GUIDE FOR

HYBRID ELECTRIC POWER SYSTEMS FOR MARINE AND OFFSHORE APPLICATIONS
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American Bureau of Shipping
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Foreword

ABS has developed a series of Guides for hybrid electric technologies (*Lithium Batteries Guide*, *Supercapacitor Guide*, *Fuel Cell Power Systems Guide*, *DC Power Distribution Guide*, etc.). With hybrid power systems in wide use in the marine and offshore industries, ABS provides Owners and Operators notations for different arrangements and configurations where electric power generation and energy storage technologies are used. This Guide focuses on the integration of those new technologies with conventional power generation to develop a hybrid electric power system (HEPS).

A HEPS utilizes multiple sources of power, both non-traditional sources (e.g. batteries, super-capacitors, fuel cells) and traditional sources (e.g. internal combustion engine driven generator sets, shaft generator driven by main engine). Technological developments are constantly being introduced for electric power systems. It is expected that in the future, other alternate electrical power sources such as solar panels, flywheels, and wind (electric) power systems will be mature enough for integration into the electric power generation systems onboard vessels. Vessels with such arrangements also incorporate specialized power and energy management systems that are relatively new in the industry. The application of HEPS onboard the vessel will serve to reduce NOx, SOx and CO_2 emissions.

Current trends in the yacht industry have also resulted in increased demand for hybrid electric installations. This Guide introduces requirements for the design, installation, and testing of HEPS on yachts.

The current edition of the ABS *Rules for Building and Classing Marine Vessels* and/or ABS *Rules for Building and Classing Mobile Offshore Units* are to be used in association with this Guide.

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 the Guide is the most current.

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

GUIDE FOR

HYBRID ELECTRIC POWER SYSTEMS FOR MARINE AND OFFSHORE APPLICATIONS

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SECTION **1** **General**

1 Introduction

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.

However, with current technological advances, an increasing number of options are now available to meet the specific needs of a vessel with a range of operational modes while meeting current and foreseen environmental regulations. 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.

This Guide provides requirements for the design, construction, testing and survey of vessels utilizing hybrid electric power systems.

3 Application and Scope

3.1 Application

This Guide is applicable to marine and offshore assets designed, constructed, or retrofitted with a hybrid electric power system. Where installed, the hybrid electric power system is to comply with the requirements in this Guide.

This Guide is intended for use in conjunction with recognized international /national codes and standards, as well as the latest edition of the ABS Rules, and/or applicable ABS Guides, as listed in 1/11.1.

3.3 Scope

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 integration of these conventional power generation and alternate power sources on a vessel or unit is also known as the Integrated Electric Power System (IEPS) for the purpose of this Guide.

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.

The unique requirements for the design, installation, and testing of HEPS on yachts are also addressed.

The scope of this Guide also encompasses HEPS with integration of lithium battery systems, supercapacitor systems, and fuel cell power systems as detailed in the applicable ABS Guides as referenced in 1/11.1.

5 Classification Symbols and Notations

5.1 Notations

5.1.1 Hybrid Notations for Marine and Offshore Vessels

Upon request, the following optional notations are offered for vessels installed with a hybrid electric power system.

i) **HYBRID IEPS** Notation

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.**

ii) Descriptive Letters for Operating Modes

Where a vessel is arranged to comply with 1/5.1.1i) above, and is also fitted with means to operate under one or more specific operating modes as identified in Section 3/Table 2, the vessel will be assigned the Class Notation **HYBRID IEPS** and **[descriptive letters, describing operating modes]**, e.g. **HYBRID IEPS [LEE], HYBRID IEPS [PMT]**, etc.

Notes:

1 The combination of two or more new technologies (e.g. ESS and Fuel Cells) when conventional generation is not installed on board also constitutes a HEPS; therefore, these vessels can have the **HYBRID IEPS** notation.

2 Internal combustion engine driven generator sets and shaft generators by themselves alone do not meet the criteria for HYBRID IEPS.

5.3 Notation Scheme Designation

The optional notation is organized as denoted in Table 1 below.

