GUIDE FOR

USE OF SUPERCAPACITORS IN THE MARINE AND OFFSHORE INDUSTRIES

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American Bureau of Shipping
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the State of New York 1862

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Foreword

Hybrid electric power applications are increasing in the marine and offshore industries. ABS recognizes the application of supercapacitor technology in support of the hybrid initiatives and its benefits for improving energy efficiency of the onboard power plant. Supercapacitors, as a commercialized energy storage device, exhibit beneficial characteristics such as high power density, a fast charging/discharging process, no thermal runaway characteristics, and wide operating-temperature range. The operating environment typical in the marine and offshore industries may differ from those considered when a supercapacitor system was originally designed and so necessitates a review of the environmental and operational aspects prior to adoption. ABS has produced this Guide to provide requirements and reference standards to facilitate effective installation and operation of on-board supercapacitor systems.

The purpose of this Guide is to establish safety guidelines for owners, operators, shipyard builders, designers, and manufacturers. The supercapacitors covered by this Guide are also referred as Electrical Double Layer Capacitors (EDLC), Electrochemical Capacitors, or Ultracapacitors. Requirements applicable to conventional electrolytic capacitors used for power factor correction or harmonic filtering are contained in Part 4 of the ABS *Rules for Building and Classing Steel Vessels*.

Supercapacitor technology is continuously evolving with respect to materials and design. Alternative arrangements or new supercapacitor technologies may be considered provided it can be shown, through either satisfactory service experience or a systematic analysis based on sound engineering principle, to meet the overall safety standards of this Guide and the ABS Rules.

This Guide becomes effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of this Guide is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.

GUIDE FOR

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SECTION 1 General

1 Introduction

ABS recognizes the application of supercapacitor technology in the marine and offshore industries and its benefits for improving energy efficiency. This Guide has been developed to facilitate the effective installation and operation of supercapacitors. This Guide is to be used in conjunction with and as a supplement to Part 4 of the ABS *Rules for Building and Classing Steel Vessels (Steel Vessel Rules)* and the ABS *Rules for Building and Classing Mobile Offshore Drilling Units (MODU Rules),* or other ABS Rules as applicable. The basic safety principles such as having sufficient power generation (storage) capacity, adequate standby and emergency power sources, continuity of supply in the event of a fault, and general electrical safety (such as proper cable sizing, appropriate insulation, appropriate equipment enclosure ratings, etc.) contained in the ABS Rules are to be followed in general. Those specific requirements are not repeated in this Guide.

3 Application

This Guide is applicable to marine and offshore assets designed, constructed, or retrofitted with a supercapacitor system used as an additional source of power with a capacity greater than 50 Wh. An optional notation **ESS-SC** may be granted to those assets once the supercapacitor installation has complied with the requirements of this Guide.

When Type Approval for supercapacitor system components is requested, applicants should contact ABS for the approval process. For ABS Type Approval Program requirements, please refer to 1-1-4/7.7, Appendix 1-1-A3, and Appendix 1-1-A4 of the ABS *Rules for Conditions of Classification (Part 1).* See Section 2, Table 1 for certification details. Alternative certification schemes are also available as documented in 1-1-A3/5.5 of the ABS *Rules for Conditions of Classification (Part 1).*

5 Scope

The supercapacitors covered by this Guide are also referred as Electric Double-Layer Capacitors (EDLC), Electrochemical Capacitors, or Ultracapacitors. For requirements applicable to conventional electrolytic capacitors used for harmonic filtering, please refer to the requirements in 4-8-2/9.23 of the *Steel Vessel Rules*.

This Guide addresses the requirements related to supercapacitors installed onboard marine and offshore assets classed by ABS that meet the requirements in Subsection 1/3 of this Guide.

Capacitor-type energy storage technology is a field that is continuously evolving with respect to materials and design. Alternative capacitor-type energy storage technologies and arrangements may be considered provided it can be shown, through either satisfactory service experience or a systematic analysis based upon sound engineering principles, to meet the overall safety requirements of this Guide and the ABS Rules.

7 Terminology

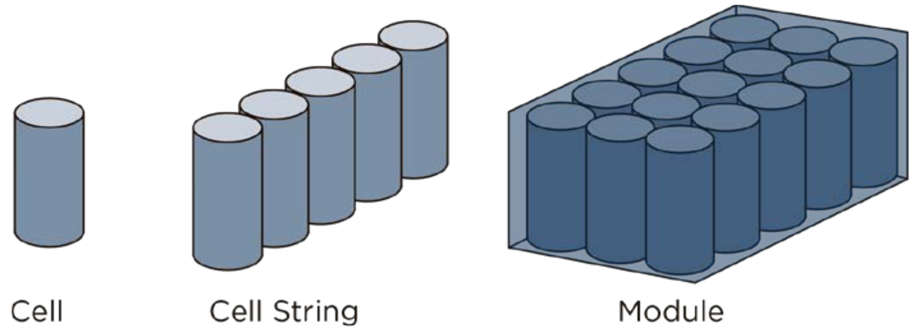
Electrochemical Capacitor. An electric energy storage device where an electrical charge is stored as a result of non-Faradaic processes at one or both of the electrodes. (A subset of electrochemical capacitors referred to as an “asymmetric electrochemical capacitor” have non-Faradaic processes at one electrode and Faradaic processes at the other electrode.) The unique highly-porous electrode increases its surface area for holding a charge, resulting in much larger capacitance and energy density than other types of capacitors. Electrochemical capacitors differ from common electrolytic capacitors in that they store a charge at the liquid-solid interface of the electrodes when a potential is applied rather than in a solid dielectric material covering the surfaces of the electrodes. Some other common names for an electrochemical capacitor are “double layer capacitor”, “ultracapacitor”, “electrochemical double layer capacitor”, “supercapacitor”, and EDLC. [UL 810A]

Supercapacitor Cell. The basic electric energy storage unit inside of a supercapacitor system, which contains an assembly of electrodes, electrolyte, separator, and current collectors.

Supercapacitor Cell String. A number of supercapacitor cells or modules connected in series to achieve a large voltage level of the supercapacitor system.

Supercapacitor Module. A group of supercapacitor cells connected together in a series and/or parallel configuration with or without protective devices and monitoring circuitry.

FIGURE 1
Supercapacitor Components (only use for reference)



Supercapacitor Pack/Rack/Stack. Energy storage device that is composed of one or more supercapacitor cells or modules electrically connected. It has monitoring circuitry that provides information to a supercapacitor system.

