard Level	Description	Classification Criteria & Effect
0	No effect	No effect. No loss of functionality.
1	Passive protection activated	No defect; no leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Temporary loss of battery functionally. Resetting of protective device needed.
2	Defect/Damage	No leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. RESS irreversibly damage. Repair needed.
3	Leakage (mass variation < 50%)	No venting, fire, or flame; no rupture; no explosion. Weight loss < 50% of electrolyte weight.
4	Venting (mass variation > 50%)	No fire or flame; no rupture; no explosion. Weight loss ≥ 50% of electrolyte weight.
5	Fire or flame	No rupture; no explosion (i.e., no flying parts)
6	Rupture	No explosion, but flying parts of high thermal or kinetic energy.
7	Explosion	Explosion (i.e., disintegration of the cell).

In the following tables, a list of the most relevant automotive battery standards is listed.

Table 6 OEM Standards for Cell and Battery Pack.

Standard	Applicability	Purpose
SAE J2464	International	Electric and hybrid electric vehicle rechargeable energy storage system (RESS) safety and abuse testing
SAE J2929	International	Electric and hybrid vehicle propulsion battery system safety standard - lithium-based rechargeable cells
ISO 12405-1/3	International	Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems Part 1: High-power applications/ Part 3: Safety performance requirements
ISO 6449-1	International	Electrically propelled road vehicles – Safety specifications Part 1: On-board rechargeable energy storage system (RESS).
IEC 62660-2/3	International	Secondary lithium-ion cells for the propulsion of electric road vehicles Part 2: Reliability and abuse testing/ Part 3: Safety requirements
UL 2580	USA	Batteries for use in electric vehicles
USABC	USA	United States Advanced Battery Consortium electrochemical storage system abuse test procedure manual
SAND 2005-3123	USA	FreeDomCAR electrical energy storage systems abuse test manual for electric and hybrid electric vehicle applications
KMVSS 18-3	Korea	Regulations for motor vehicle safety standards
AIS-048	India	Battery operated vehicles - safety requirements of traction batteries
QC/T 743	China	Li-ion storage battery for electric automotives
UNECE R100	International	Battery electric vehicle safety
BATSO 01	International	Manual for evaluation of energy systems for Light Electric Vehicle (LEV)- Secondary Lithium Batteries
Trias 67-2 (Attachment 110)	Japan	Technical Standard Concerning the Protection of Occupants from High Voltage etc. of Electrical Vehicles and Electrical Hybrid Vehicles
Trias 67-3 (Attachment 111)	Japan	Technical Standard Concerning the Protection of Passengers from High Voltage etc. after Collision of Electrical Vehicles and Electrical Hybrid Vehicles
FMVSS 571.305	USA	Part 571 Federal Motor Vehicle Safety Standards - Title 49 Transportation - Section 305 - Electric-Powered Vehicles: Electrolyte Spillage and Electric Shock Protection

Other more general standards regarding the safety of automotive batteries and electronic equipment:

Standard	Purpose
UN 38.3	Recommendations on the Transport of Dangerous Goods. Requirement for the transportation of batteries
GB 38031	Electric vehicles traction battery safety requirements
ISO 16750	Road vehicles – Environmental conditions and testing for electrical and electronic equipment
ISO 20653	Protection of electrical equipment against foreign objects, water and access

12.2 Installation and Operation of Stationary Batteries

Stationary energy storage systems (SESSs) are regulated in terms of installation and operation. The standards and regulation present prescriptions in the following aspects:

1. **Siting:** The ESS must comply with specific requirements regarding the acceptability of the foundations and protection against environmental stress (e.g., rain, snow, floods….). Moreover, ESSs must provide pathways for emergency services and maintenance, guaranteeing clearances from hazardous materials.
2. **Interconnection:** The ESS must comply to the standards when interconnected with other power, communication and control systems. Moreover, it is necessary to provide a disconnection method for the ESS.
3. **Ventilation, Thermal and Exhaust Air Management:** the installation of a dedicated or general ventilation system is prescribed by the standards both in case of enclosed battery systems (tested before the on-site deployment) and not-enclosed systems, which must be considered in the final installation site.
4. **Fire Protection:** The ESSs require fire and smoke detection systems, as well as fire suppression systems. Even for enclosed ESSs, it could be necessary to provide additional measures, depending on the on-site deployment. Besides, also fire and smoke containment systems must be included when the ESS is placed inside a building or a structure. This category of protection also includes the containment of fluids that may leak from battery systems during fire extinguishing activities and emergency operations.
5. **Signalling:** the ESSs require specific signals describing the battery technology, capacity, control devices, chemical hazards, fire suppression devices installed and instructions for emergency teams.

Useful reference standards regarding stationary applications are:

Standard	Purpose
IEC 62485-2: Safety requirements for secondary batteries and battery installations – Part 2: Stationary batteries	Stationary secondary batteries and battery installations with a maximum voltage of 1500 Vdc and describes the principal measures for protections against hazards generated from: • Electricity; • chemical emissions; • electrolytes.
IEC 62619: Secondary cells and batteries containing alkaline or other non-acid electrolytes. Safety requirements for secondary lithium cells and batteries, for use in industrial applications	Requirements on all aspects of stationary application use of Li-ion batteries including erection, use, inspection, maintenance, and disposal of cells (Under development)
IEC 62620: Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for use in industrial applications	Marking, tests and requirements for lithium secondary cells and batteries used in industrial applications including stationary applications
IEEE 1660: Guide for Application and Management of Stationary Batteries Used in Cycling Service	Differences between stationary standby and stationary cycling applications and appropriate battery management strategies in cycling operations. emphasis is on lead-acid batteries

UL 1642: Lithium batteries	Requirements for lithium batteries in stationary applications for safety of technicians, users, and other design features
IEC 62897: Stationary Energy Storage Systems with Lithium Batteries – Safety Requirements	General safety requirements for stationary energy storages with lithium batteries. Hazards to the operators and the surrounding area. Protection against electric, mechanical, fire, temperature, gases....
UL 1973: Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications	Safety for stationary batteries. Includes electrochemical capacitor systems or hybrid electrochemical capacitor and battery systems. Requirements for flow batteries and sodium beta. Construction requirements, tests and production tests.
IEC 62040: General and safety requirements for UPS both in accessible and restricted areas	Uninterruptible Power Supply for low-voltage distribution systems, intended to be installed in an area accessible by an ordinary person or in a restricted access area
IEC 62933: Electrical energy storage (EES) systems	EES systems designed for grid-connected indoor or outdoor installation and operation. Necessary functions and capabilities of EES systems, test items and performance assessment methods, requirements for monitoring and acquisition of system operating parameters, exchange of system information and control capabilities required

13 Battery safety requirements in other sectors

13.1 Automotive sector

Electromobility represents the concept of using electric powertrain technologies with a view to address climate change, improve air quality and reduce fossil fuel dependency. The current regulatory pressure to lower CO2 and pollutant emissions is helping to drive an increasing market penetration of vehicles utilizing electric powertrain (hereafter, "electrically propelled vehicles" or "EV").

Energy use in transport has increased significantly in correlation with world population growth and economic development. At the end of the twentieth century there were 500 million private cars in use globally. By 2015, that number had doubled to 1 billion. Over 20 million cars are sold each year in China alone, and the number of vehicles will continue to grow. In this sense, road transport accounts for around three quarters of transport energy consumption, with light duty vehicles responsible for around half, and a quarter is used by trucks and buses.

In order to reduce the environmental impact that will be caused by the massive growth in the use of land vehicles, many governments support the development and deployment of EV by financing research or offering incentives for consumers. Consequently, the automotive industry is investing in research and development as well as the production capacity for electric vehicles, at a scale not seen in the past, as it is shown in Illustration 1.

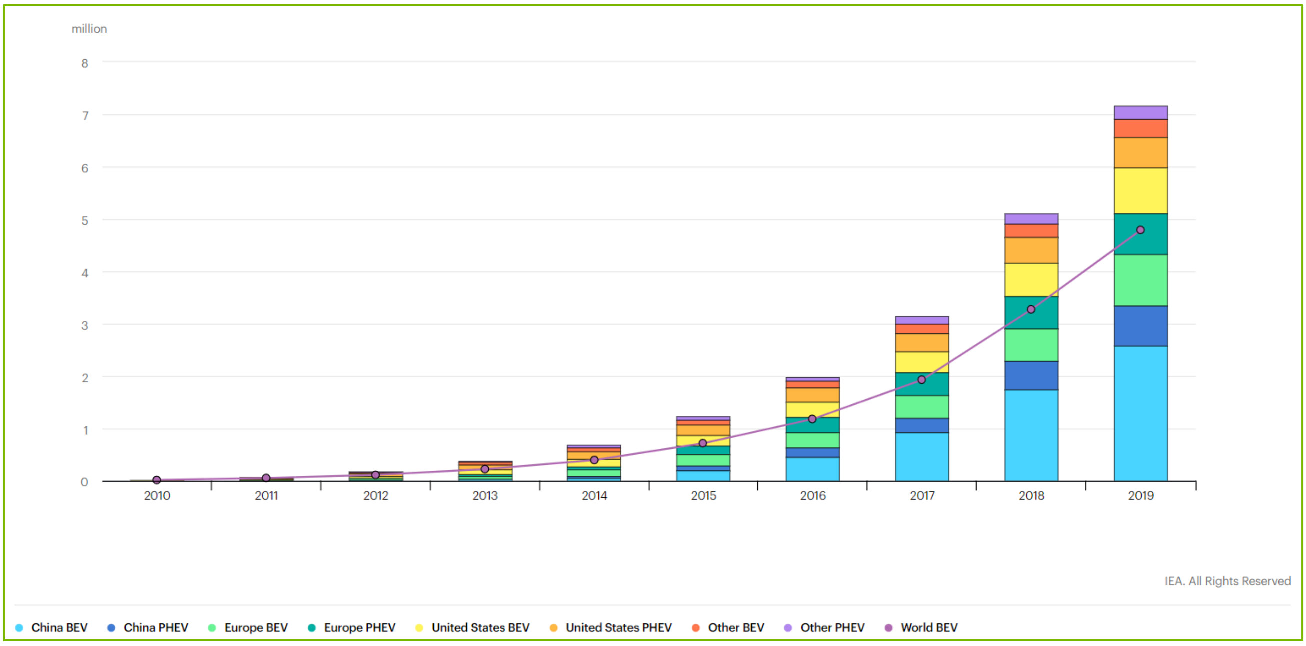


Illustration 1: Global electric car stock growth per year, from 2010 to 2019
Source: Global EV outlook 2020

Unlike in the naval sector, as stated in previous sections within this deliverable, the electrification of land vehicles is evolving and developing much faster, and for this reason many industries and governments have already started to define a common global regulation, which can result in economies of scale and large cost reductions, with the aim of ensuring safety and gaining consumer confidence, but always taking into account environmental performance measures.

More in detail, this regulation is already being generated worldwide, led by the United Nations (United Nations Global Technical Regulation), with the support of the global scientific community and the governments of Canada, China, the European Union, Japan, Republic of Korea and the United States of America, with the main objective of introducing and establishing requirements associated with the possible safety risks that electric vehicles may suffer while they are being used and when suffering an accident, including within these aspects the electrical discharges associated with the high voltage circuits that are included in this type of vehicles, as well as the potential dangers of using lithium ion batteries or other rechargeable electrical energy storage systems.

Next, the main requirements identified within the "United Nation Global Technical Regulation" will be described, which are considered key to take into account in a future global regulation within the maritime sector.

13.1.1 Requirements of a vehicle with regard to its electrical safety - in use

13.1.1.1 Protection against electric shocks

These types of requirements will only apply in conditions in which the high voltage buses are not connected to an external power supply outlet. As can be observed, these requirements are specially detailed.

Regarding direct contact protection, electrical protection barriers, enclosures, solid insulators and connectors will not be opened, disassembled or removed without the use of suitable tools. Exceptionally, they may be separated without tools as long as they meet the following protection requirements:

- For the active parts that are located inside the passenger or luggage compartments, the degree of protection must be IPXXD.
- For active parts that are located in compartments other than passenger and luggage compartments, the degree of protection must be IPXXB.
- In the event of a high voltage service disconnection, in order to be able to handle it without the need for tools, a degree of protection IPXXB must be available.

For the case of protection against indirect contacts:

- All conductive parts, including conductive barriers and enclosures, must be connected to the chassis with either electrical wiring or a ground wire, in order to avoid potential hazards.
- The resistance between all exposed conductive parts and the electrical chassis will be less than 0.1 Ω when there is a current flow of at least 0.2 A.
- In the case of motor vehicles that are intended to be connected to the external grounded power supply via the conductive connection, a device shall be provided to allow the conductive connection of the electrical chassis.

On the other hand, the regulation not only takes into account the safety of people, in relation to protection against direct and indirect contacts, but also establishes security measures within the system itself through the inclusion of isolation resistors. Depending on the system configuration, two different types are described:

- If AC high voltage buses and DC high voltage buses are conductively isolated from each other, isolation resistance between the high voltage bus and the electrical chassis shall have a minimum value of 100 Ω/V of the working voltage for DC buses, and a minimum value of 500 Ω/V of the working voltage for AC buses.
- If AC high voltage buses and DC high voltage buses are conductively connected, isolation resistance between the high voltage bus and the electrical chassis shall have a minimum value of 500 Ω/V of the working voltage. However, if all AC high voltage buses are protected by one of the two following measures, isolation resistance between the high voltage bus and the electrical chassis shall have a minimum value of 100 Ω/V of the working voltage:
    - At least two or more layers of solid insulators, electrical protection barriers or enclosures.

    - Mechanically robust protections that have sufficient durability over vehicle service life such as motor housings, electronic converter cases or connectors.
- For the vehicle inlet intended to be conductively connected to the external AC electric power supply and the electrical circuit that is conductively connected to the vehicle inlet during charging the REESS, the isolation resistance between the high voltage bus and the electrical chassis shall have a minimum value of 100 Ω/V for DC buses and a minimum value of 500 Ω/V for AC buses.

Within insulation, a key point that is identified within the regulation is the allusion to insulation against water. In the case of electric vehicles, it is established that the water insulation must be sufficient to ensure insulation in conditions of heavy rain or when being introduced into a car wash. In this sense, the vehicle manufacturers shall provide evidence and/or documentation to the regulatory or testing entity as applicable on how the electrical design or the components of the vehicle located outside the passenger compartment or externally attached, after water exposure remain safe and comply with the requirements. If the evidence and/or documentation provided is not satisfactory the regulatory or testing entity as applicable shall require the manufacturer to perform a physical component test.

13.1.1.2 Functional safety
In this case, the functional safety requirements are directly associated with the requirements that the electric vehicle driver must meet each time the propulsion system of the same is activated. In this sense, a momentary alert will be triggered indicating the "active driving possible mode" situation. However, this provision does not apply in conditions where an internal combustion engine directly or indirectly provides propulsion power at startup.

Additionally, if the REESS can be externally charged, vehicle movement by its own propulsion system shall be impossible as long as the vehicle connector is physically connected to the vehicle inlet.

13.1.2 Requirements with regard to the safety of REESS in-use
It must be taken into account that this regulation not only takes into account safety from the point of view of the vehicle and the driver, but also includes the requirements that the energy storage systems themselves must meet, which are listed and described below:
- Vibrations.
- Thermal shock and cycling.
- Fire resistance.
- External short circuit protection.
- Overcharge protection.
- Over-discharge protection.
- Over-temperature protection.
- Overcurrent protection.
- Low-temperature protection.
- Management of gases emitted from REESS.
- Thermal propagation.

13.1.2.1 Vibrations
During use, the energy storage system will be subject to constant vibrations. Therefore, the system must be able to withstand these vibrations without any rupture, electrolyte leakage, ventilation (in the case of closed-type REESS), fire or explosion.

13.1.2.2 Thermal shock and cycling

The energy storage system must be kept completely intact, without causing any electrolyte leakage, rupture, fire or explosion.

13.1.2.3 Fire resistance

Today, a large number of energy storage systems are composed of flammable electrolytes, such as lithium ion or carbonates, so that in the case of electric vehicles, the batteries cannot be placed less than 1.5 m height above the ground.

13.1.2.4 External short circuit protection and overcurrent protection

Both the external short-circuit protection and the overcurrent protection must be capable of preventing the temperature gradient of the frame in which the battery system is located from not varying more than 4 ° C after two hours after the current has been removed.

13.1.2.5 Overcharge, over-discharge, over-temperature and overcurrent protection

The protection system of the energy storage system must be capable of preventing electrolyte leakage, system breakdown, fire or explosion resulting from overcharging or over-discharge, from overheating or a surge in current.