TABLE 1
Designation Scheme of Notations

Notation	*Enhanced Notation [operating mode]*
HYBRID IEPS	**HYBRID IEPS [descriptive letters, describing operating modes]**

Note:
Operating Modes: Low-Exhaust Emission **[LEE]**, Power Management **[PMT]**, Power Backup **[PBU]**, Power Take-Off/ Power Take-In **[PTO/PTI]**, Shore Connection **[SCN]**

7 Terminology

Battery Management System. An electronic system possessing a battery module/pack that can cut power 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. [*IEC 62619*]

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 an oxidation/reduction reaction of lithium between the negative electrode and the positive electrode.

Battery Module. A group of battery cells connected together in a series and/or parallel configuration with or without protective devices and monitoring circuitry. [*IEC 62620*]

Battery Pack. An energy storage device comprised of one or more cells or modules that are electrically connected. It has a monitoring circuitry that provides information to a battery system. [*IEC 62620*]

Battery System (Array). System comprised of one or more cells, modules, or battery packs. It has a battery management system to cut power in case of overcharge, overcurrent, over-discharge, and overheating.

Battery Space (Compartment). The space in which the battery system is physically located.

Conventional generation: Internal combustion engine-generator sets, and /or shaft generators (for the purpose of the use of this Guide).

Converter. A device that receives electrical energy with a set of input parameters and exports electrical energy with a different set of parameters.

Energy Management System (EMS). A computerized control system designed to regulate the energy consumption of a vessel by controlling and monitoring the operation of energy storage systems, electrical loads and the production of power. The system can monitor environmental and system loads and adjust operations in order to optimize energy usage, and respond to demand conditions. For the purpose of this Guide the EMS can also have similar functionalities as a PMS.

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

Energy Transformation Device (ETD). A device that converts energy from one form to another. The source energy may be renewable or stored. The transformation may be unidirectional or bidirectional. A fuel cell is a type of ETD.

Fuel Cell. (FC). A Fuel Cell is a source of electrical power in which the chemical energy of a fuel is converted directly into electrical and thermal energy by electrochemical oxidation.

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

Hybrid Electric Power System (HEPS). Hybrid-electric power systems combine 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.

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

Power Backup Mode. It is the operating mode where the energy storage system (ESS) is connected to the ship's electrical main or distribution system and is able to reliably provide power for a minimum period. This is also known as the spinning reserve mode. Operating a redundant diesel generator as spinning reserve provides availability of power in a failure condition. Running an extra engine creates a less

efficient, lower load condition with higher emissions. Providing this spinning reserve via stored energy, rather than an additional diesel generator, allows the electrical system to operate with fewer generators at higher load. The stored energy (lithium batteries) provide power in the event of a loss of generator until a standby generator can be started and connected to the power system.

Power Management System (PMS). A complete switchboard and generator control system which controls and monitors power generation and distribution including multiple switchboards and ring bus systems. The PMS on board a vessel is responsible for functions such as load sharing among different power sources, load shedding, and starting reserve generators when power is insufficient. For the purpose of this Guide the PMS can also have similar functionalities as an EMS.

Power Management Mode. This mode is designated when different load schedule strategies, functions, load control strategies such as load sharing and load shedding are met through the PMS installed onboard the vessel or unit.

Power Take-In (PTI) Mode. The shaft generator functions as an auxiliary motor working concurrently with the main diesel engine or independently for electric propulsion in this mode. This is also known as shaft motor mode. This mode provides propulsion power to the shaft which boosts the main engine with extra power or as an electric propulsion motor with the main engine clutched out or secured.

Power Take-Off (PTO) Mode. This operating mode takes the energy generated in the main engine as taken off by the shaft generator to produce electricity as an additional power source.

Rated Capacity. The capacity value of a cell or battery determined under specified conditions and declared by the manufacturer. [*IEC 62620*] Capacity is usually measured in Amp-hours (Ah).

State of Charge (SOC). Available capacity in a battery expressed as a percentage of rated capacity. [*IEC 62660-1*]

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

Low Exhaust Emission Mode. Operating mode when no internal combustion engine exhaust gas from the onboard sources of electric power is generated. The ESS and fuel cell power systems are examples of electric sources of power to feed loads in the ship's electrical power distribution system with near-zero exhaust emissions.