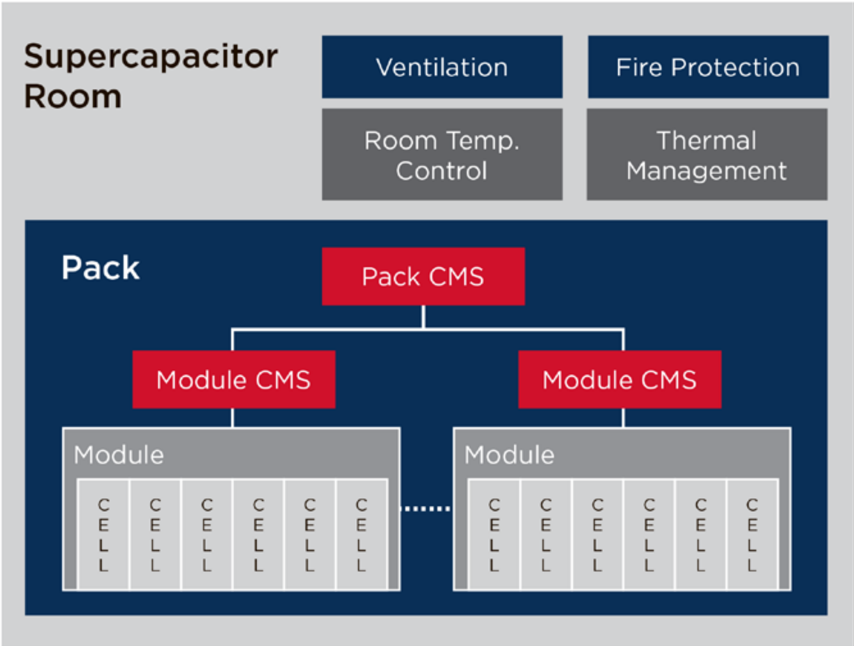
Capacitor Management System. A supervision system that contains control, monitoring, balancing, and protective functions of the supercapacitor system. It monitors and/or manages its state, calculates secondary data, reports that data, and/or controls its environment to influence the supercapacitor’s safety, performance, and/or service life.

Cell Balancing. The mechanism of forcing all supercapacitor cells within a supercapacitor module to have identical voltages. Cell balancing is achieved by means of a “balancing circuit” (usually implemented as part of the capacitor management system). Without a balancing circuit, one or more cells (as a result of different internal equivalent series resistances) may become undercharged or overcharged, either of which can lead to a failure of the capacitor module. Cell balancing is not an instantaneous process and requires a period of time before cell voltages are balanced.

Supercapacitor Space. Physical installation room including decks, bulkheads, overheads and all functions and components which contribute to keep the supercapacitor system in the defined space at a specific set of environmental conditions (also known as capacitor room/compartment).

Supercapacitor System. A complete system that contains one or more supercapacitor cells/modules/packs with Capacitor Management System, ancillary devices, and protective components. An example supercapacitor system is illustrated in Section 1, Figure 2.

FIGURE 2
Supercapacitor System



Power Management System (PMS). A complete switchboard and generator control system that controls power generation and distribution, including multiple switchboards and ring bus systems. The PMS on board marine and offshore assets is responsible for functions such as load sharing among different power sources and load shedding when generated power is insufficient.

State of Charge (SOC). Available capacity in a supercapacitor cell/module expressed as a percentage of rated capacity.

State of Health (SOH). An indication of the general condition of a supercapacitor cell/module compared to its ideal conditions (i.e., a new supercapacitor cell/module). The unit of SOH is expressed as a percent number (e.g., 100% means the supercapacitor cell's condition match all nominal manufacturer specifications).

Concept of Operations (CONOPS). A CONOPS is a user-oriented document that describes system characteristics for a proposed system from the user's viewpoint. [IEEE 1362-1998]

9 Abbreviations and Acronyms

The following abbreviations and acronyms are applied to the terms used in this Guide:

ABS: American Bureau of Shipping

CMS: Capacitor Management System

CONOPS: Concept of Operations

DPS: Dynamic Positioning System

DVTP: Design Verification Test Procedures

EMI: Electromagnetic Interference

ESD:	Emergency Shutdown
ESR:	Equivalent Series Resistance
ESS:	Energy Storage System
IEC:	International Electrotechnical Committee
FFES:	Fixed Fire Extinguishing System
LEL:	Lower Explosive Limit
NFPA:	National Fire Protection Association
PMS:	Power Management System
PSTP:	Periodic Safety Test Procedure
SoC:	State of Charge
SoH:	State of Health
SOLAS:	Safety of Life at Sea
UL:	Underwriters Laboratories
UPS:	Uninterruptible Power Systems

11 References

11.1 ABS

ABS *Rules for Building and Classing Steel Vessels (Steel Vessel Rules)*

ABS *Rules for Building and Classing Mobile Offshore Drilling Units (MODU Rules)*

ABS *Rules for Building and Classing Offshore Support Vessels (OSV Rules)*

ABS *Rules for Building and Classing Facilities on Offshore Installation (Facilities Rules)*

ABS *Guide for Dynamic Positioning Systems*

ABS *Guide for Use of Lithium Batteries in the Marine and Offshore Industries*

ABS *Guidance Notes on Alternative Design and Arrangements for Fire Safety*

ABS *Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries*

ABS *Guidance Notes on Failure Mode and Effects Analysis (FMEA) for Classification*

ABS *Advisory on Hybrid Electric Power Systems*

11.3 IEC Standards

IEC 62391-1 *Fixed electric double-layer capacitors for use in electric and electronic equipment – Part 1: Generic specification*

IEC 62391-2 *Fixed electric double-layer capacitors for use in electronic equipment – Part 2: Sectional specification – Electric double layer capacitors for power application*

IEC 62391-2-1 *Fixed electric double-layer capacitors for use in electronic equipment – Part 2-1: Blank detail specification – Electric double-layer capacitors for power application – Assessment level EZ*

IEC 62576 *Electric double-layer capacitors for use in hybrid electric vehicles – Test methods for electrical characteristics*

IEC 60812 *Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA)*

11.5 Other References

UL 810A: *Standard for Electrochemical Capacitors*

NFPA 70: *National Electrical Code 2017: Article 706 Energy Storage Systems*

11.7 Alternative Standards

Supercapacitor systems for which there are specific requirements in this Guide may comply with the requirements of alternative standards, in lieu of the requirements in the Guide, subject to such standards being determined by ABS as not less effective than the Guide. Where applicable, requirements may be imposed by ABS in addition to those contained in the alternative standard to meet the intent of the Guide. In all cases, the supercapacitor system is subject to design review, survey during construction, tests, and trials, as applicable, by ABS to verify compliance with the alternative standard.

13 Data and Plans to be Submitted

13.1 General

At a minimum, the following drawings and data are to be submitted to ABS for review.