13.1.2.6 Low temperature protection

Vehicles manufacturers must make available the following documentations, explaining safety performance of the system, in order to demonstrate that the vehicle monitors and appropriately controls REESS operations at low temperaturas at the safety boundary limits of the REESS:

- A sistema diagram.
- Written explanation on the lower boundary temperature for safe operation of REESS.
- Method of detecting REESS temperature.
- Action taken when the REESS temperature is at or lower than the lower boundary for safe operation of the REESS.

13.1.2.7 Management of gases emitted from REESS

When the vehicle is in operation, including faulty operation, the occupants of the vehicle will at no time be exposed to hazardous environments caused by emissions from energy storage systems.

Likewise, during the charging process, hydrogen emissions must always be below 125 g during 5 hours of charging, or 25 times the overcharge time at constant current. In the event that the charging process is carried out by a charger that has a fault, as specified in Annex I of the "Global Technical Regulation on the Electric Vehicle Safety (EVS)", hydrogen emissions must be below the 42 g for no more than 30 minutes.

13.1.2.8 Thermal propagation

For the vehicles equipped with a REESS containing flammable electrolyte, the vehicle occupants shall not be exposed to any hazardous environment caused by thermal propagation which is triggered by an internal short circuit leading to a single cell thermal runaway

The vehicle shall provide an advance warning indication to allow egress or 5 minutes prior to the presence of a hazardous situation inside the passenger compartment caused by thermal propagation which is triggered by an internal short circuit leading to a single cell thermal runaway such as fire, explosion or smoke.

13.1.2.9 Requirements with regard to the safety of REESS – post-crash

In this case, the regulations refer to the safety requirements that an energy storage system must meet after suffering an accident. In this sense, the regulations exhaustively affect issues such as the type of electrolyte, whether it is in a hazy or non-aqueous state, the integrity of the system during the impact and post-accident, the danger of generation and spread of fire.

In the case of the type of electrolyte, for systems that use aqueous electrolytes, the volume of electrolyte that is filtered may not exceed 7% of the total volume of the electrolyte in the compartments intended for passage and 5 liters for the compartments intended for passage. luggage for the first 60 minutes after impact. In contrast, for non-aqueous electrolytes no electrolyte leakage will be allowed.

With regard to structural integrity, the system must always remain attached and anchored to the vehicle in a way that transfers loads to the vehicle's structure. In the case of systems that are outside the passenger compartment, the system will never be able to enter said compartment.

Finally, the energy storage system must not show evidence of fire or explosion for at least the first 60 minutes after the accident.

13.2 Railway Sector with Batteries

The war on diesel is not only fought in road transport. The train tracks also want to become independent of this polluting energy to switch to electricity, even when there are no catenaries available or there is no third rail. In some countries, such as Japan or Germany, a significant percentage of the rail network is not electrified. They only have the tracks, there is no third rail, or catenaries, that feed the train to reach the entire route. To solve it, until now it has mainly opted for diesel. Traditionally used by the transport sector because it is more efficient than gasoline and therefore cheaper, many studies indicate that diesel releases more polluting particles and is responsible for much of the pollution, especially in urban areas. These countries are now testing batteries as an alternative.

On-board rechargeable battery systems provide the power for several rail industry applications, including:

- Actions to start the engine that require high currents for short periods for diesel locomotives and diesel multiple units (DMUs).
- Critical backup, short duration/high power tasks, such as in high-speed trains that support emergency and camber braking systems, and in emergencies, up to two hours after the main supply interruption.
- Support for lighting, air conditioning, ventilation, heating, communication, and control of the car door travelers, up to three hours.
- Traction for hybrid or DMU/EMU tram systems hybrids.

There are two types of batteries that are generally used in railway applications, lead-acid and nickel-cadmium applications (Ni-Cd), with a significant difference in their failure modes.

In a lead-acid battery, it can fail causing an open circuit due to the natural corrosion of the lead plate structure that occurs during the electrochemical reactions associated with charging and discharging. The effect that an open circuit cell has on a battery is the complete failure of the battery to supply current. The only way to avoid such a catastrophic situation is to use parallel strings of batteries to ensure redundancy in the system. But this affects the cost of batteries.

Instead, Ni-Cd plate construction (steel or sintered/PBE bag plate) assumes that an individual cell cannot cause an open circuit, the worst that can happen is a short circuit. The effect of a short circuit in a typical 110V on-board battery cell is that the battery voltage is reduced by one cell. Typically, an 84-cell battery converts to an 83-cell battery, a little more than 1% loss in battery performance. This is not a catastrophic situation, and the battery will continue to operate at a slightly reduced rate, so there is time to take corrective action.

Next, some battery projects for trains will be briefly described. The main companies that participate in these projects and that are the world leaders in batteries for the railway sector are SAFT (Company of TOTAL, France), ALSTOM (France), ENERSYS (USA), AMARA RAJA GROUP (India), SIEMENS (Germany) and CAF (Spain).

- SITRAS HES (SIEMENS Transportation)

SITRAS HES (Hybrid Energy Storage system) is a hybrid system that combines two storage units: the ultracapacities bank of the SITRAS MES and a traction system made up of NiMH batteries.

The system, installed on the roof of the train and connected to the power point by means of a chopper, is loaded in the sections provided with the catenary, at stops or with the energy that is regenerated during braking. This energy reserve provides the vehicle with sufficient autonomy to cover sections of up to 2500m.

With the system SITRAS HES a reduction in energy demand of up to 30% is obtained. It emits 80 tons less of CO_2 per year and stabilizes the line voltage. Also, this system can be integrated into new vehicles or existing systems.

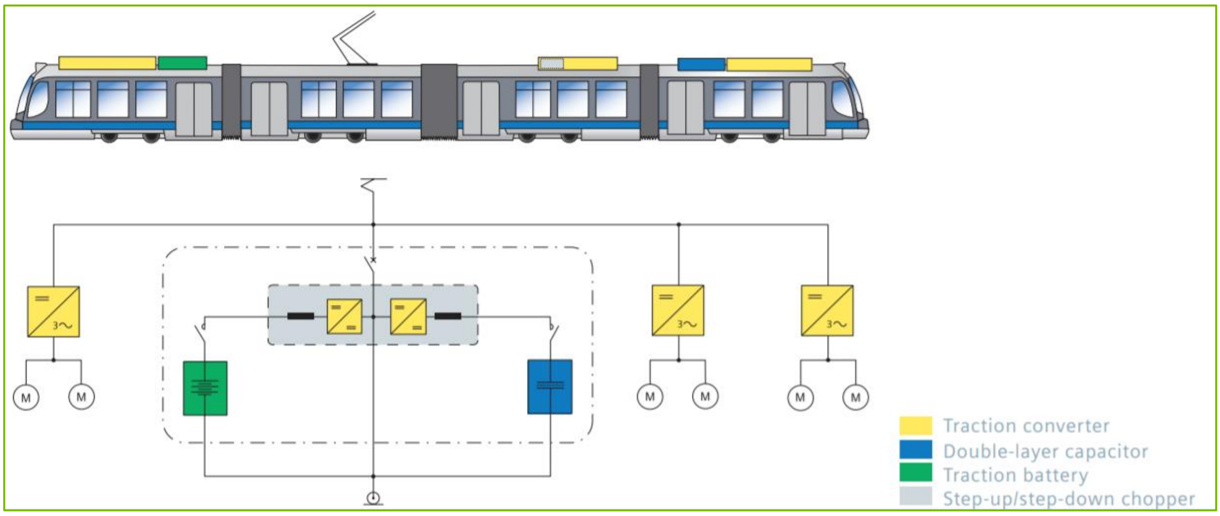


Figure 5 SITRAS HES concept. Source : SIEMENS

Figure 6 Trams from Sheffield with MRX NiCd batteries by SAFTFigure 7 SITRAS HES concept. Source : SIEMENS

The main battery system (typically 44 NPH10-340 cell blocks connected in series) characteristics are as follow:
• Usable energy: 18 kWh.
• Maximum power: 105 kW.
• Nominal voltage: 528 V.
• Cooling: water.

• Dimensions (width x depth x height): 1670x1025x517 mm^3
• Weight: 826 kg.
The first train with the SITRAS HES system, which allows the elimination of catenary in some of its sections, was installed in 2008 and runs between the towns of Almada and Seixal, in Portugal.

- <u>NiCad Batteries (SAFT MRX)</u>

The french company SAFT has been developing projects for more than 10 years to implement NiCd batteries in the railway sector.

SAFT MRX's nickel-cadmium battery systems help keep train and tram services running on time, providing vital backup power for critical safety and control systems, including emergency braking, especially if there is an interruption in the main electrical supply of the overhead lines of the catenary.

SAFT MRX batteries are a good choice for light trams as they provide maximum performance, reliability, and a low total cost of ownership (TCO by its acronym). They also stand out for their low maintenance characteristics together with a long useful life thanks to the sintering/PBE technology, it is a compact and lightweight battery pack that reduces the volume by more than 30% compared to conventional batteries.

The design of MRX batteries is very reliable and does not suffer from "sudden death", a phenomenon that can occur in some types of batteries, even in extreme temperatures ranging from -30°C to + 70°C. Another advantage is that they have a centralized water system that facilitates refilling, reducing operator maintenance and costs.

Three such MRX battery systems were installed in 2018 on board each carriage of the Sheffield trams (United Kingdom). Two 130 Ah capacity batteries provide 90 minutes of backup power for critical functions such as lighting, door opening, communications, and pantograph lift. Also, this system supports the electro-magnets to activate the brakes in an emergency. The third 70 Ah battery supplies additional backup power for onboard functions.

Figure 8 Trams from Sheffield with MRX NiCd batteries by SAFT

Figure 9 CORADIA iLINT railway. Source: ALSTOMFigure 10 Trams from Sheffield with MRX NiCd batteries by SAFT

SAFT also participates in the project together with the company CAF for the supply of integrated MRX batteries on board 12 new trams for the city of Freiburg (Germany). These batteries include 80 MRX 115 cells of 110V and 115 Ah of nominal capacity.

- CORADIA iLINT (ALSTOM)

CORADIA iLINT is the world's first passenger train to run on a hydrogen fuel cell, which generates electrical energy for propulsion. This completely emission-free train is silent and only emits water vapor and condensation water. The train includes other novel aspects such as clean energy conversion, flexible energy storage in batteries and intelligent management of the driving force and available energy. This new technology is specially designed for non-electrified lines, allowing for clean and sustainable train operations.

The CORADIA iLINT project from the company ALSTOM will be operating in the United Kingdom until the end of 2021.

Figure 11 CORADIA iLINT railway. Source: ALSTOM

Figure 12 RATP new locomotive propelled by batteries. Source: CAFFigure 13 CORADIA iLINT railway. Source: ALSTOM

The fuel cells, the central axis of the system, are fed on demand with hydrogen, and the trains are propelled by an electric traction unit. Fuel cells provide electricity by mixing the hydrogen stored in the tanks with oxygen from the outside air.

The only emission is water vapor and condensed water and no polluting gases or particles are generated. Electricity is produced without a generator or turbine, which makes the process much faster and more efficient.

The efficiency of the system is also based on energy storage in high performance lithium-ion batteries. The battery stores the energy produced by the fuel cells when it is not needed for traction, or of the kinetic energy during electric braking, thus allowing the supply of support energy during the acceleration phases. Batteries accumulate energy that is not used immediately to supply it later as needed and to ensure better management of fuel consumption.

Lastly, this train offers benefits comparable to those of the latest generation of regional diesel traction trains, both in acceleration and braking and in its maximum speed of 140 km/h, and autonomy between 600 km and 800 km, depending on the terrain. The train has the same level of comfort and capacity, up to 300 passengers.

- <u>Electric locomotives in Paris metro (CAF)</u>

CAF is the manufacturer of the new maintenance locomotives for the French operator RATP (Régie Autonome des Transports Parisiens). These are dual engines with a power of 1.000 kW, equipped with nickel-cadmium batteries to be able to carry out maintenance activities in a totally autonomous way. It is the first time that this technology has been implemented worldwide in units of this type.

It is important to highlight the replacement of diesel engines in these new locomotives. The units will be able to operate both by means of the energy obtained from the catenaries, as well as by means of batteries incorporated into them. This will bring about a significant improvement in the environmental field, eliminating polluting emissions and significantly reducing noise during operation.

Figure 14 RATP new locomotive propelled by batteries. Source: CAF

The new locomotives will be used to tow the trains that maintain the infrastructure of the RATP regional train network. The first unit of the entire project was delivered in the first quarter of 2019.

Figure 15 RATP new locomotive propelled by batteries. Source: CAF

13.3 Safety Requirements

A railway project in which batteries are included, in addition to the regulations of the railway sector, the project must comply with the regulations related to batteries:

- EN 60623: “Secondary cells and batteries containing alkaline or other non-acid electrolytes – Vented nickel-cadmium prismatic rechargeable single cells”.
- EN 50547: “Railway Applications – Batteries for Auxiliary Power Supply Systems”.
- EN 50272-2: “Safety requirements of secondary batteries and battery installations – Part 2: Stationary batteries”.
- National regulations on batteries depending on the country where the train operates (example: NTP 617 specific for lead-acid batteries).

The design of the entire battery system, including its chargers and battery voltage lines, will also be redundant, equivalent to what is required for auxiliary static converters. The battery train will have at least two batteries, with their corresponding independent chargers, connected in parallel with each other. The objective of this redundant design of the entire battery system is to ensure maximum reliability of the auxiliary services of the battery train.

The batteries will be mounted so that they are easy to access. For this reason, they will be installed on metal frames that can slide outwards and thus facilitate maintenance. The batteries will be properly ventilated. The nominal voltage of the batteries should be, desirably, 110 V and the operating temperature range will be according to EN 50547.

13.3.1 European Standard EN 50547: Railway Applications – Batteries for Auxiliary Power Supply Systems

This European Standard, published in April 2013, specifies rechargeable lead acid and NiCd-batteries for 110 V voltage auxiliary power supply system for railway vehicles. Other technologies like NiMh or lithium are not covered by this standard at present. In section 4.7 of this Standard the safety and protection requirements are described.

The battery tray shall be with electrolyte or acid retention for cells with liquid electrolyte. Not necessary for VRLA (valve regulated lead acid) batteries. The vent plugs of the cells or the filling system shall be backfire-proof in order to avoid internal explosions. The battery system shall have sufficient ventilation (no dangerous concentration of gases), calculation of ventilation shall be done according to the European Standard EN 50272-2 requirements.

- Deep discharge of lead acid batteries

Deep discharge of lead acid battery means, that more capacity (electrical energy) is discharged out of the battery than allowed, or more than defined in the discharge curves of the manufacturer, respectively. This may result in insufficient recharging.

There are different methods to protect the batteries against deep discharge. It is suggested to use parameters such as:

- voltage
- current
- temperature
- time

as a criterion for deep discharge protection. Curves showing the relationship between the current and the final discharge voltage should be available from the battery manufacturers.

- Necessary conditions after deep discharge of lead acid batteries

Deep discharge of lead acid batteries especially without proper recharge can lead to permanent damage of the battery in terms of reduced available capacity. In case of a deep discharge the operating instructions of the battery manufacturer shall be followed.

- Deep discharge of NiCd batteries

Deep discharge of NiCd battery means, that more capacity (electrical energy) is discharged out of the battery than allowed, or more than defined in the discharge curves of the manufacturer, respectively. The nominal final discharge voltage is 1.0 V/cell. All discharge voltages below this value at currents ≤ 1 C indicate a possible deep discharge.

- Necessary reconditioning after deep discharge of NiCd batteries

NiCd batteries do not require specific devices to protect the battery against deep discharge itself. However, the available capacity especially after repeated deep discharge may be temporary reduced. Therefore, after a repeated deep discharge the operating instructions of the battery manufacturer shall be followed.

• Temperature compensation

The battery charging voltage shall be temperature controlled. In practical application it has been found that following compensation factors should be used:

- NiCd batteries: -0,003 V/K per cell
- lead acid batteries: -0,004 V/K per cell

As a further measure the battery should not be operated in boost charging mode and changed to float charging mode above these temperatures:

- NiCd batteries: 45°C
- lead acid batteries: 50°C

At temperatures above 70°C, the batteries shall be not charged. This protects the battery at high temperatures, and it also ensures the maximum possible state of charge at lower temperatures and minimizes water consumption. In case of sensor failure, the system should use temporary the 20°C charging value if not specified otherwise.

•Protection against superimposed ripple current

The battery charging current shall be DC, as any superimposed AC component in the charging current can lead to a temperature increase of the battery. The AC content in the charging current should not exceed values as per EN 50272-2.

For more information for safety requirements on batteries for auxiliary power supply systems, refer to EN 50547, Section 4.7, edition April 2013.