9 Abbreviations and Acronyms

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

ABS	American Bureau of Shipping
BMS	Battery Management System
BoD	Basis of Design
CMS	Capacitor Management System
DPS	Dynamic Positioning System
EG	Emergency Generator
EMS	Energy Management System
ESS	Energy Storage System
ETD	Energy Transformation Device

ETS	Energy Transformation System
ESD	Emergency Shutdown
FC-CMSS	Fuel Cell Control, Monitoring, Safety System
FC-PS	Fuel Cell Power System
GENSET	Diesel Generator or Generator together with Prime-mover
HEPS	Hybrid Electric Power System
IEC	International Electrotechnical Commission
IEPS	Integrated Electric Power System
IC	Internal Combustion
PEC	Power electronic converters
PMS	Power Management System
PTI	Power Take In
PTO	Power Take Off
SCMS	Supercapacitor Management System
SOC	State of Charge
SOLAS	*The International Convention on the* Safety of Life at Sea
UL	Underwriters Laboratories
UPS	Uninterruptible Power Systems

11 References

11.1 ABS

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

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

ABS *Guide for Building and Classing Yachts (Yacht Guide)*

ABS *Guide for Fuel Cell Power Systems for Marine and Offshore Applications*

ABS *Guide for Direct Current (DC) Power Distribution Systems for Marine and Offshore Applications*

ABS *Guide for High Voltage Shore Connection (HVSC Guide)*

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

ABS *Guide for Use of Supercapacitors in the Marine and Offshore Industries (Supercapacitor Guide)*

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

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

ABS *Guide for Dynamic Positioning Systems*

ABS *Guide for Comfort on Yachts*

11.3 IEC References

IEC 60079-10-1: *Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres*

IEC 60092-502: *Electrical Installations in Ships*

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*

IEC 62620: *Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes – Secondary Lithium Cells and Batteries for Use in Industrial Applications*

IEC 62660 Series: *Secondary lithium-ion cells for the propulsion of electric road vehicles*

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

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

IEC 62281: *Safety of primary and secondary lithium cells and batteries during transport*

IEC 62040-1: *Uninterruptible power systems (UPS) – Part 1-1: General and safety requirements for UPS used in operator access areas*

IEC 61800-5-1: *Adjustable speed electrical power drive systems: Safety Requirements – Electrical, thermal and energy*

IEC 60146-1-1: *Semiconductor converters – General requirements and line commutated converters – Specification of basic requirements*

11.5 Other References

IMO International Convention for the Safety of Life at Sea (SOLAS)

ISO 23274-1*: Hybrid-electric road vehicles — Exhaust emissions and fuel consumption measurements*

IMO International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code)

11.7 Alternative Standards

Hybrid electric power systems may comply with the requirements of an alternative standard, in lieu of the specific requirements in the Guide, provided such standards being determined by ABS as not less effective. Where applicable, other criteria may be imposed by ABS in addition to those in the alternative standard to meet the intent of the Guide. In all cases, the hybrid electric power systems are subject to design review, survey during construction, tests, and trials as applicable by ABS to verify compliance with the alternative standard.

13 Type Approval Program

Products that can be consistently manufactured to the same design and specification may be Type Approved under the ABS Type Approval Program. When approval of such products and components as part of the hybrid electric power system (HEPS) is requested, applicants should contact ABS for the approval process. For ABS Type Approval Program requirements, 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 and 2 & Appendix 2/ Table 1 of this Guide for certification details. Alternative certification arrangements are also available in 1-1-A3/5.5 of the ABS *Rules for Conditions of Classification (Part 1)*.

SECTION 2 Plans and Data to be Submitted

1 System documents and plans to be submitted

1.1 General

In general, for vessels using any combination of two or more the following power sources, documentation showing optimization calculations/ results for sizing the HEPS is to be submitted to ABS for review.

The combination can be conventional generation[1][2] and new technology, or two or more new technologies.

i) Internal combustion engine (Diesel/ dual fuel/gas) driven electric generators [1]

ii) Power Take-Off (Shaft Generators) [1]

iii) Fuel cells

iv) Lithium battery banks or

v) Other stored energy (e.g. supercapacitors)

In addition to the plans, specifications, ship arrangements, test plans, and data required to be submitted to ABS for review and approval as listed in 4-8-1/5 of the *Marine Vessel Rules*, drawings and data outlined below are to be submitted to ABS for review, as applicable:

Notes

Notes:

1 Conventional generation: internal combustion engine driven generator sets, and /or shaft generators.

2 Internal combustion engine driven generator sets and shaft generators by themselves alone do not meet the criteria for HYBRID_IEPS.