13.3 Supercapacitor System Submissions

i) Supercapacitor system installation arrangement and associated drawings and information (i.e., load leveling service, backup power, essential service, main source of electric power, etc.)

ii) Supercapacitor System Functional Description Document (FDD), including the Supercapacitor System, that coordinates with high level schematic drawings that depict operating configurations, topology, switching

iii) Supercapacitor system capacity calculation for intended application

iv) Supercapacitor System Risk Assessment Report (e.g., Failure Modes and Effects Analysis (FMEA)) and the associated sea-trial/commissioning safety procedures (e.g., Design Verification Test Procedures (DVTP) and Periodic Safety Test Procedures (PSTP))

v) Supercapacitor system design basis and technical specifications that show power system parameters for each operating configuration and topology during steady state operation, switching, and fault conditions. Additionally, the design basis is to show power flows, energy storage, energy storage levels, etc., between all elements of the power system and the Supercapacitor System.

vi) Supercapacitor system electrical schematic drawings (block diagram with system interface) such as electrical one line diagram that depicts the electrical power system and the point of coupling of the Supercapacitor System

vii) Ventilation arrangement of supercapacitor space including fire dampers, emergency shutdown from outside space

viii) Environmental control arrangement, if applicable (temperature sensors, air conditioning unit)

ix) Fixed fire extinguishing system (FFES) arrangements, details, and validation of suitability for the supercapacitor chemistry involved

x) Fire detection and alarm system arrangement

xi) Detailed stage-by-stage Fire Fighting Procedure/CONOPS

xii) Combustible gas detection and alarm system arrangement

xiii) Structural fire protection details

xiv) Emergency shutdown (ESD) arrangement

xv) Load analysis, covering all operating conditions of the vessel, such as conditions in normal seagoing, cargo handling, harbor maneuvering, dynamic positioning, and emergency operation *xvi)* Supercapacitor installation/mounting arrangement and associated drawings and information. This is to include supercapacitor cells/modules weights, weight of the supercapacitor cabinets and connection details between supercapacitor cabinets and deck and/or bulkhead structure

xvii) Test reports, in accordance with Subsection 3/1, including all supercapacitor system components (i.e. supercapacitor cell/module, CMS, charger/converter).

xviii) Supercapacitor system sea-trial/commissioning procedures

xix) Operations and Maintenance manual for supercapacitor system (supercapacitor cell/module, charger/converter, and CMS)

xx) Supercapacitor system Maintenance schedule

13.5 Supercapacitor Cell/Module Submissions

i) The intended use of the supercapacitor cell/module

ii) Material Safety Data Sheets (MSDS)

iii) Standards to which the supercapacitor cell/module is tested

iv) The supercapacitor cell/module environmental operating envelope (i.e., pressure, temperature, humidity, vibration and inclination)

v) The supercapacitor cell/module specifications and characteristics (i.e., capacity/stored energy, rated voltage, capacitance, rated ESR, short circuit current, number of cells/modules, mass, IP rating, cooling method, shell life, design cycle life, etc.)

vi) Drawings that depict the construction of the supercapacitor module, including: capacitor cell, cell interconnections, cell and module polarities, capacitor module enclosure, external power connections, external measurement connections, module pressure relief, temperature sensors, voltage sensors, sensor cable connections, and other ancillary components

vii) Details of the provision available for prevention of electrolyte spills in the case of cell pressure relief valve open or capacitor cell accidental puncture. Handling procedure for released electrolyte is to be provided.

viii) Details confirming the capacitor module casing is constructed of a flame-retardant material

ix) Details of the pressure safety valve or other means of explosion protection (weak point) included in the supercapacitor cell design

x) Schematic drawings that depict the internal and external power, instrumentation, control, and communication systems of the capacitor module

xi) Maintenance schedule and procedures of supercapacitor cell/module replacement and details of proper custody chain of replaced/failed supercapacitor cells/modules

13.7 Capacitor Management System (CMS) Submissions

The CMS Functional Description Document (FDD) may include the following items:

i) The intended use of the CMS

ii) Block diagram of the CMS

iii) Functional description of the hardware and software included with a list of units which contain upgradeable software

iv) Functional description of the different operating modes and description of the parameters settings list for all operator visible modes of the capacitor modules

v) Safety philosophy of the CMS

vi) Functional description of the communication interfaces between the capacitor cells/modules, internal bus communication, monitoring devices, operator visible signals, warning signals, and error signals

vii) Details of the supercapacitor cell/module voltage balancing, including balancing circuit and strategy (e.g., cell voltage difference eliminating time length)

13.9 Supercapacitor Charger and/or Converter Submissions

The supercapacitor charger and/or converter technical specification may include the following items:

i) Intended use of the capacitor charger/converter

ii) Description documents showing the charger/converter is suitable for its intended service conditions (e.g., frequent operation without causing overheating conditions) for its intended design life.

iii) Capacitor charger/converter operating envelope (i.e., pressure, temperature, humidity, vibration and inclination)

iv) Capacitor charger/converter specifications and characteristics (i.e., voltage, current, power, duty cycle, etc.)

v) Standards to which the capacitor charger/converter is designed, constructed and tested

vi) Block diagram of the capacitor charger/converter

vii) Functional description document for the capacitor charger/converter, and the hardware and software included with a list of units which contain software which is capable of being modified following installation

viii) Electrical schematics of the capacitor charger/converter

ix) Functional description of the different operating modes and description of the parameters setting list for all operator visible modes

x) Safety philosophy of the charger/converter

xi) Functional description of the communication interfaces between the capacitor charger/converter and CMS

15 Onboard Documentation

15.1 General

At a minimum, the following drawings and data are to be kept on board for easy reference by the crew during maintenance or repair:

i) Operations and Maintenance Manual for Supercapacitor System (supercapacitor cell/module, capacitor charger/converter, and CMS)

ii) Supercapacitor System Maintenance Schedule

iii) Detailed stage-by-stage Fire Fighting Procedure/CONOPS

SECTION 2 Supercapacitor System Design and Construction

1 Supercapacitor System

1.1 General

The provisions of this Section apply to vessel supercapacitor energy storage systems. The supercapacitor system is to compliment the electric propulsion, the main electrical generating source, and the emergency power source. The vessel electrical system is to be so arranged that, in the event of the loss of the supercapacitor system in service, the electrical supply to equipment necessary for propulsion and steering and for the safety of the vessel will be maintained or restored in accordance with the provision in 4-8-2/3.11.2 or 4-8-2/3.11.3 of the *Steel Vessel Rules*.

1.1.1 Certification Details

TABLE 1
Certification Details – Supercapacitor System Components

Supercapacitor System Components	*ABS Type Approval Tier (See 1-1-A4 of ABS Rules for Conditions of Classification)*	*Guide Reference*
1. Supercapacitor Cells/Modules	4/5	2/3, 3/1.1, 3/1.3
2. Supercapacitor Chargers	4/5	2/5, 3/1.5
3. Supercapacitor Management Systems	4/5	2/7, 3/1.5
4. Supercapacitor Converters	2	2/5, 3/1.5

1.3 System Arrangement

1.3.1 Supercapacitor Systems Capacity

The supercapacitor system is to have sufficient capacity to provide the intended services as designed. The voltage drop produced by its charging current will not cause any unstable situation of the remaining electrical network. The charging current of the supercapacitor system may be supported by all of the installed generators or shore supply, provided arrangements are made such that its charging process is conditional upon the requisite generators being available and that it will not cause inadvertent load shedding.