13.3.2 Lead-Acid batteries safety requirements (NTP 617)

This standard, based on the guidelines of the European Union, includes a series of recommendations and good practices when working with lead-acid batteries.

For safety it is recommended that the grouping of several batteries arranged in a common receptacle should have ventilation vents in it. This ventilation of the premises is independent of those existing in the caps of the cells of each of the batteries.

Lead-Acid batteries embedded in support trays should have a lifting device designed so that the stresses are vertical. Some insulating material must be placed between the metal hooking elements and the battery to protect against accidental contacts that would lead to short circuits. The lifting device can be by chains, manual, pneumatic or electric action with safety protection for flammable atmospheres.

The operations carried out in the battery charging room must have the following equipment and facilities:

- Lifting equipment with elevated monorail travel along the load line.
- Wheelbarrow, pallet truck or similar for other movements.
- Support racks as trays to place the batteries on charge. They must be made of insulating materials or with coatings that prevent the generation of sparks and are resistant to acids.
- Own cargo equipment.
- Maintenance utensils: hydrometers to measure the density of the electrolyte, direct current voltmeters, thermometers, inclination support for filling electrolyte containers or siphon device for handling and transferring the same.
- Battery washing facility with adequate drain and register for neutralization and cleaning of spilled electrolyte.

- Water connection with standard connections.
- Compressed air and water cleaning hoses. Vacuum cleaner for cleaning.
- Place to keep documentation and maintenance records.
- Table or workbench Spare parts.
- Repair tools (cell extractor, arc welding equipment, drilling machine, etc.).
- Installation of ventilation with suitable design Collective and individual protection equipment.
- Shower and eyewash fountain.
- Signposted passing lines for the movement of forklifts and means of transport.
- Signs prohibiting smoking and introducing flame utensils.

A battery charging facility is understood to be one in which batteries are charged in large series, outside of the equipment and vehicles that use them. Battery charging facilities must be located in areas designed for that purpose. Lead-Acid batteries must store the maximum capacity to provide power to train cars. Good preventive maintenance and proper charging are important for good performance and long battery life.

The premises will be built of non-combustible materials, covered with a light roof in anticipation of explosions and without dependencies with occupation of people on the upper floor. The access door should open outward and will be normally closed. The floor will be waterproof, resistant to acids and will have a slope for the elimination of cleaning water and possible acid spills. The walls will be covered with a watertight plaster up to a minimum height of one meter from the ground.

In battery room premises, combustible products should not be stored. The room should be cleaned frequently, and the battery cells must be removed by suctioning, taking care not to suck up electrolyte.

The heating of the premises should only be done by heating fluid (air, water, or water vapor) and the temperature of the outer casing of the ducts should not exceed 150°C. The heating boiler will be located in a room outside the batteries room and if it is contiguous, it will be separated by a fire wall of minimum resistance to fire RF 120. Any other heating system may be admitted if it presents equivalent safety guarantees.

Motors, transformers, mechanical devices, fans, transmissions, machines, etc. They will be installed and conditioned in such a way that their operation does not affect health, safety, or cause discomfort to third parties due to noise or trepidation.

For more information for safety requirements on lead-acid, refer to NTP 617 “Locales de carga de baterías de acumuladores eléctricos de plomo-ácido sulfúrico”, edition year 2010.

14 Discussion, Conclusions and Recommendations

14.1 General considerations

As a general consideration, the current regulatory framework applicable to the marine battery installations is the result of a fragmented approach, with prescriptive rules, codes and standards developed on rather conservative principles. Rules often refer to traditional battery cell solutions and construction techniques, despite the impressive rate of technology growth in other industrial sectors.

This may be a barrier to the uptake to innovative solutions based on new battery cells and technologies.

Likewise, a generic performance-based approach, including risk assessment and technology qualification processes to verify if the battery installations are “fit for purpose” may result in complex and time-consuming activities – mainly when not supported by agreed acceptance criteria – eventually slowing down the exploitation opportunities on large marine applications.

The possible way forward is found in a balanced use of prescriptive regulations – when supported by the experience – supplemented by performance assessment methods, computational tools and models. as well as risk analysis where required.

This may offer a way around the lack of operational experience on new technologies, essential for assessing equivalence by proving that the materials/manufacturing processes/final products are suitable for their required design and operational safety and performance specifications.

14.2 Conclusions

The first and most evident difference among Class Societies is in the Application, which is in relation to the capacity of the batteries and/or in relation to the purpose of the batteries i.e. if the lithium-battery system is used or not for the propulsion of the ship, or as main source of electrical power.

In general safety requirements should not be in relation to the purpose of the lithium-batteries, but a limit in term of energy may be taken into consideration in case of small batteries installation such as UPS.

Risk assessment is in any case required by all the Class Societies, to evaluate the measures to be adopted for minimizing the risks associated to the use of lithium-battery system and to their installation onboard ships.

DNV, for example, requires that also for small installation, such as lithium-ion battery systems that have an aggregated energy of less than 20 kWh without the notations Battery (Safety) or Battery (Power), should be based on a safety assessment for their acceptance.

For what concerns constructional requirements, all Class rules are in general aligned, except for the degree of protection (IP) which is a very important matter, e.g. in case of risk of flooding in relation to the installation of the batteries.

Degree of protection on the rules seems to be only in relation to rated voltage of the battery system (e.g. > or < of 1500 Vdc) or to the type of fire extinguishing system used in the battery space, rather than with the place of installation and as consequence of flooding.

Risk of flooding should be taken into consideration also during the certification, to avoid type approved systems which should be further subject to additional tests for their installation onboard. As an example, following the results of the Risk Assessment, saltwater immersion tests might be required to check that this condition will not immediately lead to dangerous situations for human safety and safety of the vessel.

Another important aspect to be considered is that the battery working temperature is to remain within the Manufacturer's declared limits. Different methods can be acceptable for this purpose: direct cooling or ventilation of the battery spaces. Currently, direct cooling of the battery system is not mandatory.

The risk related to the use of direct liquid cooling should be taken into consideration: only DNV considers the risk of a cooling liquid leakage inside the module to avoid the risk of off gassing from the module (electrolyze vapors or hydrogen gas).

Requirements related to the direct liquid cooling of the battery system should be considered.

Where no direct cooling is used, the ventilation of the space becomes very important: not all Class Societies impose mechanical ventilation, which should be required, providing clear requirements.

The ventilation requirements should be addressed, checked and clarified by the rules:

- if ventilation is to be mechanical or natural,
- number of air changes per hours,
- number of motors for mechanical ventilation and their power supply (from main source of power only, or also from the emergency source of power),
- type of electrical motors (i.e., Ex or not) and fan (i.e., non-sparking type),
- ventilation ducting in relation to the ventilation ducting of other spaces onboard.

It is important to note that ventilation is also necessary for the extraction of gasses following a thermal runway.

Other constructional requirements have been considered by all Class Societies, such as the design of the module to prevent propagation of a thermal event, flame retardant materials, pressure relief valve of the casing of a cell, module, battery pack and battery systems, as well as the request to have an emergency shutdown device independent from the control system and located outside the space and on the navigation bridge for batteries serving propulsion.

For fixed fire-extinguishing system in battery spaces, different requirements have been issued: while RINA, ABS, BV require a system in relation to the battery manufacturer instructions and, as consequence, appropriate to the battery chemistry (e.g. powder, or gas based, or water-based fixed fire extinguishing system), LR and DNV strongly recommend a water-based fixed fire-fighting system, due to its inherent heat absorbing capabilities.

It is to be noted that the requests of installation of a Gas Detection is not mandatory by all Class Societies: for RINA and DNV the installation of a gas detection is in relation to the battery chemistry, taking into consideration the gases (flammable/toxic gases) which may be emitted by the battery system in the event of a fault, while for ABS the installation of a Gas Detection is mandatory with automatically disconnection of the battery system if the concentration of gas in the battery space reaches 30% LEL.

The rules do not clearly specify where gases, which may be emitted from the battery system in the event of a fault, are to be released: they can be released on the battery spaces for all the type of lithium-battery installation, or the battery system can have an integrated duct capable to release the gas on the open deck.

Only DNV Rules cover the matter with specific requirements, in case of:

1. Gases released into the battery space;

— an off-gas exhaust fan of non-sparking type shall be provided in the EES space
— the off-gas exhaust fan shall be continuously running or start automatically upon detection of off-gas from the EES system
— the off-gas exhaust fan shall have a capacity:

1) not less than six air changes per hour (ACH), when the EES system are designed according to design option 1 as given by [4.1.2.6]
2) as determined by analysis in the safety description [4.1.2] but not less than six ACH, when the EES system is designed according to design option 2 given by [4.1.2.6].

Guidance note:

The amount of off-gas used for consideration or analysis should be related to the number of cells releasing off-gas.

2. EES systems installed in enclosed cabinets with an integrated off-gas ventilation duct:

2.3.1.5 For EES systems installed in enclosed cabinets with an integrated off-gas ventilation duct, then:

— the EES space ventilation, as required in [2.3.1.1] and [2.3.1.2], shall be designed for over-pressure compared to the cabinets
— EES systems designed according to design option 1 as given by [4.1.2.6] need not incorporate an off-gas exhaust fan in the duct
— EES systems designed according to design option 2 as given by [4.1.2.6] shall incorporate an off-gas exhaust fan of non-sparking type in the duct
— the off-gas exhaust fan shall be continuously running or start automatically upon detection of off-gas from the EES system
— cabinet off-gas ventilation duct inlets shall be provided with non-return valves/flaps where provided.

Guidance note:

Alternative means of purging battery cabinets during off-gas incidents can be accepted if supported by the safety description and the safety assessment on a case-by-case basis.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

2.3.1.3 The ventilation system for EES spaces shall be an independent ducting system of any other ventilation systems serving other spaces unless the EES system is installed in an enclosed cabinet with an integrated off-gas ventilation duct , in which case supply may be taken from ventilation systems serving other spaces and with exhaust directly to open air.

In general, lithium-battery spaces are not considered as hazardous spaces, since in normal operation there is no release of gases, but DNV Rules include specific requirements for the space considered as hazardous area in relation to the flammable/toxic gases released following a failure/damage of the EES system.

Other aspects of the battery spaces are different, e.g. RINA requires self-closing doors, ABS gas-tight doors or self-closing gas-tight doors with no holdback arrangement only if battery space is located adjacent to and within machinery space of category A, DNV requires normally closed doors with alarm or self-closing doors.

The structural fire protection category of the space depends on the Class Societies:

- ABS: spaces are considered as an auxiliary Machinery Space or a Machinery Space other than category A.
- BV: Boundaries are to be fitted with the thermal and structural subdivision corresponding to “Other machinery spaces”.

- LR: requires that the safety systems to be at least equivalent to those of a machinery space of Category A.
- DNV: defines the space as a "machinery space (SOLAS Reg. II-2/3.30)".

Function and purpose of the BMS are clearly stated in the rules of all the Classification Society, but requirements relevant to its power supply are missing.

RINA only has issued specific rules on power supply of BMS:

3.2.2 *(1/1/2019)*

The BMS is to be continuously powered so that a single failure of the power supply system does not cause any degradation of the BMS functionality; an alarm is to be given in the event of failure of any of the power supplies.

Unless the power supply is derived from different strings of batteries, one of the power supplies is to be derived from the emergency source of electrical power.

Where each battery is fitted with a BMS card, the individual cards may have a single power supply from the relevant battery.

An alarm is to be given and safety action taken in the event of loss of all the power supplies.

This aspect is very important to define the effects of a black-out/dead ship condition on BMS and the consequence on the safety of the batteries.

In general, all Class Societies have requirements on certification, factory and onboard tests and require manuals for maintenance and operation. In addition, DNV requires instructions for emergency operation. In general tests on batteries are based on IEC 62619.

What is common to all Class Societies is the request to have two independent battery systems located in two independent battery spaces when the ship main source of power is based on lithium-battery installations.

As a summary of everything exposed throughout the document, the content of this deliverable will serve as a guide to the consequent WPs, including work packages 3, 4, 5 and 6. The WP3 will take advantage of the content of this deliverable using those requirements that it They are useful for designing the battery system from a modular, flexible and scalable point of view. The WP4 will use the content of this deliverable to design and develop the components that will be part of the hybrid battery system based on the identified necessary requirements, as well as the WP5 will use it to carry out the correct integration of the full hybrid Battery Energy Storage System . Finally, WP6 will validate that the developed battery system concept, for waterborne applications, fulfills the identified requirements in this deliverable and the specifications developed in WP3, which include to prove reliability and effectiveness of the concept chosen, in order to validate that the developed battery system topology works as intended in a realistic environment, verifying fault-tolerance and fault ride-through capabilities of the developed system.

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17 ANNEX 1 - Regulatory requirements for Marine battery installations

Item Title	Sub-item title	Ref. to IMO provisions	Ref. to Class Society provisions	Ref. to internat. std.	Notes
Fire Protection systems		No IMO Publications have been issued on the matter.	List of applicable Rules, by IACS Class Societies: ✓ RINA Rules for the classification of ships Pt C, Ch 2, App 2 (Ed. 2021). ✓ ABS GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES (FEBRUARY 2020) ✓ BV ADDITIONAL CLASS NOTATION BATTERY SYSTEM. ✓ DNV GL Part 6, Chapter 2, Section 1 "Electrical energy storage". ✓ LR Rules and Regulations for the Classification of Ships Part 6, Chapter 2. No IACS Resolutions have been issued on the matter.	IEC Standards containing requirements and tests for the safe operation of lithium-ion batteries in industrial application: IEC 62620 (2014): Secondary cells and batteries –Secondary lithium cells and batteries for use in industrial applications IEC 62619 (2017): Safety requirements for secondary lithium cells and batteries for use in industrial applications Other standards mentioned in the IACS class society applicable rules: ✓ IEC 62660: Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes – Secondary Lithium Cells and Batteries for Use in Industrial Applications ✓ IEC 62281 Safety of primary and secondary lithium cells and batteries during transport ✓ UL 1642 Standard for Safety of Lithium Batteries ✓ UL 2054 Standard for Household and Commercial Batteries ✓ NAVSEA TM-S9310-AW-SAF-010 US Navy Technical Manual for Batteries, Navy Lithium Safety	

				Program Responsibilities and Procedures ✓ NAVSEA SG270-BV-SAF-010 High-Energy Storage System Safety Manual ✓ UN 3481 ✓ USCG 46 CFR ✓ UN DOT 38.3 ✓ UL 810A ✓ UN 38.3.	
			RINA rules		
Item Title	**Sub-item title**	**Ref. to IMO provisions**	**RINA Rules for the classification of ships Pt C, Ch 2, App 2**	**Ref. to internat. std.**	**Notes**
General ✓ Application ✓ Definition ✓ Documentation to be submitted	[1]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 1 General		
System Design	[2]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 2 System Design		
General	[2.1]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 2 System Design		
Constructional requirements	[2.2]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 2 System Design		
Electrical protection	[2.3]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 2 System Design		
Battery charger	[2.4]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 2 System Design		
Control, monitoring, alarm and safety systems	[3]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 3 Control, monitoring, alarm and safety systems		
General	[3.1]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 3 Control, monitoring, alarm and		

			safety systems		
Battery management systems (BMS)	[3.2]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 3 Control, monitoring, alarm and safety systems		
Alarm system	[3.3]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 3 Control, monitoring, alarm and safety systems		
Safety system	[3.4]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 3 Control, monitoring, alarm and safety systems		
Energy Management system (EMS)	[3.5]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 3 Control, monitoring, alarm and safety systems		
Location	**[4]**		RINA rules for the classification of ships Pt C, Ch 2, App 2, 4 Location		
General	[4.1]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 4 Location		
Battery space	[4.2]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 4 Location		Covering Fire Protection Systems
Testing and inspection	**[5]**		RINA rules for the classification of ships Pt C, Ch 2, App 2, 5 Testing and inspection		
Testing	[5.1]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 5 Testing and inspection	Ref. to **IEC 62619** **IEC 62620** for functional and safety tests.	
Plans to be kept on board	[5.2]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 5 Testing and inspection		
Testing and inspection after installation on board	[5.3]		RINA rules for the classification of ships Pt C, Ch 2, App 2, 5 Testing and inspection		