1.3 HYBRID IEPS Submissions

i) For general requirements for documentation related to battery power system design, see Subsection 1/13 of ABS *Guide for use of Lithium Batteries in the Marine and Offshore Industries (Lithium Batteries Guide)*.

ii) For general requirements for documentation related to supercapacitor power system design, see Subsection 1/13 of ABS *Guide for use of Supercapacitors in the Marine and Offshore Industries (Supercapacitor Guide)*.

iii) For general requirements for documentation related to fuel cell power system design, see Subsection 1/9 of ABS *Guide for Fuel Cell Power System for Marine and Offshore Applications (Fuel Cell Guide)*.

iv) A description of the PMS, including location and arrangement plan.

v) Arrangements, details, and location of the propulsion control consoles and or panels including schematic diagrams of the system therein.

vi) Arrangements and details of the semiconductor converter enclosure for propulsion system, where applicable, including cooling system with its interlocking arrangement.

vii) Risk assessment documentation (identifying risks associated with the design, installation, test and sea-trial/ commissioning, and safe operation of the electrical power system as new and conventional technologies are integrated onboard). See also Section 3/15.

viii) General Arrangement of power distribution system including energy storage system.

ix) Fuel consumption data in various operating modes, as applicable, for record .

x) Calculations for sizing energy storage system (ESS), e.g. battery selection, type and size, etc.

xi) Basis of design and or specifications of integration of control systems, EMS, PMS, BMS, SCMS, ESS, etc.

xii) Electrical one line diagram and schematics of propulsion control system for power supply, circuit protection, alarm, monitoring, safety, and emergency shutdown systems including list of alarm and monitoring points.

xiii) Operations and maintenance manual.

xiv) Test plans required for the testing listed in 5/1.7i.

xv) Commissioning Test Plan required by 5/1.7ii.

xvi) Fuel containment inspection plan required by 5/1.7iii.

xvii) Operating Mode Trials Plan required by 5/1.7iv.

xviii) Emergency shutdown (ESD) arrangement.

xix) Load analysis and balance, covering all operating conditions of the vessel, such as normal seagoing, cargo handling, harbor maneuvering, dynamic positioning, emergency operation, peak shaving, zero-emission, and any other operating mode as applicable

xx) Ventilation arrangement of energy storage space including fire dampers, emergency shutdown from outside space.

xxi) List of minimum alarms/displays and shutdowns as required in Section 3/Table 4.

xxii) Description of the operating modes of the components, equipment and systems and specific parameter values during each mode of operation as well as during transition from one mode to another, and during fault conditions.

xxiii) Details of piping system and components associated with the hybrid/ESS systems, where applicable.

xxiv) Manufacturer's recommendation regarding HEPS equipment’s service life and inspection cycles (e.g. ESS’, fuel cell’s, etc.). See 3/1.5.1.

xxv) Designer’s documentation (e.g. estimation/calculations) regarding HEPS equipment/system’s integration service life (e.g. ESS’, fuel cell’s, etc.) considering the overall configuration. See 3/1.5.1.

xxvi) Modeling, simulation, and the detailed results are to be submitted as applicable for review as required in 3/19.3 of this Guide.

xxvii) A list/booklet identifying all electrical equipment installed in the hazardous areas, as applicable.

1.5 HYBRID IEPS [Operating Mode] Submissions

In addition to 2/1.3 above, the following are to be submitted:

i) System arrangement and associated drawings and information for each operating mode as applicable.

ii) A list of any additional alarms, monitoring and safeguards for each operating mode as applicable.

iii) Overload and load shedding arrangement.

iv) Arrangements and details of shaft generator electric coupling/clutch, where applicable.

v) Control strategy and detail arrangements for the interconnection of ESS, FC, SC, and conventional generators (including shaft generator) for the different operating modes and operation profiles.

1.7 Yacht Submissions

i) Paragraphs 2/1.3 and 2/1.5 above as applicable.

ii) See also Appendix 2/3.