The discharging process of the supercapacitor with other electrical generating sources connected in parallel will not cause any overload or overvoltage condition in the rest of the electrical network. The supercapacitor system during the discharging process may supply power with other generators connected online, provided that it will not cause any generator overspeed.

1.3.2 System Connection

The supercapacitor system may be connected with the vessel electrical system with the following configurations:

- Direct connection with DC switchboard,
- Connection with DC switchboard through a DC/DC converter,
- Connection with AC switchboard through a DC/AC inverter

The transformer may be installed between the supercapacitor system and vessel switchboard, which is not covered in this Guide. The transformers for the supercapacitor system are to be in accordance with 4-8-3/7 of the *Steel Vessel Rules*.

1.3.3 Use of Supercapacitor System in Port

Unless instructed otherwise by the flag Administration, the supercapacitor system may be used during lay time in port for supplying power to the vessel standalone or with other onboard power sources.

1.5 Supercapacitor System Used as Emergency/Transitional Source of Power

1.5.1 Location

If the supercapacitor system is used in conjunction with another emergency power source (e.g., emergency diesel generator), it should not be located in the same space as the emergency power source. Both spaces are to be readily accessible and as near as practical.

If the supercapacitor system is installed for starting the emergency generators, these devices are to be installed in the same space as the emergency generators.

1.5.2 Emergency Services

The supercapacitor system is not to be considered as the sole source of emergency electrical power.

Where the supercapacitor system is used as part of the emergency source of electrical power, it is to be capable of:

i) Automatically connecting to the emergency switchboard in the event of failure of the main source of electrical power

ii) Immediately supplying the services it is designed to supply

ii) Carrying the emergency electrical load without recharging while maintaining the load input voltage within the equipment design limitation

For other requirements for the supercapacitor system used as part of emergency/transitional source of power, unless specified above, see 4-8-2/5 of the *Steel Vessel Rules* as applicable, with particular attention on the duration requirements of the emergency/transitional services.

1.5.3 Use of Supercapacitor in UPS

If the supercapacitor cells/modules are used as energy storage device in shipboard UPS, they are to be in accordance with 4-8-3/5.9 of the *Steel Vessel Rules*, as applicable.

1.7 System Protection

1.7.1 Protection for Supercapacitor System

Supercapacitor systems, other than engine starting supercapacitor systems, are to be protected against overload and short circuits by devices placed as near as practicable to the supercapacitor cells/modules. The charging equipment for all supercapacitor cells/modules, except rectifiers, is to be provided with reverse current protection. Engine starting supercapacitors are to be installed in the same space where the engine is installed, and are to be located close to the engine.

Circuit breakers, fuses and disconnecting devices for the supercapacitor system are to be in accordance with 4-8-3/5.3 of the *Steel Vessel Rules*, as applicable.

1.7.2 Protection for Personnel

i) Warning labels informing the user of the dangers of working with the different parts of the supercapacitor system are to be placed at all appropriate places of the assembly.

ii) Arrangements (e.g., interlock mechanism) are to be provided for preventing personnel from electrical shock during normal operation, maintenance, testing, repairing and replacement.

iii) Arrangements are to be made for the safe discharge of isolated supercapacitors.

iv) Insulated handrail or insulated handles are to be provided for each front panel of the supercapacitor system. Where access to the rear is required, insulated handrails or insulated handles are to be fitted to the rear of the supercapacitor racks/packs as well.

1.9 Shore Connection

1.9.1 General

The supercapacitor system may be charged by either shore connection or onboard power source. The interlock requirements refer to 4-8-2/11.1.2 of the *Steel Vessel Rules*.

1.9.2 Instrumentation

An indicator light is to be provided at the supercapacitor management system (CMS) to which shore power is connected showing the energized status of the supercapacitor system. Means are to be provided for confirming the polarity of incoming supply in relation to the supercapacitor system.

1.11 Control, Monitoring, Alarm and Safety Systems

i) Control, monitoring, and safety systems are to have the ability to self-monitor. In the event of failure to the systems or power supply, an alarm is to be activated.

ii) The safety system is to be designed so as to limit the consequence of failures. It is to be constructed upon the fail-safe principle.

iii) Sensors for safety functions are to be independent from sensors used for other purposes (e.g., for alarm systems).

iv) The sensors are to be designed to withstand the local environment. The enclosure of the sensor and the cable entry are to be appropriate to the space in which they are located. Any malfunctioning in the sensors is to be detectable and is not to cause supercapacitor system failure.

v) The supercapacitor system is to be designed such that it can be remotely disconnected from the main and/or emergency electrical network by motor control center/bridge.

1.13 Emergency Shutdown Arrangement

The supercapacitor system is to be fitted with an emergency shutdown mechanism adjacent to but outside the supercapacitor space. The emergency shutdown circuit is to be hardwired and independent of any control, monitoring, and alarm system circuits. If the supercapacitor system is used to provide power for propulsion and steering of the vessel, there should be an additional emergency shutdown arrangement at the propulsion control station.

1.15 Ambient Temperatures

i) All components of the supercapacitor system are to be designed according to the expected operating temperature.

ii) The temperature rating of the supercapacitor system is to be in consistent with 4-8-3/1.17 of the *Steel Vessel Rules*. Where if the supercapacitor system is installed in the environmentally-controlled space with reduced ambient temperature, the supercapacitor system is not to be used for emergency services.

iii) If the supercapacitor system is to be used in the environment with expected temperatures below the supercapacitor cell electrolyte freezing point, a thermal management system is to be provided for the low temperature operation.

iv) If the supercapacitor cells/modules are exposed to high temperatures for periods of time exceeding manufacturer specifications, a means is to be provided such that the degraded supercapacitor cells/modules are identified for replacement or proper maintenance purpose.

1.17 Integration

In cases where the supercapacitor system is integrated into the shipboard power/energy management system that has other subsystems and components, the integration tests of the whole system are to be carried out in accordance with relevant portions of the ABS Rules and manufacturer requirements.

3 Supercapacitor Cells/Modules

3.1 General

In general, supercapacitor cells and modules are to be designed, constructed, and tested to a national, international, or other recognized standard and in accordance with requirements of this section.