			Other RINA RULES/Guide		
			//		
			ABS Rules		
Item Title	**Sub-item title**	**Ref. to IMO provisions**	**GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES**	**Ref. to internat. std.**	**Notes**
General 1 Introduction 3 Application 5 Scope 7 Terminology. 9 Abbreviations and Acronyms 11 References 13 Data and Plans to be Submitted 15 Onboard Documentation			GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 – Section 1 General	At para 11.3 reference to: ✓ IEC 62619 ✓ IEC 62620 ✓ IEC 62660 ✓ IEC 62281: ✓ UL 1642: ✓ UL 2054: ✓ NAVSEA TM-S9310-AW-SAF-010: ✓ NAVSEA SG270-BV-SAF-010 ✓ UN 3481	
Battery System Design and Construction	[1]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - Section 2 Battery System Design and Construction		
Certification Details	[1.1]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - Section 2 Battery System Design and Construction		
General	[1.3]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - Section 2 Battery System Design and Construction		
Control, Monitoring, Alarm and Safety Systems	[1.5]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - Section 2 Battery		

			System Design and Construction		
Battery Chargers	[3]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - Section 2 Battery System Design and Construction		
Battery Management System (BMS)	[5]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - Section 2 Battery System Design and Construction		
Battery System Testing Requirements	[1]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - - Section 3 Battery System Installation		
Battery Space	[3]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - - Section 3 Battery System Installation		
Fire Safety	[3.1]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - - Section 3 Battery System Installation		
Hazardous Area Requirements	[3.3]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - - Section 3 Battery System Installation		
Battery System Risk Assessment	[5]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - - Section 3 Battery System Installation		
Battery System Operation and Maintenance	[7]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - -		

			Section 3 Battery System Installation		
Installation and Commissioning	[7.1]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - - Section 3 Battery System Installation		
Operation and Maintenance	[7.3]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - - Section 3 Battery System Installation		
General	[1]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - SECTION 4 Battery System Used as Main Source of Electrical Power		
System Requirements	[3]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - SECTION 4 Battery System Used as Main Source of Electrical Power		
Redundancy	[3.1]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - SECTION 4 Battery System Used as Main Source of Electrical Power		
Capacity	[3.3]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - SECTION 4 Battery System Used as Main Source of Electrical Power		
Power Management System (PMS)	[3.5]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - SECTION 4 Battery		

			System Used as Main Source of Electrical Power		
Protective Systems	[3.7]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - SECTION 4 Battery System Used as Main Source of Electrical Power		
Monitoring	[3.9]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - SECTION 4 Battery System Used as Main Source of Electrical Power		
Fire protection	[3.11]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - SECTION 4 Battery System Used as Main Source of Electrical Power		
Trials	[3.13]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020 - SECTION 4 Battery System Used as Main Source of Electrical Power		
General	[1]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020, SECTION 5 Battery System Surveys		
Surveys During Construction	[3]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020, SECTION 5 Battery System Surveys		
Surveys After Construction (1 March 2018)	[5]		GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE AND OFFSHORE INDUSTRIES FEBRUARY 2020,		

			SECTION 5 Battery System Surveys		
			Other ABS Rules/Guide		
			ABS ADVISORY ON HYBRID ELECTRIC POWER SYSTEMS		
			BV RULES		
Item Title	**Sub-item title**	**Ref. to IMO provisions**	**ADDITIONAL CLASS NOTATION BATTERY SYSTEM Pt F, Ch 11, Sec 21**	**Ref. to internat. std.**	**Notes**
General 1.1 Application 1.2 Documents to be submitted	[1]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM Pt F, Ch 11, Sec 21, 1 General		
Definitions and acronyms 2.1 System considered 2.2 Definitions	[2]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 2 Definitions and acronyms		
Safety and design issues	[3]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM , 3 Safety and design issues		
Battery compartment	[3.1]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM , 3 Safety and design issues		Covering Fire Protection Systems
Battery pack	[3.2]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM , 3 Safety and design issues		
Availability of power	[4]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 4 Availability of power		
Ship configuration	[4.1]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 4 Availability of power		
Case 1: global battery system failure leads to loss of propulsion or of main electrical sources	[4.2]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 4 Availability of power		
Case 2: global battery system failure does not lead to any loss regarding ship propulsion and main source of power	[4.3]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 4 Availability of power		

Test and certification process for batteries	[5]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 5 Test and certification process for batteries		
Battery cells	[5.1]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 5 Test and certification process for batteries	At 5.1.2 reference to: IEC62619 IEC 62281	
Equipment used in battery systems	[5.2]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 5 Test and certification process for batteries		
Battery packs and associated BMS	[5.3]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 5 Test and certification process for batteries		
Onboard tests of battery compartment and fire-extinguishing system	[5.4]		ADDITIONAL CLASS NOTATION BATTERY SYSTEM, 5 Test and certification process for batteries		
			Other BV Rules/Guide		
			ADDITIONAL CLASS NOTATION - ELECTRIC HYBRID Pt F, Ch 11, Sec 22		
			LR RULES		
Item Title	**Sub-item title**	**Ref. to IMO provisions**	**Rules and Regulations for the Classification of Ships Part 6, Chapter 2**	**Ref. to internat. std.**	**Notes**
Lithium battery systems	[1.2.17]		Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2 ELECTRICAL ENGINEERING, Section 1 General requirements		
Lithium battery systems	[1.3.11]		Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2 ELECTRICAL ENGINEERING, Section 1 General requirements		

Definitions	[1.6]		Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2 ELECTRICAL ENGINEERING, Section 1 General requirements		
General	[12.1]		Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2 ELECTRICAL ENGINEERING, Section 12 Batteries		
Design and construction	[12.2]		Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2 ELECTRICAL ENGINEERING, Section 12 Batteries		
Location	[12.3]		Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2 ELECTRICAL ENGINEERING, Section 12 Batteries		
Instlallation	[12.4]		Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2 ELECTRICAL ENGINEERING, Section 12 Batteries		
Thermal management and ventilation	[12.5]		Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2 ELECTRICAL ENGINEERING, Section 12 Batteries		
Testing	[21.1]		Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2 ELECTRICAL ENGINEERING, Section 21 Testing and trials		
			Other LR Rules/Guide		
			Rules and Regulations for the		

			Classification of Ships Part 6, Chapter Section 24 Hybrid electrical power systems		
			Large battery installations - Key hazards to consider and Lloyd's Register's approach to approval		
			DNV RULES		
Item Title	**Sub-item title**	**Ref. to IMO provisions**	**ADDITIONAL CLASS NOTATION Part 6, Chapter 2, Section 1 "Electrical energy storage"**	**Ref. to internat. std.**	**Notes**
General	[1]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage	— IEC 62619 — IEC 62620 — UL 810A — UN 38.3	1.1 Introduction............ 1.2 Objective................ 1.3 Scope...................... 1.4 Application............... 1.5 References............... 1.6 Definitions and abbrev 1.7 Procedural requiremen
Introduction	[1.2]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Objective	[1.3]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Scope	[1.4]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Application	[1.5]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
References	[1.6]		DNV Part 6 Additional class notation,		

			Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Definition and Abbreviations	[1.7]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Procedural requirements	[1.8]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Class notation Battery (Safety)	**[2]**		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		2.1 Design principle..... 2.2 Arrangement..... 2.3 Ventilation..... 2.4 Fire safety for EES spaces..... 2.5 Safety assessment of the of th 2.6 System design..... 2.7 Testing..... 2.8 Operation and maintenance....
Design principle	[2.1]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Arrangement	[2.2]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Ventilation	[2.3]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Fire safety for ESS spaces	[2.4]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Safety assessment of the onboard installation	[2.5]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and		

			auxiliary systems, Section 1 Electrical energy storage		
System design	[2.6]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Testing	[2.7]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Operation and maintenance	[2.8]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Class notation Battery (Power)	[3]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		3.1 General............. 3.2 System design.... 3.3 Testing............... 3.4 Operation and ma
General	[3.1]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
System Design	[3.2]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Testing	[3.3]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Operation and maintenance	[3.4]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and		

			auxiliary systems, Section 1 Electrical energy storage		
Battery system	[4]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		4.1 Battery system 4.2 Testing............
Battery system design	[4.1]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Testing	[4.2]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Electrochemical capacitor system and installations	[5]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
General	[5.1]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Design principle for electrotechnical Battery (Safety) notation	[5.2]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Design principle for electrotechnical Battery (Power) notation	[5.3]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
Electrochemical capacitor system	[5.4]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and		

			auxiliary systems, Section 1 Electrical energy storage		
Appendix	[6]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		6.1 List of alarms and monitori
List of alarms and monitored parameters	[6.1]		DNV Part 6 Additional class notation, Chapter 2 Propulsion, power generation and auxiliary systems, Section 1 Electrical energy storage		
			Other DNV Rules/Guide		
			GUIDELINE FOR LARGE MARITIME BATTERY SYSTEMS		
			IN FOCUS –THE FUTURE IS HYBRID - – a guide to use of batteries in shipping		
			Technical Refence for Li- ion battery Explosion risk and fire suppression		

IACS CLASS SOCIETIES						
Main issue	**RINA** RULES FOR THE CLASSIFITION OF SHIPS	**ABS** GUIDE FOR USE OF LITHIUM BATTERIES IN THE MARINE	**BV** ADDITIONAL CLASS NOTATION “BATTERY SYSTEM” Pt F, Ch 11, Sec 21	**LR** Part 6 CONTROL, ELECTRICAL, REFRIGERATION AND FIRE, Chapter 2	**DNV** ADDITIONAL CLASS NOTATION “Electrical energy storage” Pt 6, Ch 2, Sec 1	**NOTES**

	Pt C, Ch 2, App 2	AND OFFSHORE INDUSTRIES		ELECTRICAL ENGINEERING		
Application	- Essential or not-essential services and emergency services (except batteries embedded in consumer products like computers and similar appliances).	- When used as an additional source of power with a capacity greater than 25 kWh. - When batteries are being <u>used as the main source of power</u>, the additional requirements set forth in Section 4 *"Battery System Used as Main Source of Electrical Power"* are to be met.	- Additional class notation when battery system is used for propulsion and/or electric power supply. - Requirements are mandatory when the ship is relying only on batteries for propulsion and/or electrical power supply for main sources.	NO SPECIFIC REQUIREMENTS	1) Additional class notation **POWER** for vessels where the EES power is used for electrical propulsion of the vessel: — All-electric vessel, i.e. all main sources of power are based on EES. — Hybrid vessel where one of the main sources of power is based on EES. — Hybrid vessel having an operational mode where the vessel is operating on EES power only, with the other main source of power in standby. — Hybrid vessel using the EES system as a redundant source of power for main and/or additional class notations, e.g. dynamic positioning. 2)Additional class notation **SAFETY** for vessels where the aggregated EES installation in one EES space has a rated capacity of 20 kWh or above and not having the Battery (Power) notation. Installation of lithium-ion battery systems that have an aggregated capacity of <u>less than 20 kWh without the notations Battery(Safety) or Battery(Power)</u>, should be based on a safety assessment	• **RINA, BV, LR** requirement are applicable to all the battery installation without limit of capacity. • **ABS** when used as additional source of power only for capacity above 25 kWh. Only requirements of section 4 re mandatory when used as main source of power. • **DNV** requirements of class notation **SAFETY** applicable only when aggregated EES installation in one EES space is above 20 kWh.

					as described in [2.5].	
Risk assessment	YES (2.1.6) Risk Assessment, to be initiated in the design phase.	YES (Section 3/ 5) Risk Assessment or Failure Mode and Effects Analysis (FMEA) can be accepted as an alternative.	YES (3.2.4) Risk analysis	YES (12.1.9) Procedure Assessment of Risk Based Designs only for lithium battery system installations of nominal voltages exceeding 1500 V d.c. + (Clause 12.2.2) Failure Mode and Effects Analysis (FMEA)	YES (2.5) For both class notation Safety assessment	**LR** requires a procedure assessment of Risk Based Designs only above 1500 Vdc.
Design					Only for additional class notation **POWER** - The cables from the EES system to the main switchboard shall follow the <u>routing requirements</u> as given in Pt.4 Ch.8 Sec.2 [9.5]. - It shall be possible to <u>operate the EES system locally</u>. This local operation shall be independent from any remote control (PMS, IAS) systems. (local operation workstation can be located at the EES system, switchboard or at the EES converter).	
Construction al requirement s	-Avoid cells of different physical characteristics - Flame retardant materials for battery casing. -Pressure relief valve. - Thermal protection device. - Provision for avoid thermal propagation between cells.	- Avoid cells of different physical characteristics. - Flame retardant materials for battery casing. - Pressure relief valve. -Isolation mechanism for maintenance (independent from ESD). - Degree of protection	- Degree of protection: • IP 2X for battery packs less than 1500 V DC; • IP 32 for battery packs more than 1500 V DC. - <u>Battery pack cooling ensured either by the ventilation of the battery compartment or by direct cooling</u>.	- Pressure relief function(s).	- EES Converters: *shall communicate with and operate within the limits given by the battery/capacitor management system; *shall be designed with the needed capacity specified by the EES application. - Design of a module should prevent	**RINA/LR** have no specific requiremen t for degree of protection. **ABS** require a minimum degree of protection IP44. **BV** requires minimum degree of

	-Terminals disconnecting device between the battery system and the DC distribution. -Degree of protection (not specific requirement) -Location to prevent overheating. - Appropriate means to maintain the battery working temperature within the Manufacturer's declared limits are to be provided (e.g. by means of liquid cooled solutions or ventilation systems provided with control of air temperature).	(minimum IP44).			propagation of a thermal event. - Main power connectors with an integrated safety interlock (HVIL), securing that connection/disconnection only can be performed when the battery contactor is open. - Battery modules with liquid cooling designed such that the risk of a cooling liquid leakage inside the module is minimized and do not lead to hazardous off-gassing from the module (electrolyze vapour or hydrogen gas). - Flame retardant materials for battery casing. - Degree of protection depending on the location (at least IP 44 but in any case not lower than IP2X for low voltage (< 1500 Vdc) installations or IP 32 for high voltage (> 1500 Vdc) in relation to the fire extinguishing system used in the battery space.	protection IP2X or IP32 in relation to the voltage of the batteries. **DNV** degree of protection IP44 but in general depending on the location and fire extinguishing system used in the battery space. • For many Class Society Direct cooling is not mandatory. Ventilation system can be considered as an alternative to the direct cooling.
Emergency shutdown (ESD)	YES (Clause 2.3.2/3.4.4) - Hardwired circuit and independent from the control system. - Activated locally, from outside the battery space, and from a continuously manned control station.	YES (Clause 1.3 iii) -Hardwired and independent of any control, monitoring, and alarm system circuits. - If the battery system is used to provide power for propulsion of the asset, there should be an additional emergency shutdown	NO SPECIFIC REQUIREMENTS	YES (Clause 12.2.5) - A fully independent hard-wired means to disconnect the battery system in an emergency from power distribution. - Located outside of the battery space and situated such that it will remain accessible in the event of an emergency inside the battery space. - ESD is to initiate an audible and visual alarm at the relevant control stations to	YES (Clause 4.1.2.4) - Hardwired circuit separated from cables used for control, monitoring and alarm functions. -Arranged adjacent to (outside of) the EES space and on the navigation bridge.	In general required outside the space and on the navigation bridge for batteries serving propulsion.

	- When battery installation is used as storage of power for the propulsion or dynamic positioning systems or as part of the main source of electrical power, the emergency shutdown is also to be located on the bridge.	arrangement on the navigation bridge and the centralized control station (CCS) or enclosed operating station (EOS).		advise duty personnel of the emergency condition.		
Electrical protection	- Switchgear for isolating purposes. - Over current protection, up to short circuit protection for paralleled strings. -Each string of batteries provided with individual protection.	-Outgoing circuits of the battery system protected against overload and short-circuit, excluding the emergency batteries used for engine starting.	NO SPECIFIC REQUIREMENTS	NO SPECIFIC REQUIREMENTS	- Outgoing circuits on a EES system protected against short circuit and over current. - Switchgear for isolating purposes protection (for maintenance). -ESS Converters protected against overvoltage and undervoltage. (When the vessel has several EES converters and/or a EES converter located on shore then the independent voltage protection could be implemented in the DC switchboard where the EES system is connected). - Battery modules equipped with an overcharge protection independent of the BMS. This protection shall be arranged with components independent from those used for the required indication, alarm and control functions.	DNV requirements include also converters protection (intended as “the equipment controlling the charging and discharging of the EES system”).