3 Certification

Hybrid electric power systems are to be certified in accordance with Section 2/Table 1 and Section 2/Table 2 below. This table also provides the applicability of the certification requirements for certain equipment and components as referred to in applicable Sections of the *Marine Vessel Rules and MOU Rules*. See also notes under this Table.

TABLE 1
Hybrid Electric Power System Certification(4)

System, Equipment, Component	*ABS Certification(1)*	*ABS Type Approval Tier (See Appendix 1-1-A4 of ABS Rules for Conditions of Classification)*	*Rule (Marine Vessel Rules) Reference*
Power Transformers for Essential Service and for Emergency Source Power and Convertors of Low Voltage		1	MVR 4-8-3/7, 4-8-3/8
Power Transformers and Convertors for High Voltage System	Required	5	MVR 4-8-5/3.7.5(e)
Non-Sparking Fans		2	MVR 4-8-3/11
Other Electrical Equipment	Required	1/2/4/5	MVR 4-8-3, 4-1-1/Table 3 as applicable
Other Rotating Machines	Required	1/2/4/5	MVR 4-8-3, 4-1-1/Table 3 as applicable
Propulsion Generators	Required	5	MVR 4-8-3/3, 4-1-1/Table 3, 4-8-5/5.17.5
Shaft Generators & Propulsion Motors (3)	Required	5	MVR 4-3-2/1.5, 4-8-3/3, 4-8-5/5.17.5
Pipe, Valves and Fitting	Required (2)	1/2/4/5	MVR 4-6-1, 4-1-1/Table 6 as applicable

Notes:

1) ABS Certification means plan review, and surveyors' attendance during construction and after installation to verify that a vessel, structure, item of material, equipment or machinery is in compliance with the Rules, Guides, standards or other criteria of ABS and to the satisfaction of the attending Surveyor.

2) Where indicated as 'required' in 4-6-1/Table 2 of the *Marine Vessel Rules*, the piping component is to be certified by ABS. This involves design approval of the component, as applicable, and testing in accordance with the standard of compliance at the manufacturer's plant. Such components may also be accepted under the Type Approval Program.

3) Shaft generators/motors used for power take-off, power take-in (propulsion boosters), or similar equipment, rated 100 kW (135 hp) and above are to be designed, constructed and tested (for both functionalities if applicable) in accordance with the appropriate requirements of the *Marine Vessel Rules.*

4) For units which are designed to the *MOU Rules* corresponding requirements of the *MOU Rules* are to be applied.

TABLE 2
Hybrid Electric Power System Certification

System, Equipment, Component	***ABS Certification[(1)]***	***ABS Type Approval Tier (See Appendix 1-1-A4 of ABS Rules for Conditions of Classification)***	***Guide Reference***
Battery System Components	Required	4/5	Section 2/Table 1 of *Lithium Batteries Guide*
Battery Chargers	Required	4/5	Section 2/Table 1 of *Lithium Batteries Guide*
Battery Management Systems	Required	4/5	Section 2/Table 1 of *Lithium Batteries Guide*
Supercapacitor Cells/ Modules	Required	4/5	Section 2/Table 1 of *Supercapacitor Guide*
Supercapacitor Chargers	Required	4/5	Section 2/Table 1 of *Supercapacitor Guide*
Supercapacitor Management Systems	Required	4/5	Section 2/Table 1 of *Supercapacitor Guide*
Supercapacitor Converters	Required	2	Section 2/Table 1 of *Supercapacitor Guide*
Fuel Cell Modules	Required	4/5	Section 1/Table 3 of *Fuel Cell Guide*
Fuel Cell Power System	Required[(2)]	4/5	Section 1/Table 3 of *Fuel Cell Guide*
Fuel Cell Control and Monitoring System	Required	4/5	Section 1/Table 3 of *Fuel Cell Guide*

Notes:

1) ABS Certification means plan review, and surveyors' attendance during construction and after installation to verify that a vessel, structure, item of material, equipment or machinery is in compliance with the Rules, Guides, standards or other criteria of ABS and to the satisfaction of the attending Surveyor.

2) Fuel cell power systems having a net electrical output of 100 kW or greater are required to be certified by ABS. (See Note 1). For fuel cell power systems having a net electrical output of less than 100 kW, the manufacturer is to certify the standard to which it is designed, fabricated and tested to, and to report the results of the tests conducted.