3.3 Enclosure and Casing

i) Enclosures and assemblies are to be constructed of steel or other suitable noncombustible, moisture-resistant materials and reinforced as necessary to withstand the mechanical, electromagnetic, and thermal stresses which may be encountered under both normal and short-circuit fault conditions.

ii) Enclosures are to be of the closed type. The supercapacitor module enclosures are to have a degree of protection not lower than IP44.

iii) The exposed supercapacitor cell/module casing is to be constructed of durable, flame-retardant, moisture resistant materials, which are not subject to deterioration in the marine environment and at the temperatures to which it is likely to be exposed.

iv) The casings of a supercapacitor cell, module, and rack are to be provided with pressure-relief mechanisms/arrangements to prevent rupture or explosion due to overcharging, overvoltage, overheating, etc. The individual supercapacitor modules are also to have arrangements to prevent corrosion caused by spilling of electrolyte after the internal cell pressure-relief mechanism is activated. If spilling or release of the internal electrolyte is inevitable, a proper handling procedure is to be followed to clean up the releases to prevent structure corrosion or personnel injury.

3.5 Cooling and Prevention of Condensation

i) Where water cooling is used, the cooler is to be so arranged to avoid entry of water into the supercapacitor cells/modules, whether through leakage or condensation in the heat exchanger.

ii) Supercapacitor cells/modules are to be provided with a means to prevent moisture condensation in the enclosure.

3.7 Nameplate Data

Any corrosion-resistant material is to have a nameplate indicating at least the following, as applicable:

- Manufacturer’s serial number (or identification mark)
- Manufacturer's name
- Year of manufacture
- Model
- Mass
- Degree of protection by IP code
- Rated capacity
- Rated voltage
- Rated operating temperature range
- Shelf life

3.9 Cell Connection

3.9.1 Bus-bar Type

If the cell connections of are of the bus-bar type, the bus bars are to be sized and arranged such that any temperature rise will not affect the normal operation of the connected supercapacitor cells/modules.

The bus bars are to be mounted, braced, and located so as to withstand thermal effects and magnetic forces resulting from the maximum prospective short-circuit current.

Bolted bus bar connections are to be suitably treated to avoid deterioration of electrical conductivity over time. Nuts are to be fitted with the means to prevent loosening.

3.9.2 Cables

Soldered connections are not to be used for connecting or terminating any cable of 2.5 mm^2 (0.0039 in^2) or greater. These connections are to be made by the use of crimp lugs or equivalent.

3.11 Supercapacitor Cell Life

The supercapacitor cell/module is to be replaced or properly maintained after its lifetime is reached.

Note: The lifetime of a single supercapacitor cell is defined as a 20% decrease in capacitance and/or 100% increase in resistance due to deterioration.

3.13 Supercapacitor Cell/Module Polarity

The supercapacitor cells/modules are to be installed, replaced, and maintained with consistent polarity. A means to detect reverse voltage is to be provided for incorrect polarity installation.

5 Supercapacitor Chargers/Converters

i) Where the supercapacitor system is connected to a single charger/converter and is the sole means of supplying DC power to equipment for essential services as defined in the *Steel Vessel Rules*, or are used for battery starting systems in 4-8-2/11.1 of the *Steel Vessel Rules*, the supercapacitor chargers/converters are to be in accordance with 4-8-2/3.7 of the *Steel Vessel Rules*, as applicable.

ii) The supercapacitor charger/converter is to operate under the operation modes (i.e., charging and discharging, disabling charging current) set in the CMS as specified by the supercapacitor cells/modules and CMS manufacturer.

iii) The supercapacitor charger/converter is to be designed to maintain charging/discharging within the voltage, current, and temperature limits for the supercapacitor cells/modules as specified by the supercapacitor cells/modules and CMS manufacturer.

iv) The supercapacitor charger/converter is to be interfaced with, and controlled by, the CMS or higher system level control and monitoring systems.

v) The supercapacitor charger/converter is to be designed for the intended service environment in accordance with the test requirements in Section 3, Table 3.

7 Capacitor Management System

7.1 General

i) The supercapacitor system is to have a capacitor management system (CMS).

ii) The CMS is to, at a minimum, monitor the supercapacitor cell voltage, cell temperature, supercapacitor string current, and module voltage.

iii) The CMS is to be continuously powered and an alarm is to be given in the event of failure of the normal power supply.

iv) The following conditions are to result in an individual or group audible and visual alarm to be displayed in a continuously manned location:

a) Cell overvoltage

b) High ambient temperature

c) Cell voltage unbalance

d) Cell over-temperature

e) Supercapacitor module/pack ground fault

f) Communication failure with the Power Management System of the vessel

g) Tripping of mechanism that provides electrical isolation

h) Failure/shutdown of the supercapacitor system or failure of any of the individual modules

i) Reverse polarity charging current

j) State of charge of the supercapacitor system below preset lower limitation

k) Cooling system temperature for supercapacitor module/pack and/or supercapacitor charger/converter higher than preset higher limitation

l) Ventilation system failure

m) Supercapacitor cells internal short circuit

v) The CMS is designed to disable the charging current input to prevent further damage to the system if the supercapacitor cell/module exceeds overvoltage and/or over-temperature limits.

vi) The CMS is to adjust the supercapacitor operating voltage at high ambient temperatures to prevent over-temperature condition.

vii) The CMS is to comply with the requirements in Section 4-9-3 of the *Steel Vessel Rules*. The appropriate computer-based system category for the CMS is to be assigned in accordance with 4-9-3/7 of the *Steel Vessel Rules*. The CMS is to be considered as a computer-based system with system Category II or III. The exact category is dependent on the risk assessment for all operational scenarios (e.g., intended use for the supercapacitor system). The relevant software design requirements and ABS Surveyor witness requirements for Category II or III systems are to be complied with.

viii) The safety system is to be activated automatically in the event of identified conditions that could lead to damage of the supercapacitor system. Activation of any automatic safety action is to trigger an alarm in a continuously manned location.

ix) A software-based feature/mechanism is to be installed to prevent the crew from overriding or ignoring CMS alarms and shutdown as listed in 2/7.1iv). Manual override of safety functions is not permitted.

x) If the supercapacitor system is used as emergency/transitional source of power, the CMS is to be provided with an independent power source in the case of loss of power supply from main generating source.

xi) As far as practicable, when the supercapacitor system has multiple parallel/series supercapacitor cells/modules, load sharing between the multiple supercapacitor cells/modules is to be distributed uniformly.

7.3 Voltage Balancing

i) Mechanisms to balance the voltage of the supercapacitor cells and modules are to be provided in the CMS.

ii) An automatic voltage balancing circuit is to be fitted for each supercapacitor cell/module, as applicable. The balancing circuits are not to derive their source of power from the cells/modules being controlled.

iii) The voltage balancing strategy employed by the CMS is to be suitable for the supercapacitor cells/modules controlled by the CMS.

iv) Reverse voltage protection is to be provided for unbalanced supercapacitor cell/module voltages when the supercapacitor system is discharging.

Note: The mixing of aged and new cells/modules is not recommended as there may be a large difference between old and new supercapacitor capacitance and ESR which may impact the CMS balancing performance.