					Only for additional class notation **POWER** - A EES system shall be able to supply the short circuit current necessary to obtain selective tripping of downstream circuit breakers and fuses.	
Battery Charger	-General rules applicable (current and voltage level). - Communication implemented between BMS and charger. -Alarm in case of failure. -Battery charger stopped when the upper limit of the charging voltage is exceeded.	-General rules applicable. - Designed to maintain charging within the voltage, current, and temperature limit for the battery. -Interfaced with and controlled by the BMS.	-Charging and un-charging controlled with a BMS.	NO SPECIFIC REQUIREMENTS	NO SPECIFIC REQUIREMENTS	
Fire protection, detection and extinction	- Fire detection system. -Fixed fire extinguishing system (in relation to the battery manufactured instruction): * automatic release only acceptable for small, not accessible, battery spaces. * for automatic release of fire extinguishing media , activation to be confirmed by more than one sensor.	- Fixed Fire Extinguishing System (recommended by the vendor and appropriate to the battery chemistry used). -Portable fire extinguishers.	-Fixed fire extinguishing system (according to the battery's manufacturer Specification).	- Suitable fixed detectors (in accordance with manufacturer's recommendation) for identification of a fire or thermal runaway condition. -Ventilation necessary for extraction of gasses, active cooling systems, and thermal/safety monitoring and alarm are to be continued prior to, during and after an overheating or fire event. -Appropriate water-based fixed fire-fighting system. Fixed fire-fighting systems using a medium other than water which provide	- Boundaries of EES spaces part of vessels structure or enclosures with equivalent structural integrity. - EES spaces shall with reference to SOLAS Reg. II-2/3.30 be defined as a machinery space. With respect to structural fire protection as given in SOLAS Reg. II-2/9.2.2.4 and 9.2.3 the EES space shall be defined as other machinery spaces with the additional requirements given in [2.4.1.2]. - EES spaces are considered as not normally manned.	**LR** and **DNV** requires a water-based fixed fire-fighting system, while other class society left the decision to the manufacturer of the batteries (**RINA/ABS/ BV**).

				equivalent heat removal, boundary cooling and/or extinguishing for the duration that the heat and/or gas release is present can be taken into consideration provided that appropriate fire tests have been conducted. In particular, the fire-extinguishing media are to be chosen as appropriate for the specific type and characteristics of fire foreseen. - In addition at least two (2) portable and suitable fire-extinguishers located outside the space at or near the entrance(s) positioned in close proximity to the lithium battery space. -Fixed fire detection and alarm system. When activated, the fire detection system is to initiate an alarm to the relevant control stations and on the navigating bridge and is to initiate the automatic isolation of electric systems within the lithium battery space, except as described below, and activate the fixed fire-fighting system.	- Fire integrity of EES spaces shall be enclosed by A-0 fire integrity and have A-60 fire integrity towards: *machinery spaces of category A as defined in SOLAS Reg. II-2/3; * enclosed cargo areas for carriage of dangerous goods; * muster and embarkation stations for passenger vessels. - Smoke detection within the spaces. - Fixed total-flooding fire extinguishing system approved for use in machinery spaces of category A as given in SOLAS Reg. II-2/10 and the FSS code with detailed requirements (a water based extinguishing system is recommended due to its inherent heat absorbing capabilities.). -EES space fire alarm shall be given at the bridge	
Control, monitoring, alarm and safety systems	-General requirements of rules applicable to electronic and programmabl e equipment. -Alarmed abnormal condition of the batteries. - Safety system are to	- Control, monitoring, and safety systems are to have self-check facilities. - Safety system based on the fail-to safety principle. -Safety system activated automatically in the event of	NO SPECIFIC REQUIREMENTS	- List of alarms and safeguards to be provided. - State of charge (SOC) and state of health (SOH) to be displayed at relevant control stations and on the navigating bridge. -System alarms displayed at relevant control stations and	-List of monitored parameters at a manned control station. -List of alarms at a manned control station. - Sensors used for EES space temperature alarm and indication independent of sensors used	In general sensors for safety functions are to be independe nt from sensors used for other purpose (RINA/ABS).

	be self-monitoring. -Safety system based on the fail-to safety principle. -Safety system activated automatically in the event of identified conditions which could lead to damage of the battery system. -Sensors for safety functions independent from sensors used for other purpose. -Sensors are to be designed to withstand the local environment.	identified conditions that could lead to damage of the lithium battery system. -Sensors for safety functions to be independent from sensors used for other purposes. -Sensors designed to withstand the local environment. -High ambient temperature in the battery space monitored and alarmed at a continuously manned location.		at least a common alarm displayed on the navigating bridge. - In the event that a fire or thermal runaway condition is identified, the battery monitoring system is to initiate protective features such as automatic safe isolation of the batteries. -Failure of the monitoring system alarmed to the ship's safety system (battery system automatically reverting to a defined safe state).	for temperature monitoring of EES modules. - Charging/discharging failure shall give alarm at a manned control station. - Parameters to be measured (cell voltage, cell or module temperature, battery string current). - List of parameters to be indicated at local control panels or in remote workstations. - Parameters to be available for the energy management system (EMS). - Minimum abnormal condition in the battery system shall initiate an alarm in the vessel's main alarm system with individual or group-wise indication(for vessels without a centralized main alarm system, battery alarms shall be presented at the bridge). -Abnormal conditions that can develop into safety hazards alarmed before reaching the hazardous level. Sensors and other components used for such alarms separate from emergency shutdown or other protective safety functions. - Requirements for protective safety functions (alarms following activation, alarms for failure of the protective safety functions).	DNV requires sensors capable to monitor abnormal conditions that can develop into safety hazards separate from emergency shutdown or other protective safety functions. In any case according to the DNV rules if temperature sensors are arranged in close vicinity of the battery module so that loss of functionality of a broken sensor element or circuitry will be mitigated by a neighbouring sensor, the sensor element/circuitry can be common for indication, alarm, control and safety functions. Such arrangements shall still be designed with independency

					Added Guidance note for protective safety function. Only for additional class notation POWER - Monitoring of EES systems supplying propulsion power for dynamic positioning systems, shall follow requirements as given in Ch.3 Sec.1 [6.12], and Ch.3 Sec.2 [6.10] as applicable. -- The SOC and SOH of the EES systems shall be monitored and available for the operator. -In case of over-temperature in a EES system, a request for manual load reduction shall be issued both visually and acoustically on the bridge. Alternatively an automatic load reduction can be arranged. - An individual warning shall be given at the navigating bridge when the EES system reaches minimum Capacity.	between control and safety functions for CPUs and other electronic parts of the system. The objective is that no single failure shall cause loss of both safety and alarm functions at the same time.
Battery management (BMS)	-Interfaced with battery charger. -Self-check facilities. - Failure alarmed. -Requirements for power supply. - Alarmed in case of power failure. -Monitoring function (charging/disc	-Monitoring function (battery cell voltage, cell temperature, and battery string current) -Power supply requirement (only continuously powered). - Alarmed in case of power failure.	-Monitoring of battery pack state. - Control the proper connection and disconnection. - Optimise battery lifetime and energy availability by monitoring and controlling battery pack.	- To continuous monitor the condition of cells, battery modules or battery packs and to maintain them within their specified safe operating region. - Compliance with general requirements.	- The BMS shall communicate the voltage and current limits to the battery converter. - The battery management system (BMS) shall: * provide limits for charging and discharging to the battery converter * protect against over-current, over-voltage and under-voltage by	Requirements on power supply arrangements of the BMS should be issued.

	harging of the battery, battery temperature and cell to cell Balancing) - List of parameter to be indicated and monitored at local control panel and in a continuously manned control position.	- List of parameters to be indicated at the continuously manned location. - Compliance with general requirements for Marine Vessel Rules.			disconnection of the battery system * protect against over-temperature by disconnection of the battery system * provide cell and module balancing. Protection of over current may also be done by limiting the current from the battery converter.	
Energy managemen t (EMS)	-EMS required ONLY when batteries are used as storage of power for the propulsion or dynamic positioning system or as part of the main source of electrical power -Several levels of controls and alarm functions. - Independency from EMS/PMS -Indication on the bridge.	NO SPECIFIC REQUIREMENTS	NO SPECIFIC REQUIREMENTS	NO SPECIFIC REQUIREMENTS	Only for additional class notation POWER - Energy management system (EMS) shall be installed. - EMS functions may be integrated in the vessel's automation system or the power management system. -For EES systems providing power to main and/or redundant propulsion or dynamic positioning, the EMS shall provide a reliable measure of the available energy and power, taking into consideration the EES systems SOH and SOC. -The following parameters shall be provided with remote monitoring at the navigating bridge: * available energy of the EES systems * available power of the EES systems * remaining time or range that the EES system can supply energy for the	DNV correctly accept that the EMS can be integrated in the PMS (as usual onboard ship).

					planned operation/voyage.	
Location	- Battery space aft of collision bulkhead. - Not located on the open deck. -Located such as to prevent cascade effects in case of a thermal runaway. - For batteries used as storage of power for the propulsion or dynamic positioning systems or as part of the main source of electrical power, are to be located in a battery space placed within the borders of the main machinery space or adjacent to it.	-Battery spaces are not to be located forward of the collision bulkhead of the vessel. -Specific requirements where battery space is located adjacent to and within machinery space of category A : -A60 -ventilation requirements -ventilation ducts requirements -gas-tight doors or self-closing gas-tight doors with no holdback arrangement, -emergency stop in case of fire in the ER.	NO SPECIFIC REQUIREMENTS	Differet requirements on the basis of capacity. < 20 KWh it is to be housed in a gastight steel enclosure with a gastight ventilation duct leading to a safe space on open deck and is to be suitable for withstanding the temperatures and pressures generated in the worst case thermal runaway condition. > 20kW Pt 6, Ch 2, 12.1 General 12.1.9; • Pt 6, Ch 2, 12.2 Design construction 12.2.2 to Pt 6, Ch 2, 12.2 Design and construction 12.2.6; • Pt 6, Ch 2, 12.3 Location 12.3.12; • Pt 6, Ch 2, 12.4 Installation 12.4.5 to Pt 6, Ch 2, 12.4 Installation 12.4.11; • Pt 6, Ch 2, 12.5 Thermal management and ventilation 12.5.8 and Pt 6, Ch 2, 12.5 Thermal management and ventilation 12.5.12; • Pt 6, Ch 2, 21.1 Testing 21.1.6. - Separate from other spaces and compartments. - Not located forward of the collision bulkhead. - Not contiguous to the boundaries of machinery spaces of Category A or those spaces containing the main source of electrical power, associated transforming equipment (if any) or	Only for additional class notation SAFETY - Positioned aft of collision bulkhead.	RINA required that the battery space is located within the borders of the main machinery space or adjacent to it when serve the main source of power/propulsion/DP but without specific requirements. ABS has specific requirement when the battery space is located adjacent to and within machinery space of category A, but this requirement is not mandatory. LR requires that the battery space is not contiguous to the boundaries of machinery spaces of Category A or those spaces containing the main source of electrical power, associated transformin

				the main switchboard.		g equipment (if any) or the main switchboard
Battery space	-Self-closing doors. -Ventilation requirement (not stated if mechanical or natural). -Gas detection (not mandatory) with alarm and disconnection of the batteries. -Category of the bulkhead of the battery space. -No heat sources or high fire risk equipment located in battery spaces. -No systems supporting essential or emergency services, including piping and electric cables serving such systems located in the battery space (in order to prevent their loss upon possible failures).	- Environmentally controlled space. - Means to vent gases from the battery space to open deck. - Battery System located clearance of distances between any other equipment in the room. -Mechanically ventilated. -Exhaust ventilation duct(s) for the battery space are to be from and to a safe location on open deck. -Fan is to be of the non-sparking type and shall provide six (6)air changes per hour. -Ventilation ducting for the battery space is to be separate from the other HVAC systems. -Gas detection appropriate to the battery chemistry being used (alarm and disconnection of the batteries). - Not to be located adjacent to spaces with combustible/flammable materials and berthing compartments.	- No piping systems not involved in battery operation. - Protection against falling objects. - Boundaries are to be fitted with the thermal and structural subdivision corresponding to "Other machinery spaces". - Accessibility for maintenance. -Ventilation according to valve regulated sealed batteries.	- Boundaries part of a vessel structure or enclosures. - Provided with 'A-60' insulation of the bulkhead (unless the space is adjacent to spaces of negligible fire risk). - Penetrations through these boundaries are to be protected to the same fire protection standard. -All other safety systems at least equivalent to those of a machinery space of Category A. - The lithium battery space and the crates, trays, boxes, shelves and other structural parts therein are to be designed and constructed such that the structural integrity of the battery space will not be compromised in the event of a lithium fire. - Two means of escape, at least one independent of any watertight door and leading to a safe position outside the space. -At each entrance/exit an emergency escape breathing device (EEBD) is to be provided. -Where the maximum travel distance to the door within the lithium battery space is less than 5 m, a single means of escape is acceptable. The lithium battery space is not to be	Additional class notation SAFETY - Boundaries of EES spaces shall be part of vessels structure or enclosures with equivalent structural integrity. - EES spaces shall ,with reference to SOLAS Reg. II-2/3.30 , be defined as a machinery space. - Mechanical ventilation system is required for the EES space. - Mechanical ventilation system activated upon off-gas incidents from the EES system, but advises the continuously running with minimum two air changes per hour (ACH) in normal operation . - The ventilation system for EES spaces shall be an independent ducting system of any other ventilation systems serving other spaces unless the EES system is installed in an enclosed cabinet with an integrated off-gas ventilation duct , in which case supply may be taken from ventilation systems serving other spaces and with exhaust directly to open air. - Requirements for EES systems designed to	Requirements for the battery spaces are very different between the different class societies. RINA require ventilation of the battery space without specify if its is to be natural or mechanical . ABS and DNV requires mechanical ventilation. DNV does not require that the ventilation is continuously running but activated upon failures. // ABS required as mandatory means to vent the gases to open deck (3 vii)) and gas detection. DNV accept that the off-gas are

		-Spaces considered an auxiliary Machinery Space or a Machinery Space other than category A as defined in SOLAS Regulation II-2. - Gas-tight door to prevent escape of combustible gasses. - No heat sources or high fire risk objects located in the battery space. -No systems supporting essential services, including piping and electric cables serving such systems located in the battery space (in order to prevent their loss upon possible failures). Specific requirements where battery space is located adjacent to and within machinery space of category A : -A60 -ventilation requirements -ventilation ducts requirements -gas-tight doors or self-closing gas-tight doors with no holdback arrangement, -emergency stop in case of fire in the ER.		considered as part of an escape route (primary or secondary) from any other accommodation, control, service space, machinery space of Category 'A' and high fire risk area such as a garage, paint store, etc. -Ventilating fans such as to minimise risk of sparking in the event of the impeller touching the casing, and are to be suitable for the potentially hazardous and corrosive gases produced in a thermal runaway condition. Non-metallic- impellers are to be of an anti-static material. - Any part of the fire-fighting system which crosses through the lithium battery space without serving it is to be avoided.	ventilate possible off-gas directly into the EES space during a failure incident. - Access to the space shall be through normally closed doors with alarm or self-closing doors. - - The EES space shall not contain other systems supporting essential vessel services, including pipes and cables serving such systems (to prevent loss of propulsion or steering upon possible incidents). - The EES space shall not contain heat sources or high fire risk objects.	vented in the ESS space giving specific requirements. RINA do not requires as mandatory means to vent gas to the open deck. // RINA requires self-closing doors. ABS gas-tight doors or self-closing gas-tight doors with no holdback arrangement only if battery space is located adjacent to and within machinery space of category A. DNV normally closed doors with alarm or self-closing doors. // ABS requires an exhaust ventilation duct(s) for the battery space are to be from and to a safe location on open deck.

						RINA has no requirement on ventilation ducts. DNV requires be an independent ducting system of any other ventilation systems serving other spaces, unless the EES system is installed in an enclosed cabinet with an integrated off-gas ventilation duct , in which case supply may be taken from ventilation systems serving other spaces and with exhaust directly to open air. LR depend on the capacity of the batteries. // ABS and LR has requirement for the fans (non-sparking type), the other class society have no requirement.

						// Category of the space depend on the class societies: • ABS: Spaces considered an auxiliary Machinery Space or a Machinery Space other than category A. BV: Boundaries are to be fitted with the thermal and structural subdivision corresponding to "Other machinery spaces". LR: All other safety systems at least equivalent to those of a machinery space of Category A. • DNV: be defined as a machinery space (SOLAS Reg. II-2/3.30).
Hazardous area requirements	NO SPECIFIC REQUIRMENTS	NO SPECIFIC REQUIRMENTS	NO SPECIFIC REQUIRMENTS	NO SPECIFIC REQUIRMENTS	-If explosion protected equipment (ex equipment) is needed then the equipment selection shall	Only DNV has issued hazardous area requirement in relation to the

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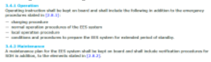
<td>comply with the zone 2 requirements given in Pt.4 Ch.8 Sec.11.
-The temperature class and gas group for the ex rated equipment shall be based on the gas composition for the actual EES system used.
- Areas on open deck within 1.5 m of inlet or exhaust openings of EES spaces/cabinets are classified as extended hazardous area zone 2.
- If a failure/damage of the EES system can lead to release of flammable/toxic gases in the EES space,then gas detection shall be arranged.</td>
<td>possible release of flammable gases based on the gas composition for the actual EES system.</td>
</tr>
<tr>
<td>Testing /Certification</td>
<td>-Testing requirements according to IEC 62619 /62620 for batteries (no reference to specific tests).
- Electronic device type tested.
-Battery charger type tested.
-Performance tests at FAT (not specified which performance tests are to b carried out).