5 Onboard Documentation

5.1 General

The following documentation and data are to be kept on board for reference by the operator for system operation and troubleshooting, maintenance, repair, and safety.

i) Applicable documents/operation and maintenance manuals such as EMS, PMS, BMS, CMS, FC-CMSS, etc.

ii) Hybrid electric power system operations and maintenance manual

iii) Hybrid electric power system functional test schedules

iv) Records of safety training of personnel for ships' handling systems, storage, and equipment associated with fuel cell, battery, and supercapacitor

v) Mitigating plans or control measures for adverse events in case of possible safety critical scenarios including fire and explosion

SECTION **3** **System Design**

1 Design Principles & System Configuration

1.1 General

Hybrid electric power systems incorporate multiple sources of power, usually a combination of both non-traditional sources (batteries, capacitors, and fuel cells) and traditional sources (gas, diesel, and dual fuel internal combustion engine driven generators). The design, construction, installation testing and maintenance is to be in general in accordance with this Guide, the ABS *Rules for Building and Classing Marine Vessel Rules,* the *Mobile Offshore Units Rules,* or other ABS Guides applicable to the type of vessel or installation under consideration.

For vessels, the applicable Parts of the *Marine Vessel Rules* are:

- Part 4, Chapter 8, Electrical Systems
- Part 4, Chapter 9, Automation

For offshore units, the applicable Parts of the *Mobile Offshore Units Rules* are:

- Part 4, Chapter 3, Electrical Installations

For yachts the applicable Parts of the *Yacht Guide* are:

- Part 4, Chapter 6, Electrical Installations
- Part 4, Chapter 7, Shipboard Automatic or Remote Control and Monitoring Systems

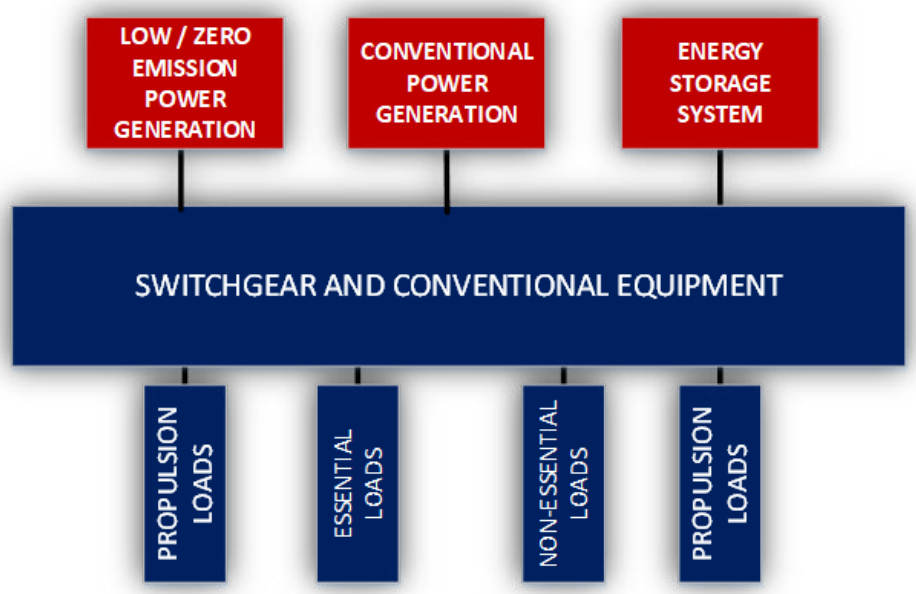
When an ESS is being proposed as an emergency source of electric power, consideration will be given in a case-by-case basis, provided all requirements of 4-8-2/5 of the *Marine Vessel Rules* are complied with as applicable.

1.3 Main Source of Electrical Power

i) Integration of Different Technologies

Integration of different sources of power and the combination of these with different energy storage technologies are shown in the basic configuration, Figure 1.