7.5 Power Management System

i) The vessel Power Management System (PMS) is to be provided as per 4-8-5/5.3.3 of the *Steel Vessel Rules* or 4-3-5/3.3.3 of the *MODU Rules*.

ii) The CMS is to be controlled/supervised and coordinated by the PMS.

iii) The CMS is to be compatible with the computer operating system of the PMS.

SECTION 3 Supercapacitor System Testing and Installation

1 Supercapacitor System Testing Requirements

1.1 Supercapacitor Cell Tests and Measurement

The supercapacitor cell is to undergo Type Tests and Routine Tests carried out to the satisfaction of attending ABS Surveyors as per Section 3, Table 1. Type Tests are to be carried out on one prototype while the Routine Tests are to be carried out on all supercapacitor cells, as per the test procedure in the respective standard/section given.

TABLE 1
Summary of Type and Routine Tests and Measurement for Supercapacitor Cells

No.	*Test*	*Type Test*	*Routine Test*	*Reference*
1	Drop test	x		ISO 16750-3
2	Vibration test	x		UL 810A/ISO 16750-3
3	Shock test	x		UL 810A/ IEC 60068-2-27,-29
4	Impact test	x		UL 810A
5	Crush test	x		UL 810A
6	Heating test	x		UL 810A
7	Abnormal charge test	x		UL 810A
8	Short circuit test	x		UL 810A
9	Dielectric voltage-withstand test	x		UL 810A
10	Termination test	x		UL 810A
11	Visual examination and check of dimensions		x	IEC 62391-1
12	Endurance test	x		IEC 62391-1
13	Characteristics at high temperature and low temperature	x		IEC 62391-1
14	Pressure relief (if applicable)	x		IEC 62391-1
15	Capacitance, internal resistance, and maximum power density		x	IEC 62576
16	Voltage maintenance characteristics		x	IEC 62576
17	Energy efficiency		x	IEC 62576

1.3 Supercapacitor Module Tests and Measurement

The supercapacitor module is to undergo Type Tests and Routine Tests carried out to the satisfaction of attending ABS Surveyors as per Section 3, Table 2. Type Tests are to be carried out on one prototype while the Routine Tests are to be carried out on all supercapacitor modules, as per the test procedure in the respective standard/section given.

TABLE 2
Summary of Type and Routine Tests and Measurement for Supercapacitor Modules

No.	*Test*	*Type Test*	*Routine Test*	*Reference*
1	Vibration test	x		UL 810A/ISO 16750-3
2	Shock test	x		UL 810A/ IEC 60068-2-27,-29
3	Crush test	x		UL 810A
4	Heating test	x		UL 810A
5	Abnormal charge test	x		UL 810A
6	Short circuit test	x		UL 810A
7	Dielectric voltage-withstand test	x		UL 810A
8	Termination test	x		UL 810A
9	Endurance test	x		IEC 62391-1
10	Capacitance, internal resistance, and maximum power density		x	IEC 62576

1.5 Supercapacitor Charger/Converter and Management System Tests and Measurement

The supercapacitor charger/converter and management system are to undergo Type Tests and Routine Tests carried out to the satisfaction of attending ABS Surveyors as per Section 3, Table 3. Type Tests are to be carried out on samples while the Routine Tests are to be carried out on all supercapacitor management systems, as per the test procedure in the respective standard/section given.

TABLE 3
Summary of Tests for Supercapacitor Chargers/Converters and CMS

No.	*Test*	*Type Test*	*Routine Test*	*Reference*
1	Type test for control, monitoring and safety equipment	x		4-9-8/Table 1 of the *Steel Vessel Rules*
2	Unit Certification tests for control, monitoring and safety equipment		x	4-9-8/Table 2 of the *Steel Vessel Rules*
3	Supercapacitor system and CMS safety function tests		x	2/1 and 2/7 of this Guide
4	Rated Load Test and Temperature Rise Measurements		x	See Note 1

Notes:

1 Rated Load Test and Temperature Rise Measurements. The temperature rises are to be measured after being charged and discharged at the output, voltage, operation frequency, and duty.

2 The supercapacitor system may comply with requirements in an alternative standard provided it has been determined by ABS as being not less effective. Where applicable, requirements may be imposed by ABS in addition to those in the alternative standard so that the intent of the Rules is met.

3 Supercapacitor Space

3.1 General

i) The supercapacitor space is not to be located forward of the collision bulkhead of the vessel. Special cases may be considered for powering loads located forward of the collision bulkhead.

ii) Supercapacitor spaces are not to contain any heat sources or high fire risk objects.

iii) The supercapacitor system location and arrangement plan should clearly show the supercapacitor modules/packs with respect to the space they are being installed in as well as the clearance of distances between any other equipment in the room and the supercapacitor modules/packs.

iv) The supercapacitor space is to be fitted with flammable gas detection, appropriate to the supercapacitor chemistry being used. The gas detection is to give an alarm at a continuously manned location and automatically disconnect the supercapacitor system if the concentration of gas in the supercapacitor space reaches 30% LEL. Alternatively, the electrolyte design must rule out the possibility of exceeding the LEL requirement above.

v) The supercapacitor space is to be designed and arranged to provide accessibility to parts requiring inspection or adjustment.

vi) The supercapacitor space is not to contain any equipment (including cables and pipes) supporting essential services as defined in 4-8-1/7.3.3 of the *Steel Vessel Rules* or 4-1-1/3.5 of the *MODU Rules*, so as to prevent loss of such essential services in the event of a supercapacitor incident.

Where pipes routed in the vicinity of the supercapacitor system cannot be avoided, such piping is to be of all welded joints or means are to be provided to prevent any joint leakage under pressure to impinge on the supercapacitor system.

3.3 Fire Safety

i) The supercapacitor space is to be considered an Auxiliary Machinery Space or a Machinery Space other than Category A as defined in SOLAS Regulation II-2, and is subject to the structural fire protection requirements listed herein.

ii) The supercapacitor space is to be fitted with a suitable Fixed Fire Extinguishing System (FFES) recommended by the supercapacitor manufacturer and appropriate to the supercapacitor cell electrolyte chemistry. A fixed system is to have provisions (i.e., selection of proper metallic material for nozzles, grounding methods) to prevent a buildup of static electricity at the nozzle during release of the extinguishing agent. The FFES is to comply with the provisions of Part 4, Chapter 7 of the *Steel Vessel Rules* or Part 5 of the *MODU Rules*, to the extent applicable, and is to adequately consider the potential fire loads involved (e.g., size and number of the supercapacitor cells/modules, supercapacitor cell electrolyte chemistry, etc.). Technical validation of the FFES is to be carried out in accordance with the procedures outlined in the ABS *Guidance Notes on Alternative Design and Arrangements for Fire Safety*, and sufficient documentation to verify the same is to be submitted for review along with arrangements and details of the FEES.

iii) Portable fire extinguishing facilities are to be provided as required in 4-7-2/1.7 of the *Steel Vessel Rules* or 5-2-4/1 of the *MODU Rules*. Proper PPE and fire suppression instructions are to be provided according to the supercapacitor cells/modules material safety data sheet (MSDS).

iv) The supercapacitor space is to be provided with a fume-tight door to prevent escape of combustible gases and a deck drain, and is not to be adjacent to spaces with combustible/flammable materials, berthing compartments, or machinery spaces of Category A, except for emergency generator starting capacitors located in a space adjacent to the emergency generator.