FOR TYPE APPROVED products, tests to verify the conformity of the product with the approved</td>
<td>YES (section 3/table 1)
List of Type and Routine Tests (with reference to IEC 62619).
<table>
<tr><th colspan="5">TABLE 1
Summary of Type and Routine Tests</th></tr>
<tr><th>No.</th><th>Test</th><th>Type Test</th><th>Routine Test</th><th>Reference</th></tr>
<tr><td>1</td><td>[illegible]</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>2</td><td>Impact test</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>3</td><td>Drop test</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>4</td><td>Thermal abuse test</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>5</td><td>Overcharge test</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>6</td><td>Forced discharge test</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>7</td><td>[illegible]</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>8</td><td>[illegible]</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>9</td><td>[illegible]</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>10</td><td>[illegible]</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>11</td><td>[illegible]</td><td></td><td>x</td><td>[illegible]</td></tr>
<tr><td>12</td><td>Type tests for control, monitoring and safety equipment</td><td>x</td><td></td><td>[illegible]</td></tr>
<tr><td>13</td><td>[illegible]</td><td></td><td>x</td><td>[illegible]</td></tr>
</table>
</td>
<td>Battery cells
-Battery cells are to be type approved.
- Battery cells are to be constructed and tested in accordance with the relevant IEC Publications 62619 and 62281.
- List of prototype type for battery cells.
5.1.3 Prototype tests
The following items, at least, are to be checked:
• External short circuit
• Impact / Crush
• Drop
• Thermal abuse / Thermal cycling
• Overcharge
• Forced discharge
• Insulation tests (High voltage test and insulation resistance test)
- Battery cells FAT: High voltage test and insulation resistance.

Battery pack and associated BMS
- Battery packs are to be type approved.
- Battery pack are to be constructed and tested in accordance with the relevant IEC Publications 62619 and 62620.</td>
<td>-Lithium battery systems LR's Type Approval System - Test Specification Number 5 (2019) applicable.
- Lithium battery management LR's Type Approval System Test Specification Number 1 (2018).

• (Section 21) List of tests to be carried out at manufacturers' works for lithium battery installation.
<table>
<tr><th colspan="3">Table 2.21.3 Test requirements on lithium battery systems</th></tr>
<tr><th>Item</th><th>Tests</th><th>Trials</th></tr>
<tr><td>Discharge performance validation</td><td>X</td><td></td></tr>
<tr><td>Capacity validation test *</td><td>X</td><td>X</td></tr>
<tr><td>Internal d.c. resistance test</td><td>X</td><td></td></tr>
<tr><td>Overcharge control test</td><td>X</td><td></td></tr>
<tr><td>Cell balancing functional test</td><td>X</td><td></td></tr>
<tr><td>Sensor failures test</td><td>X</td><td></td></tr>
<tr><td>SOC validation test *</td><td>X</td><td>X</td></tr>
<tr><td>SOH validation test *</td><td>X</td><td>X</td></tr>
<tr><td>High voltage test</td><td>X</td><td></td></tr>
<tr><td>Insulation resistance test</td><td>X</td><td></td></tr>
<tr><td>Emergency trip functional test *</td><td>X</td><td>X</td></tr>
<tr><td>Over-temperature protection test</td><td>X</td><td>X</td></tr>
<tr><td>Over-voltage protection test</td><td>X</td><td>X</td></tr>
<tr><td>Under-voltage protection test</td><td>X</td><td>X</td></tr>
<tr><td>Communication failure between BMS and external charge control system test *</td><td>X</td><td>X</td></tr>
<tr><td>Pressure relief valve test</td><td>X</td><td></td></tr>
<tr><td>Additional safety functions tests and trials of the battery management system</td><td>X</td><td>X</td></tr>
<tr><td colspan="3">Note. Items marked * are required to be tested annually.</td></tr>
</table>
</td>
<td>The test requirements for EES systems is partly based on the following standards:
— IEC 62619
— IEC 62620.
— UL 810A
— UN 38.3</td>
<td>In general tests are based on IEC 62619.</td>
</tr>
</table>

	prototype are to be carried out before installation on board; the tests are to be carried out according to a test program which is to include functional tests (alarm system, safety system, control system, etc.).		- List of prototype type for battery pack. **5.3.3 Prototype tests** The following items, at least, are to be checked: a) Propagation/internal thermal event b) Overcharge control of voltage c) Overcharge control of current d) Overheating control e) Insulation tests (High voltage test and insulation resistance test) f) IP characteristics g) Safety function tests : • Emergency stop function • Alarms and shutdowns • Temperature protection BMS • Overvoltage protection BMS • Undervoltage protection BMS • Communication Failure h) Discharge performance (rated capacity check) i) Endurance j) Charge retention and recovery (self discharge) k) Additional tests based on FMEA (sensors failures,...) l) Environmental tests according to Pt C, Ch 3, Sec 6. - Battery pack FAT: list of test: **5.3.4 Factory acceptance tests** The following items, at least, are to be checked: • ability to achieve safety functions • proper working of alarms and defaults and related functions and/or interfacing to the other ship systems • proper working of monitoring systems • when direct cooling is provided, temperature rise test in order to check the proper working of the cooling circuit (see [3.2.1]) Note 1: The test condition to be selected is the most unfavourable nominal operating conditions of the batteries (maximum charging or discharging current which will produce the maximum heating losses) • Insulation tests (High voltage test and insulation resistance test) • IP characteristics.			
Testing and inspection after installation on board	YES (5.3.1) List of tests to be carried out: **5.3 Testing and inspection after installation on board** **5.3.1** (1/1/2019) After installation, and after any important repair or alteration which may affect the safety of the arrangement, following a check of compliance with the plans, the battery system is to be subjected at least to the following tests and inspections, to the satisfaction of the Surveyor in charge: • visual inspection, • operational tests, • tests of all the alarms and safety functions, • charging and discharging capacities, • emergency shutdown operation, • checking of operation of sensors, including simulation of changes in parameters and simulation of sensor failure, • simulation of communication failure, • insulation resistance test, • correct operation of ventilation, cooling, gas detection system, fire detection system and fire extinguishing system, etc., where provided.	YES (Section 5/3) List of tests and verification to be carried out: [illegible] • Visual inspection • Operational tests • Tests of all the alarms and safety functions • Emergency shutdown operation • Fire protection systems • Fire and Gas detection systems • Simulation of communication failure with power management system • Correct operation of ventilation, cooling, gas detection system, fire detection system, fire extinguishing system, etc., where provided [illegible]	YES (5.1.5/5.3.5) Battery cells: Battery cell test in itself is to be included in the battery pack test. <u>Battery pack and associated BMS:</u> List of tests: **5.3.5 Onboard tests** The following items, at least, are to be checked: • proper working of alarms and defaults and related functions and/or interfacing to the other ship systems • proper working of monitoring systems • fitting of battery pack arrangement to battery compartment • battery capacity and loading duration, at least for the cases mentioned in the ship availability failure analysis • Insulation resistance test • IP characteristics. <u>Onboard tests of battery compartment and fire-extinguishing system:</u> **5.4.1 Fire detection** Efficiency of fire detection is to be tested. **5.4.2 Dangerous gas detection** Efficiency of dangerous gas detection is to be tested. This includes testing that detectors were properly positioned to detect dangerous gas concentration in any normal circumstance of operation of the ventilation system. **5.4.3 Fire-extinguishing system efficiency** Efficiency of fire-extinguishing system is to be tested. Gas concentration after fire-extinguishing system operation is to be measured and found high enough to prevent an explosion or stop a fire. Other criteria may be defined or asked for, at the satisfaction of the Society. **5.4.4 Accessibility of battery compartment** Accessibility for common maintenance and devices used for battery overhaul, if any, are to be tested.	• YES (Section 21) List of tests at trials to be carried out: **Table 2.21.3 Test requirements on lithium battery systems** Item / Tests / Trials Discharge performance validation / X / Capacity validation test * / X / X Internal d.c. resistance test / X / Overcharge control test / X / Cell balancing functional test / X / Sensor failures test / X / SOC validation test * / X / X SOH validation test * / X / X High voltage test / X / Insulation resistance test / X / Emergency trip functional test * / X / X Over-temperature protection test / X / X Over-voltage protection test / X / X Under-voltage protection test / X / X Communication failure between BMS and external charge control system test * / X / X Pressure relief valve test / X / Additional safety functions tests and trials of the battery management system / X / X **Note**. Items marked * are required to be tested annually.	• YES (Para 2.7) List of testing after installation: **2.7.1 Testing** After installation, the following tests shall be performed: — test of correct interface between the EES converters and the EES sy[illegible] — test of EES converter's protection functions. — test of the EES system and its auxiliaries, including alarms and safety functions — test of functions in the EES space (e.g. possible ventilation, liquid cooling, gas detection, [illegible] leakage detection) as installed. Guidance note: [illegible] -Requirements for testing of the electrical installation is given in Pt.4 Ch.8 Sec.10 [4.4]. - Requirements for testing of the control systems is given in Pt.4 Ch.9 Sec.1 [4.5]. (Para 3.3) FOR NOTATION Battery(Power) additional tests are required supplementary to the tests stated in [2.7]: **3.3.1 Testing** Supplementary to the tests stated in [2.7], the following shall be verified by testing: — verification of SOH. This shall be performed by coulomb counting during a complete charge or discha[illegible] or other method as documented in the maintenance manual, see [3.4.2] — charging and discharging capacities to verify maximum C-rates as specified for the intended operatio[illegible] the vessel. [illegible]	
Operation and Maintenance	YES (5.2) • Request of: • an <u>operation manual</u> to be	YES (section 5/3/iv) -Request to have a <u>maintenance</u>	YES (Tab. 1) - Request for information a <u>maintenance manual</u>	YES (1.3.11) -<u>Operation, maintenance and training manuals</u> for the battery system	YES (2.8) -<u>Instructions for emergency operation</u>	In general a maintenanc e and operation

	kept on board; • a maintenance manual for systematic maintenance and functional testing to be kept on board.	schedule and procedures of batteries replacement are to be provided and maintained onboard.	and maintenance schedule	are to be kept on board.	-A plan for systematic maintenance and function testing shall be kept on board. (Para 3.4) FOR NOTATION Battery(Power) additional documentation is required supplementary to the tests stated in [2.8]: -Operating instruction & -maintenance plan for the EES system shall be kept on board and shall include verification procedures for SOH in addition, to the elements stated in [2.8.2].  3.4.1 Operation Operating instruction shall be kept on board and shall include the following in addition to the emergency procedures stated in [2.8.1]: — charging procedure — normal operation procedures of the EES system — local operation procedure — conditions and procedures to prepare the EES system for extended period of standby. 3.4.2 Maintenance A maintenance plan for the EES system shall be kept on board and shall include verification procedures for SOH in addition, to the elements stated in [2.8.2].	manual is required. In addition **DNV** also requires instruction for emergency operation.
Specific requirements for batteries as main source of electrical power	- Design capacity sufficient for the intended operation of the ship. - In ships or units where the main source of electrical power is based on battery installations only, the battery installation is to be divided into at least two independent battery systems located in two separate battery spaces, each having a capacity sufficient for	- Meet flag State and SOLAS requirements design capacity based on the asset's intended operations. - Two independent battery systems are to be provided and located in separate spaces (fire risk associated with thermal runaway is the main reason for separate compartments). -Propulsion design is to incorporate at least two independent systems as defined in 4-8-5/5.3.1 of the Marine Vessel Rules or	**Case 1: global battery system failure leads to loss of propulsion or of main electrical sources:** The ships falling onto SOLAS Convention cannot, from the Society point of view, be allowed to have configuration as mentioned in case 1. -Minimum requirements The battery system fitted with at least two independent packs of batteries to supply the main energy source. A failure analysis is required. **Case 2: global battery system failure does not lead to any loss regarding ship propulsion and main source of power**	-Integration of a lithium battery system that satisfies a ship's main power demand into the ship's electrical power system is to be in accordance with Pt 6, Ch 2, 24 Hybrid electrical power systems.	Only for additional class notation POWER **When all the main sources of power is based on EES only,** -at least two independent EES systems located in two separate EES spaces. **When a EES system replaces one of the required main sources of power** -the capacity sufficient for the intended operation of the vessel. - The design capacity stated in the appendix to the class certificate as an operational limitation. **When EES systems are used as redundant power**	**RINA** require the separation in different space only for ship batteries based **ABS** requires two separate spaces always

	the intended operation of the ship. - Battery system is used as storage of power for the propulsion system or as part of the main source of electrical power, State of Charge (SOC) and State of Health (SOH) displayed at at a continuously manned alarm on the bridge. -In case of over temperature in the battery system, an alarm and a request of manual load reduction is to be given on the bridge at a temperature lower than the one causing intervention of the BMS.	4-3-5/3.3.1 of the MOU Rules.. -Mandatory the PMS to be provided. - System protection requirements of 4-8-2/9 of the Marine Vessel Rules or 4-3-2/9 of the MOU Rules are applicable. - Load Shedding - SOC and SOH are to be monitored remotely at the navigation bridge. -Battery Space is considered Machinery Space Category A. -Complete sea trial tests in accordance with 4-8-5/5.19 of the Marine Vessel Rules.	• Minimum requirements as above. • Additional requirements for compliance to SOLAS Convention from the Society point of view: When the battery pack is supposed to replace the main energy source and the propulsion energy source, it is to be able to provide energy for 8-hour operations, as mentioned in Pt C, Ch 1, Sec 10, [11].		**sources for dynamic positioning** -The capacity of the EES systems shall be sufficient for the planned operation.	
Specific requirements for batteries as emergency source of electrical power	NO SPECIFIC REQUIREMENTS	-Batteries are not to be installed in the same space as the emergency switchboard. - If the battery bank is used in conjunction with an emergency power source (e.g., emergency diesel generator), it should not be located in same space as the emergency power source.	NO SPECIFIC REQUIRMENTS	NO SPECIFIC REQUIRMENTS	NO SPECIFIC REQUIRMENTS	

		-Both spaces readily accessible and as near as practical.				

18 ANNEX 2 - CONSIDERATIONS ON TESTS

18.1 Functional tests

18.1.1 Electrical and environnemental test

After the safety, one of the most important items is the life time. To define the type of test needed to check the lifetime, we need to define the Li-ion battery life impact:

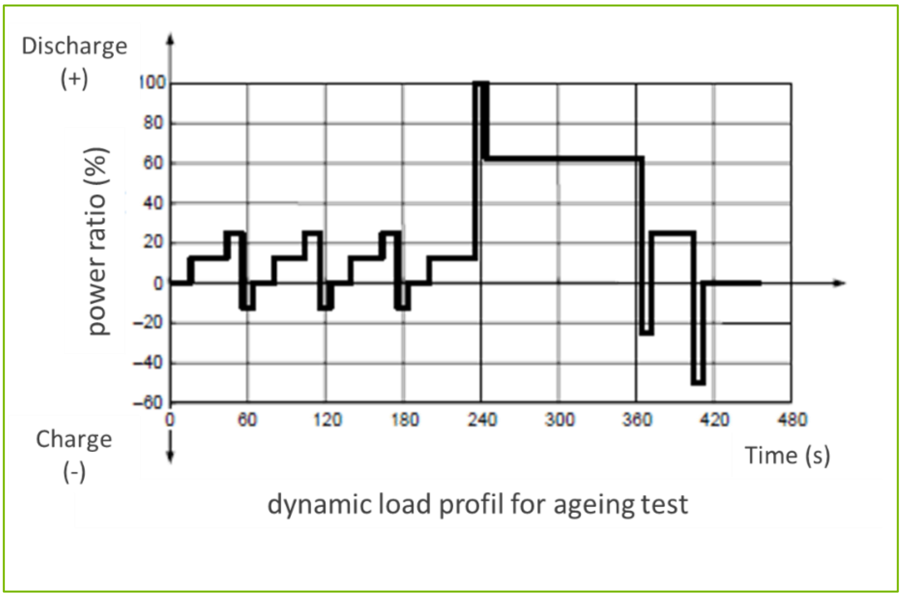
- Operating temperature (ambient, cooling, inhomogeneity,).
- Load profile (C rate, CC, CV, ripple, range of SOC use).
- Mechanical (vibration, compression, etc.
- Interconnections (Pack configuration, contact resistance,).