3.5 Ventilation

A ventilation system is required in the supercapacitor system space. The ventilation system is to have sufficient air exchange capacity as defined by the vendor:

i) The ventilation system is to vent the smoke out of the supercapacitor space after a fire has been suppressed.

ii) The ventilation system during smoke venting is not to affect the normal operation of the vessel (i.e., helideck, as applicable) or crew safety.

3.7 Environmentally-Controlled Space

Where the supercapacitor system installed in an environmentally-controlled space, it is to be in accordance with 4-8-3/1.17.2 of the *Steel Vessel Rules*, as applicable.

3.9 Hazardous Area Requirement

Depending on the supercapacitor design and chemistry, flammable gases may be released from the sealed casing during abnormal operation (i.e., overcharging, heating). The supercapacitor space may be considered as a hazardous area on a case-by-case (size, number of cells, chemistry) basis. If the supercapacitor space is classed as a hazardous area, the following requirements are to be met as a minimum:

i) The Operations and Maintenance Manual is to list hazardous gases likely to be released.

ii) The equipment selection is to comply with applicable requirements in 4-8-4/27 of the *Steel Vessel Rules* or Section 4-3-6 of the *MODU Rules*.

iii) The hazardous area plan and related electrical equipment list for the supercapacitor space is to be part of the overall hazardous area plan for the asset.

iv) The supercapacitor space is to have an independent deck drain or no deck drain at all.

5 Supercapacitor System Risk Assessment

The primary objective of the risk assessment is to identify technical risks and uncertainties associated with the proposed supercapacitor system design and its incorporation on a vessel. The risk assessment is to demonstrate the vessel safety and the continuity of power supply in case of failure of the supercapacitor.

A Failure Mode and Effects Analysis (FMEA) is typically used but alternatively other risk assessment techniques may also be used. The use of other risk assessment techniques should be discussed with ABS prior to performing the risk assessment. The risk assessment is to be carried out in accordance with ABS *Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries*, ABS *Guidance Notes on Failure Mode and Effects Analysis (FMEA) for Classification* or other ABS-recognized industry standards (e.g., *IEC 60812*).

All foreseeable hazards, their causes, consequences (local and global effects), and associated risk control measures are to be documented. The supercapacitor system risk assessment report is to be submitted for review, and at a minimum, is to address the following issues:

i) Appropriate measures taken into account for external hazards (i.e., possible fire, gas development, flood, etc.)

ii) Potential hazards introduced by the supercapacitor system to the vessel

iii) Loss of communication with the asset's Power Management System (PMS), as applicable: Appropriate measures taken to isolate the supercapacitor system in the event of a communication failure with the PMS

iv) Inherently safer design implemented (usually by the CMS) for the safe operation of the supercapacitor system, redundancies in place, and communication protocols used

v) Temperature and/or voltage instrumentation failure

vi) Appropriate quality plan implemented by the manufacturer to identify manufacturing defects in individual components

vii) Failure due to abuse conditions:

- Overvoltage (loss of capacitance, increase in ESR, bulging, pressure-relief mechanism activating)
- Over temperature (loss of capacitance, increase in ESR, bulging, pressure-relief mechanism activating)
- Mechanical stress (deformation, broken lead, increase in ESR)

Notes:

1 There may be two risk assessments carried out in some cases. One performed by the supercapacitor vendor/manufacturer and the other by the shipyard/system integrator.

2 The shipyard/system integrator's risk assessment covers items *i), ii)* and *iii)*.

3 The supercapacitor vendor/manufacturer's risk assessment covers items *iv), v), vi)* and *vii)*.

7 Supercapacitor System Operation and Maintenance

7.1 Installation and Commissioning

The supercapacitor system installation and sea-trial/commissioning procedures submitted for review are to address the following:

i) Correct interface between the supercapacitor system and the DC-bus or supercapacitor charger/ converter, as applicable

ii) Testing of the following safety functions and associated alarms:

- Overvoltage detection/protection
- Undervoltage detection/protection
- Emergency shutdown arrangement
- Ground fault detection,
- Loss of communication detection/protection

iii) Testing of the expected performance functions of the supercapacitor system on the particular asset

iv) Testing of protective functions in the supercapacitor space, as applicable to asset specific installation

7.3 Operation and Maintenance

The supercapacitor system operations and maintenance manual submitted for review is to address normal and emergency operating procedures and maintenance procedures for the use of the supercapacitor system. The emergency procedures are to include those that should be taken in events such as fire, overheated supercapacitor cells/modules, etc.

A supercapacitor system maintenance schedule is to be provided for review and maintained on board. Refer to 4-8-4/5.1.5 of the *Steel Vessel Rules* or 4-3-3/3.7.5 of the *MODU Rules* for requirements related to the maintenance schedule.

After supercapacitor cells/modules replacement process finished, the degraded/damaged supercapacitor cells/modules are to be kept in a designated space when fully discharged, or otherwise be appropriately maintained in order to prevent damage to the asset or personnel.

The supercapacitor cells/modules stored onboard for replacement should be appropriately maintained and handled according to the storage and handling procedure/practices instruction provided by the supercapacitor cells/modules manufacturer.

SECTION 4 Supercapacitor System Surveys

1 General

The provisions in this Section are for any vessel fitted with supercapacitor systems and/or in order to maintain the **ESS-SC** notation. These requirements are in addition to the provisions noted in other ABS Rules and/or Guides, as applicable to the asset. See the ABS *Rules for Survey after Construction (Part 7)* or Part 7 of the *MODU Rules* for further detailed requirements.

3 Surveys during Construction

This Section pertains to surveys carried out on any vessel fitted with a supercapacitor system and/or with the **ESS-SC** notation during construction, installation, and testing of the asset at the builder's yard/facility, including required onboard testing and trials.

All surveys and testing listed in 3/7.1 of this Guide are to be carried out to the satisfaction of the attending Surveyor. The supercapacitor system is to be installed and tested in accordance with the Guide.

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

i) *Location and Arrangements.* The supercapacitor system is to be installed in accordance with the location and arrangement plan.

ii) *Testing.* The supercapacitor system testing is to follow the approved sea trial/commissioning procedures and is to include at least the following items:

- 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 the power management system
- Correct operation of ventilation, cooling, gas detection system, fire detection system, fire extinguishing system, etc., where provided

iii) *Ventilation and Environmental Control.* The supercapacitor space is to follow the approved ventilation arrangement and environmental control arrangement plan, including emergency ventilation system, as applicable.

iv) *Maintenance and Replacement.* A maintenance schedule and procedures for supercapacitor cells/modules replacement are to be provided and maintained onboard.

v) *Installation of the Supercapacitor System.* The installation of the supercapacitor system and associated cabinets are to be effectively secured to the surrounding structure to the satisfaction of the attending Surveyor.

5 Surveys after Construction

5.1 General

The supercapacitor system equipment is to be surveyed in conjunction with the Class required electrical system and equipment surveys.

5.3 Annual Surveys

For any vessel fitted with supercapacitor systems and/or in order to retain the **ESS-SC** notation, at each Annual Survey, the supercapacitor system is to be generally examined as far as practicable and verified to be placed in satisfactory condition.

The survey is also to include:

i) *Schedule of Supercapacitor Cells/Modules.* Details of the schedule and records for storage, maintenance, and replacement of supercapacitor cells/modules are to be verified.

ii) Verification Onboard Documentation:

- Operations and Maintenance Manual for Supercapacitor cells/modules, capacitor charger/ converter, and Capacitor Management System
- Supercapacitor System Maintenance Manual and Schedule
- Detailed stage by stage Fire Fighting Procedure

5.5 Special Periodical Surveys

The Special Periodical Survey is to include all items listed under the Annual Survey to the satisfaction of the attending Surveyor.

Measurements are to be taken to determine the level of supercapacitor degradation. The degradation level is to be within the acceptance range recommended by supercapacitor manufacturers.

The following tests are to be verified:

i) Emergency shutdown operation

ii) Simulation of communication failure with the power management system

APPENDIX 1 Commentary on Supercapacitors

1 General

Interested parties in the marine and offshore industries are currently exploring various shipboard energy arrangements (i.e., renewable energy, energy storage, hybrid systems) to increase energy efficiency and reduce emissions in response to increasingly restrictive environmental regulations. Supercapacitors, which have been widely applied to automotive, railway, and large grid applications, are being considered as an energy storage and electrical network optimization solution to be deployed on vessels and offshore installations.

In bidirectional energy exchange applications, supercapacitors may be initially charged to some fraction of their energy storage capacity, and then allowed to float on the electrical network, delivering stored energy when needed and absorbing excess or regenerative energy when available. Another application of supercapacitors is the delivery of stored energy to an electrical network when normal sources of power are not available. Although supercapacitors do not store as much energy as do batteries, they may be capable of delivering enough energy between an electrical network and a load to allow it to ride through a temporary interruption of normal electrical power until such time as another source of electrical power comes on line to assume the load.

Currently, supercapacitors are a leading energy storage choice in applications where a fast rate of charge or discharge is required or where the required cycle life is high (e.g., dramatic changes in electric loads due to environment disturbances which are foreseeable for those assets equipped with DPS under harsh sea conditions). Supercapacitors have excellent performance capabilities allowing for management of peak power and average power demands of power grids or acting as backups for primary energy supplies such as diesel generators, gas turbine generators, or fuel cells.

3 Supercapacitor Properties

3.1 Construction

The fundamental element of a supercapacitor system is the supercapacitor cell. It is within the cell that the non-Faradaic process takes place to absorb and release energy when charging and discharging.

The primary functional components of a commercial supercapacitor cell are:

- Porous electrodes (anode and cathode)
- Separator (ion-permeable membrane)
- Electrolyte
- Current collector
- Terminals
- Casing

3.3 Supercapacitor Electrical Characteristics

The voltage of supercapacitor cells decreases when they discharge their stored energy, whereas batteries can be discharged at a constant voltage.

Supercapacitor cells possess a trade-off between energy storage and voltage rating. The stored energy is directly proportional to the capacitance and the square of the applied voltage. The capacitance is directly proportional to the area of the electrodes and inversely proportional to the thickness of the dielectric. The voltage rating of the capacitor is related to the thickness of the dielectric. Keeping other parameters fixed, as the thickness of the dielectric layer decreases, the capacitance increases and the voltage rating of the capacitor decreases.

3.5 Supercapacitor Connections

In power applications where there is a need for energy storage at higher voltages, individual supercapacitor cells/modules can be combined in series to achieve the required terminal voltage, and strings of supercapacitor cells/modules can be combined in parallel to achieve the required energy storage and string current requirements.

5 Supercapacitor Use

5.1 Classes

International standards divide supercapacitors into five classes, according to the capacitance value and internal resistance value depending upon the application:

- Class 1: memory backup
- Class 2: energy storage
- Class 3: power
- Class 4: instantaneous power
- Class 5: high power

See IEC 62391-1 for classification details.

Supercapacitors can be generally used for the following applications in the marine and offshore industries:

- Additional/supplemental source of power (Class 2, Class 5)
- Emergency/transitional source of power (Class2, Class 3, Class 5)

Note: Supercapacitors have lower energy density compared to lithium batteries, which may not be suitable for long duration emergency services (e.g., emergency lighting supply).

5.3 Benefits

Some examples of the benefits of supercapacitors in different applications in the marine and offshore industries are:

i) When used for load leveling/peak-shaving, supercapacitors act as an energy buffer to supply/absorb power, which allows generators to be operated at a near constant load. Usage of supercapacitors can reduce maintenance on prime movers due to optimal loading and reduced running hours. With optimal loading, a higher average load can be maintained, resulting in a smoother and more stable operation of prime movers.

ii) Supercapacitors may be used in some instances as an additional power source in the case of generator shutdown.

iii) Supercapacitors may be used for blackout prevention, fault ride-through and blackout recovery in some instances.

iv) Supercapacitors may be used as part of an emergency source of power for essential and emergency services in some instances.

v) *Dynamic Positioning Vessels.* Supercapacitors may be used to supply thrusters and act as a buffer in DP mode and/or standby power for fault ride-through on DPS-2/DPS-3 vessels operating in closed bus. For DPS-2/DPS-3, redundancy criteria applies.

vi) *Bollard Pull.* Supercapacitors may be used for bollard pull in order to meet maximum required power on AHTS vessels.

vii) *Heave Compensation.* Supercapacitors may be used on MODUs or OSVs as a buffer for heave compensation equipment and to harvest regenerative power from cranes.

viii) *Renewable Energy Storage.* Supercapacitors may be used as an energy storage device on vessels/ offshore installations with cyclic renewable energy sources in order to stabilize the fluctuating power flow connected to the shipboard grid.

ix) Supercapacitors can also be installed with batteries as a combination which can protect the batteries from extreme peak loads, extending battery life and achieving both high-power density and high-energy density

x) *Low Temperature Environment Usage.* Supercapacitors may be used in low temperature environments, which constrains battery performance significantly.