18.1.2 Automotive reference

One of the test standards reference is Standard NF EN IEC 62660-1: 2019-02, established for performance and life tests of lithium-ion accumulators used for the propulsion of electric vehicles, including battery electric vehicles (BEV) and hybrid electric vehicles (HEV). This in order to ensure reliability of use and life. Marine standards require even superior reliability in the automotive world.

The major interest to use this type of standards is the amount of publications and data reference.

Figure 16 : Example of dynamic load profile for Ageing test. Application for BEV



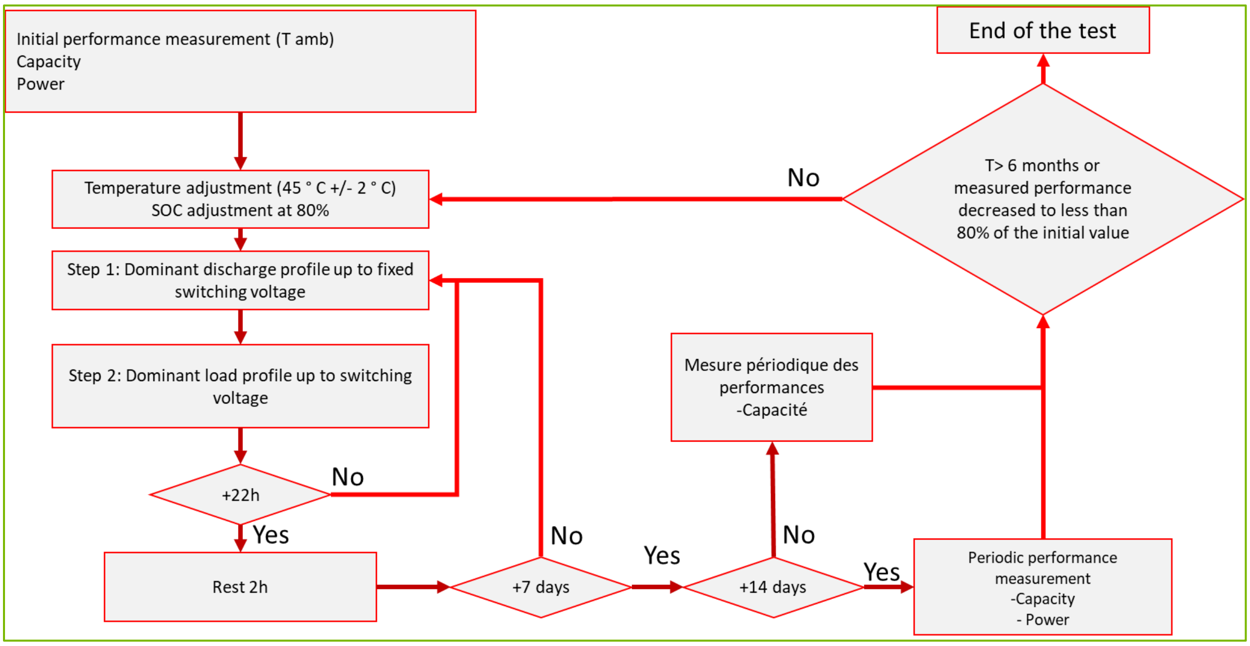


Figure 17 : Standard NF EN IEC 62660-1: 2019-02: HEV aging cycle

After that test, some additional data are to be analyzed (number of cycles, current, voltage, temperature, time...) and additional tests are to be carried out.

One study parameter is the inner resistance, further subdivided into three different groups:

Ohmic Resistance: intrinsic resistance of materials (electrode + electrolyte).

- Value specific to materials and geometry (independent of imposed stress and SOC).
- Material resistance + contact resistance + SEI resistance.

Diffusion resistance: diffusion of the Li^+ cation.

- dependent on electrical demand and SOC.

Activation resistance: Load transfer

- Linked to the activation energy of the electrochemical reaction.
- Dependent on demand and SOC.
- Capacity attenuation in Lithium is attributed to several phenomena: for example lithium stock loss (LLI) or active material loss (LAM).

Electrochemical impedance spectroscopy (EIS) is particularly powerful. it can distinguish between the physicochemical electrolytic phase and the electronic conduction in the electrode phase, processes with different time constants. The study of the data makes it possible to know the influence of each parameter on the battery. Performance losses are thus assessed and identified. This also makes it possible to establish a battery mapping according to the conditions of use and to define its field of action

CEA Tech in Nantes has the ability of test real system part in controlled climatic conditions. Furthermore, a large nondestructive facility can improve materials and system design by detecting nonconformity by X-ray imaging.

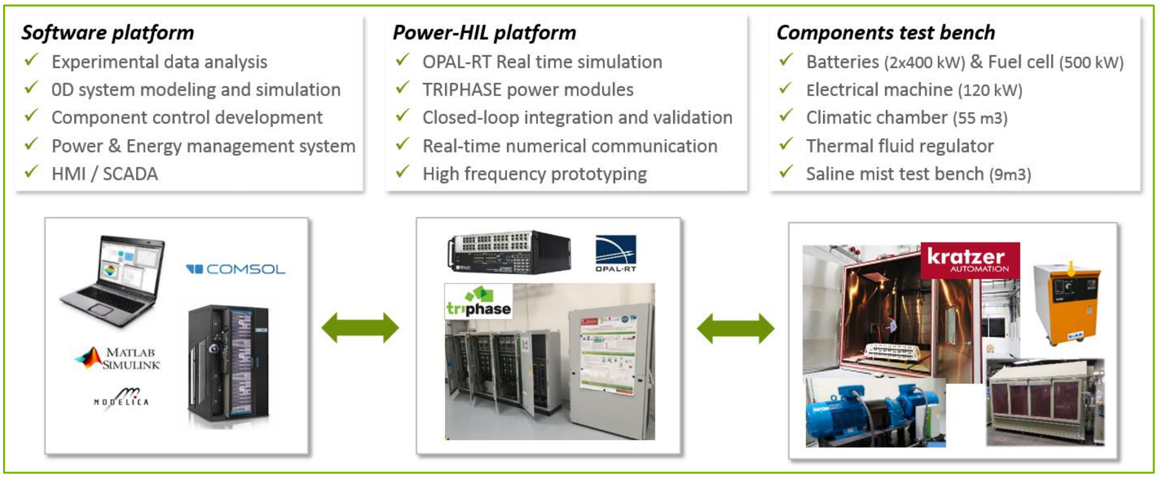
- Tests on a large climatic chamber
  - ✓ Environmental tests on industrial systems (climatic and salt spray tests)
  - ✓ Power tests under monitored climatic environment
- Mechanical tests
  - ✓ R&D on monitoring fatigue tests using *in situ* 3D X-ray imaging, understanding and modeling the mechanisms of initialization and propagation of cracks until failure
  - ✓ R&D on fatigue tests under atmospheric corrosion and understanding of the interactions between cracks and corrosion
- Nondestructive testing
  - ✓ Robotized X-ray inspection of industrial parts and 3D analysis.

18.1.3 Environmental tests facilities

CEA Tech can lead experiments on parts and entire systems to test the durability of materials. A large salt spray (7.8 m^3, and 800 kg load limit) can provide automatic climatic and corrosion cycles on real industrial systems. A large climatic chamber provides power cycle tests on energetic systems in a controlled environment (54 m3, 6 T load limit, 800 kW).

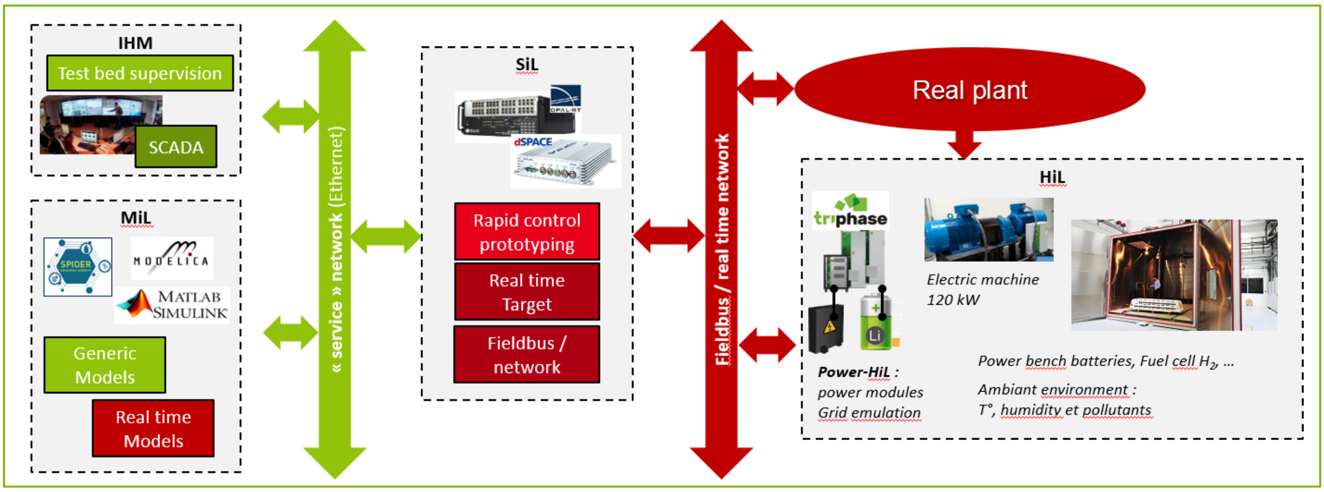
Facilities description

- ***SEA'Nergy : a systemic and integrative platform***

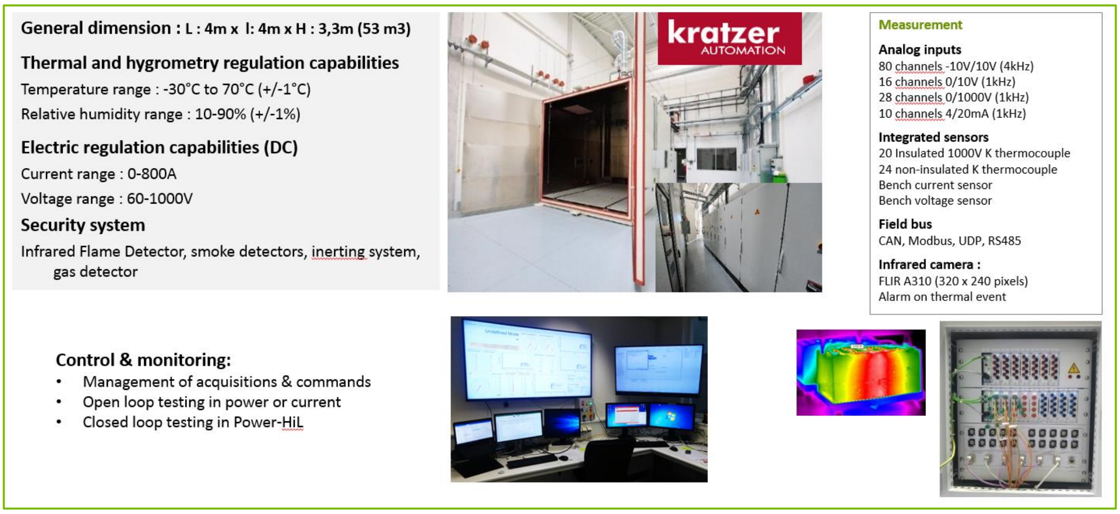


- ***XiL connectivity framework***
  - ✓ Integrated modeling and simulation tool chain (MiL -> SiL -> HiL).
  - ✓ Emulation of the environment and specific profile / uses.
  - ✓ Applicative integration of software bricks and components.

this type of approach and particularly interesting in the case of boats where the study at scale one in the laboratory is often not possible. The evaluation at a lower scale then a complete emulation, makes it possible to robustify the final design.



- ***Electrical test bench and climatic chamber***



Possible study example:

- ✓ Corrosion impact on contact resistors: with or without battery.
- ✓ Impact of severe conditions on packs: temperature + humidity + salinity.
- ✓ Advanced temperature management and marinization test.
- ✓ Stress impact comparison: Marinization / Automotive: comparison with all auto studies.

18.2 Focus on atmospheric severity and corrosion

18.2.1 Environmental severity/atmospheric corrosivity

The classification societies define different environmental categories. Those classes depend on the location of the system on the vessel and describe the aggressiveness of the environment. The position on ship give range of physical parameters as seen in the table below taken from RINA rules for temperature and relative humidity.

Location	Temperature range, in °C	
Enclosed spaces	+ 5	+ 45
Inside consoles or fitted on combustion engines and similar	+ 5	+ 55
Exposed decks	- 25	+ 45

Location	Humidity
General	95% at 55 °C
Air conditioned areas	Different values may be considered on a case by case basis

Coolant	Temperature range, in °C	
Sea water	0	+ 32

Table taken from RINA – C; ambient air temperature, humidity and water temperature

In all classification rules, the value for salt mist in air is fixed at 1 mg.m^{-3}. Design for equipment installed in these zones must integrate this constraint.

RINA and Bureau Veritas have the same method to define the environment rules. In a same approach, the DNV rules define a class from a selection of a physical parameters and a location on the ship. The next table show a selection taken from DNV.

Table 1 Location classes – selection guide

Column I		*Column II*				
		Main areas on board				
Parameters	*Location within main area*	*Machinery spaces*	*Control room, accommodation*	*Bridge*	*Pump room, holds, rooms with no heating*	*Open deck*
Temperature	Inside cubicles, desks, consoles, etc. with temperature rise of 5°C or more	B	B	B	D	D
	All other locations	A	A	A	C	D
Humidity	Locations where special precautions are taken to avoid condensation	A	A	A	A	A
	All other locations	B	B	B	B	B
Vibration	On machinery such as internal combustion engines, compressors, pumps, including piping on such machinery	B	—	—	B	B
	Masts	—	—	—	—	C
	All other locations	A	A	A	A	A
EMC electro-magnetic compatibility	All locations within specified main areas	A	A	B	A	B
Enclosure	Submerged application	D	—	—	D	D
	Below floor plates in engine room	C	—	—	—	—
	All other locations	B	A	A	B	C

Table taken form DNV

Each class defines a set of tests to check the durability of a system in its environment. The severity level of a set of tests define the minimum equipment specification for a class requirement.

ISO 9223 describes more precisely the corrosion risk of metals on different environment. This standard defines six categories of atmospheric corrosivity, from very low to extreme. This classification derives from empirical studies combining environmental parameters and mass loss on standard metallic samples. Four physical parameters expressed as annual averages govern the categories of corrosivity of the atmosphere. These key factors are the temperature, the relative humidity, the chlorides and the sulfur dioxide pollution levels. The time of wetness, meaning the time when the relative humidity is higher than 80%, give the annual average value of relative humidity.

Table 1 — Categories of corrosivity of the atmos

Category	Corrosivity
C1	Very low
C2	Low
C3	Medium
C4	High
C5	Very high
CX	Extreme

Table 3 — Parameters used in the derivation of dose-response f including symbol, description, interval and unit

Symbol	Description	Interval	Unit
T	Temperature	–17,1 to 28,7	°C
RH	Relative humidity	34 to 93	%
P_d	SO_2 deposition	0,7 to 150,4	mg/(m²
S_d	Cl^- deposition	0,4 to 760,5	mg/(m²

The sulfur dioxide (SO_2) values determined by the deposition method, P_d, and v method, P_c, are equivalent for the purposes of this International Standard. The rel between measurements using both methods may be approximately expre $P_d = 0{,}8\ P_c$ [P_d in mg/(m²·d), P_c in μg/m³].

NOTE All parameters are expressed as annual averages.

Tables from ISO 9223

To ensure a good corrosion resistance of metallic structures, these categories of corrosivity call for a metal coating or anticorrosion design adapted to the atmospheric severity. The range of categories of corrosivity is large and goes from very low to extreme. The CX category for extreme condition describe an offshore exposition.

In addition, the standard ISO 11844 can express a more detailed class of the levels low and very low. This standard suit for indoor exposition. Temperature and relative humidity is still use to define levels of corrosivity, and a table for various pollutant gives the pollution factor.

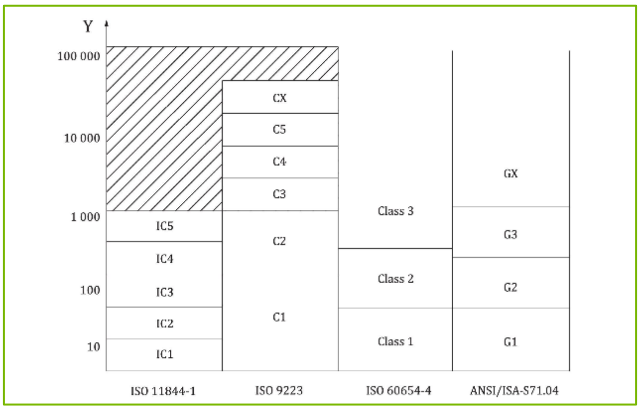


Table taken from ISO 11844-1

Atmospheric corrosion sensors can monitor the corrosivity and its evolution with time of an environment. These sensors can be exposed outside or indoor. For instance, automotive industry usually check the corrosivity in different part of a car to adapt its anticorrosion design. Same methods could be used to check the aggressiveness of the environment where is located the batteries. Specific sensors can also monitor separately the physical parameters used in the ISO 9223/ISO 11844 standards, as temperature or relative humidity.

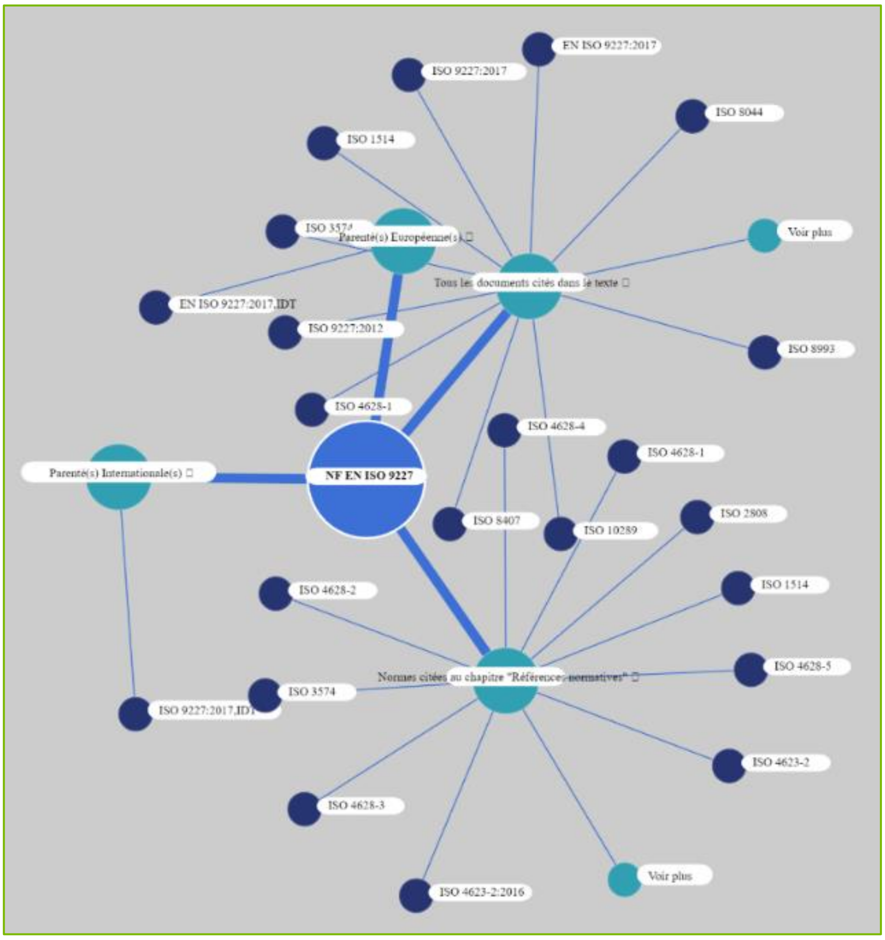
18.2.2 Accelerated corrosion tests standards

The standards define different accelerated corrosion test depending on the industrial context. The table below list some of these tests. The aim of these standards is to improve anticorrosion design or coating durability in aggressive environment.

ISO 11845	Corrosion of metals and alloys - General principles for corrosion testing
ISO 9227	Corrosion tests in artificial atmospheres - Salt spray tests
IEC 60068-2-52	Test Kb : salt mist, cyclic (sodium chloride solution)
ISO 16701	Test involving exposure under controlled conditions of humidity cycling and intermittent spraying of a salt solution
ISO 12944	Performance testing of the paint system – cyclic ageing test Civil engineering
ISO 4628	Methods of visual inspection of corrosion issues after corrosion test

Standards used for accelerated corrosion test

The most used standard in corrosion tests is the ISO 9227. This standard is the so-called salt spray test, which is an artificial atmosphere created by projection of 5% sodium chloride solution in a temperature-controlled environment. As it is a constant artificial atmosphere, this standard is not suitable to compare results with real life application. However, as it is the most common corrosion standard, results can be compared with a strong background in the literature.



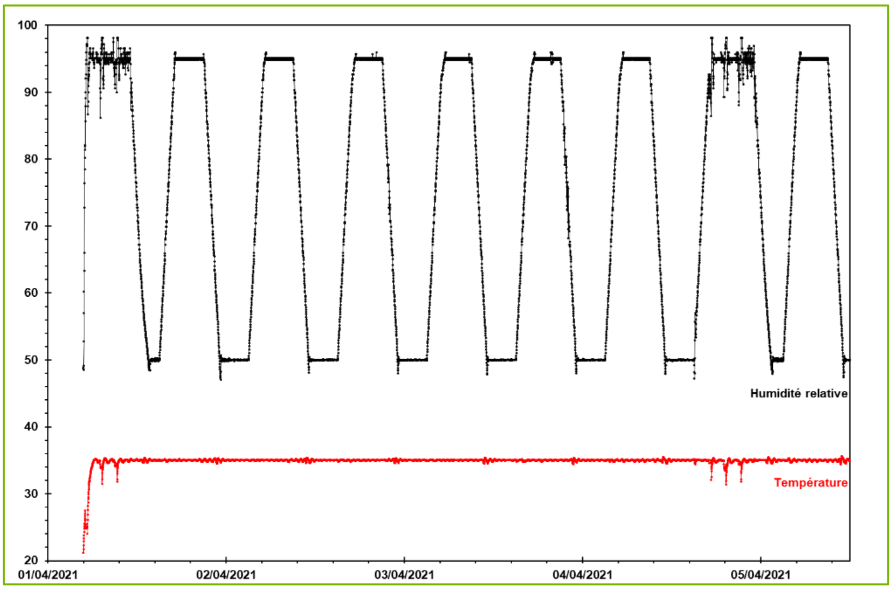
ISO 9227 (from AFNOR website)

The ISO 9227 is a well-known reference for accelerated corrosion test in many environmental test. This standard is often call as a sub cycle aggressive step of more general climatic tests.

The accelerated corrosion test required by the classifications society rules refers to the standard IEC 60068-2-52. This test combines climatic steps with salt spray tests (from ISO 9227). The standard proposes different arrangement of this step to suite with the categories of corrosivity defined in the ISO 9223. Functional tests are done before the corrosion tests and then every seven days.

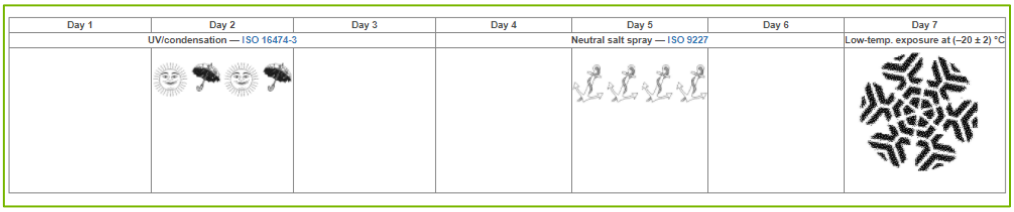
The IEC 60068 series deals with procedures for environmental and severities tests for electronic devices. The IEC 60068-1 standard give general information on environmental testing, and the others of the series give methods and prescription for each environmental test.

In automotive industries, each car manufacturer has its own corrosion test standards, but most of them are close to the ISO 16701. It alternates automatic climatic cycles and salt solution spray. As can be seen in the graph, the climatic cycles alternate steps of high relative humidity with dry steps.



Temperature and relative humidity during ISO 16701 cycles

The ISO 12944 standard described civil engineering anticorrosion design. Accelerated carrion tests in this industrial context are mainly done under the ISO 9227 standard and the ISO 12944-9 one. This one alternates steps with climatic cold cycles, UV rays and salt spray (from ISO 9227).



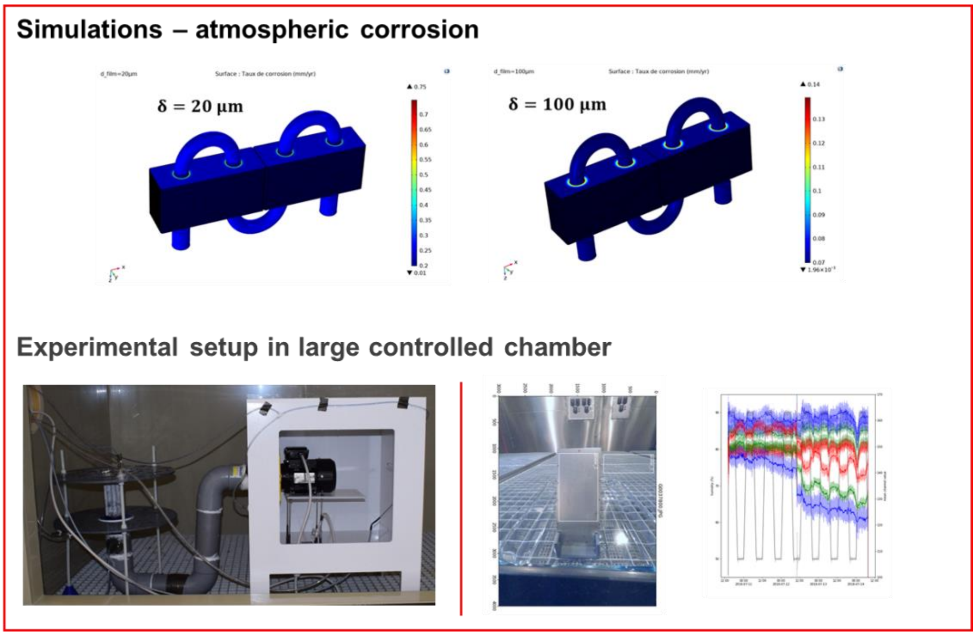
Prescription of accelerated corrosion from ISO 12944-9 standard; Civil engineering context

18.2.3 CEA Tech facilities in Nantes on atmospheric corrosivity

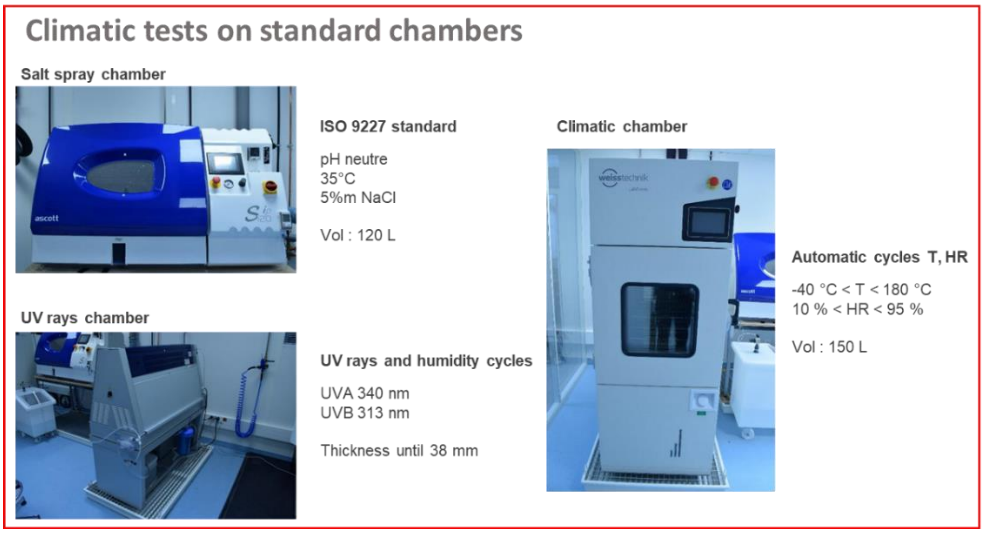
CEA Tech in Nantes provides facilities to pass accelerated corrosion test at different scales of an equipment. A large salt spray chamber can test real part from different industrials contexts.

This salt spray chamber can make automatic cycles with temperature and relative humidity controlled – range 20°C-70°C and 20%RH-95%RH. This chamber can also provide compliance with ISO 9227 standard.

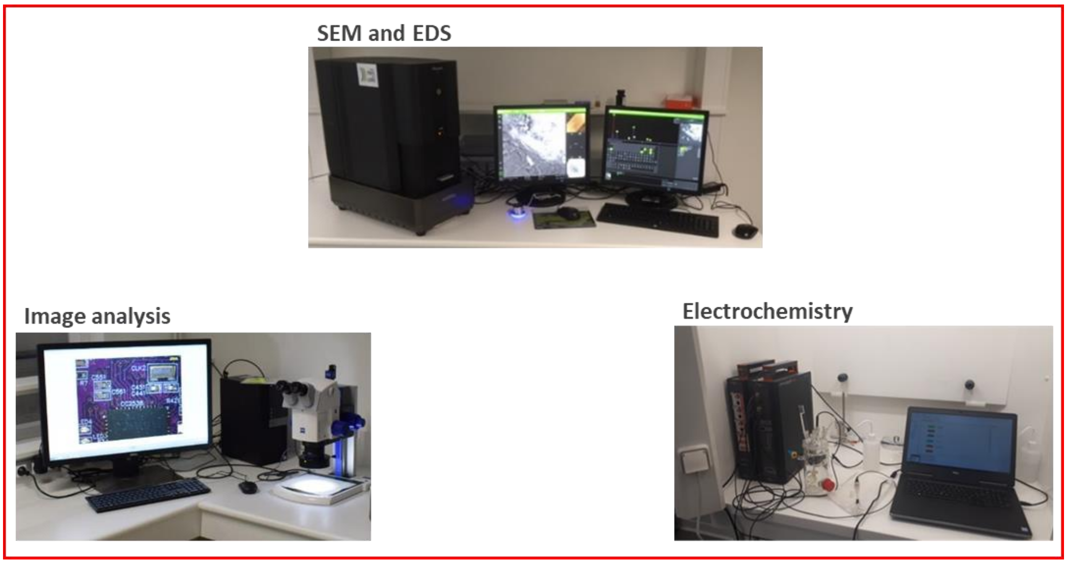
Large climatic and salt spray chamber allows testing real systems. Moreover, experimental setup can be installed on these chambers to test specific parts of a system. For example, studies have been made on PAC filters to test their efficiency in aggressive environments. Furthermore, as a support of experimental tests, modeling and simulation can bring more insight on material durability.



A set of small chambers – salt spray chamber, climatic chamber and UV rays chambers – can pass a large panel of ageing tests on standard samples or small industrial parts.



Finally, material characterization provide information on material evolution in aggressive environment. For instance, comparison of scanning electron microscope analysis done before and after ageing test shows the influence of salts on materials surface degradation.



18.3 Focus on abusive tests

The CEA near Tours has two test sites where abusive tests are performed depending on energy of the battery:

- CEA Le Ripault 300m² mound type building with 2 test rooms dedicated to low energy (<1kWh) batteries
- CEA Terrain d'expérimentation du Ruchard composed of a 200 m² mound type building with 1 test room dedicated to middle energy (<5kWh) batteries and a 400 m² outdoor (under construction, 2021) platform dedicated to high energy batteries (packs <50kWh) and equipped with a catapult for impact tests.

Each site allows remote control of the abusive tests. Each test room includes a fume extraction system.

Major types of hazards are addressed:

- Mechanical (nail penetration, controlled crush, fall)
- Electrical (short-circuit, overdischarge, overcharge/overvoltage)
- Environnemental (overheated, thermal propagation, fuel fire)
- Chemical (gas sampling (excepted hydrofluoric acid), gas volume at cell level)

Most of electrical and environmental test are available at cell, module and pack levels. Mechanical tests are limited at cell and module levels while gas volume measurement can also be provided at cell level. Physical variables (electrical, thermal…) are acquired with data acquisition units with time step down to 10ms or oscilloscope for higher accuracy. HD cameras record global events while thermal cameras track thermal propagation. Fluxmeter can also be added to follow convection are infra-red transmitted energy. High-speed camera is used for shorts event detection.

These abusive tests have been largely performed at CEA for automotive and spatial applications.

Test benches have been developed to respond to specific requests which are not linked to standard tests. For instance:

- Drilling, sawing
- Nail penetration with voltage feedback (automotive application)
- Time-resolved short-circuit down to 1ms (aeronautics and automotive application)
- Short-circuit with very low charge (down to 3,5mΩ and up to 100mΩ) (spatial and automotive applications)
- Thermal propagation induced with heating wire or cartridge heater (automotive application)
- CO_2 extinction (automotive application)
- Tests under specific atmospheres (Ar or N_2 - spatial application)