FIGURE 1
Integration of Different Sources of Power Generation and Driven Loads

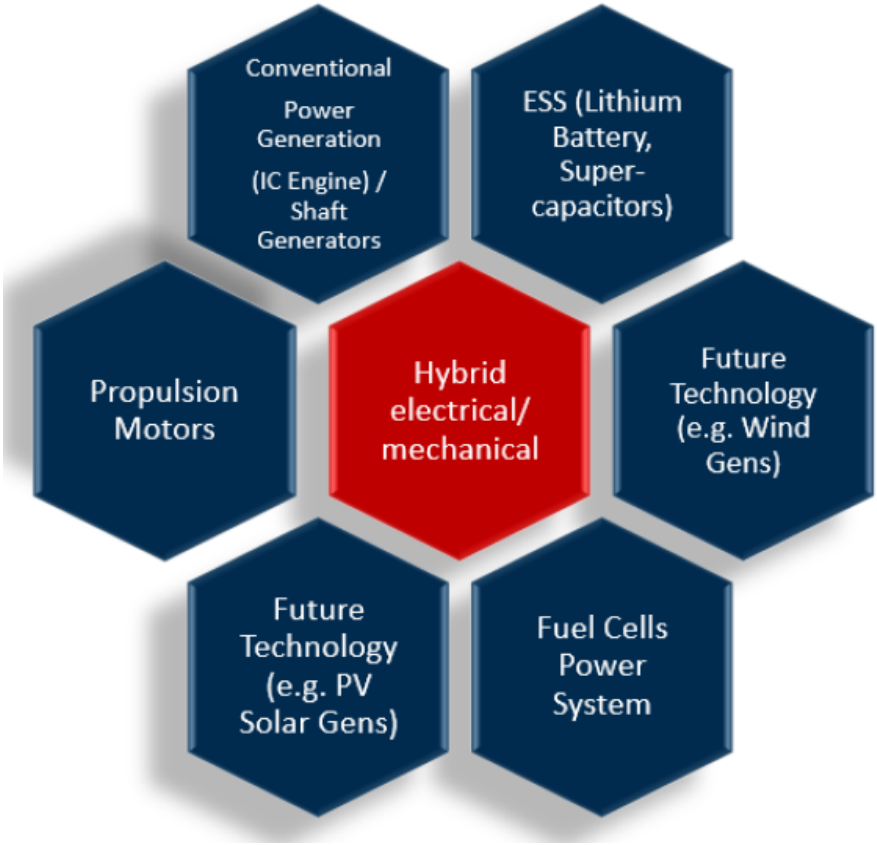


ii) Selection of Electric Source of Power and Energy Storage Systems

Different types of power generation and ESS sources contribute to the hybrid electric power system (HEPS). These provide electrical power to the ship's service electrical loads and the electric motor driven propulsion loads of the vessel or unit. See Figure 2.

The combination of hybrid electric power systems provides alternatives to traditional electrical plant configurations and allow vessel operators more options for optimizing the configuration to best serve the varied load profiles during different operating modes. See Section 3/3 – Operating Modes.

FIGURE 2
Combination of Different Type of Power Generation, Energy Sources, and Driven Loads



1.5 Generation and Energy Storage Systems Capacity

1.5.1 General

The energy transformation devices (ETD) and the energy storage systems (ESS) are to be selected and sized accordingly in order to enable the HEPS to operate and provide the functionality that is required for, without damage throughout its service life.

In the event that the nature of the ESS is such that it will normally exhibit a loss of capacity or performance due to usage or age, the ESS should be selected and sized based upon the capacity and performance of the ESS expected towards the end of its life.

For vessels installed with lithium batteries, supercapacitors and/or fuel cell power system, the requirements as shown in Table 1 are to be met as a minimum.

TABLE 1
Requirements for ESS/ETD

	Applicable System	*Guide Reference*
ESS	Lithium Batteries - Battery Management System (BMS)	ABS *Guide for Use of Lithium Batteries in the Marine and Offshore Industries*
	Supercapacitors - Capacitor Management System (CMS)	ABS *Guide for Use of Supercapacitors in the Marine and Offshore Industries*
ETD	Fuel Cell Power System	ABS *Guide for Fuel Cell Power System for Marine and Offshore Applications*

3 Operating Modes

3.1 General

The operational requirements of the HEPS are defined at the beginning of the design process; allocating space, weight, loading profile for the equipment and systems that will be installed during construction and operated during the service life of the vessel. The basis of design and specifications should be utilized to develop the load analysis and energy/power balance so that requirements for the elements and components of the hybrid electric power system may be developed.

The basis of design, specifications and operational plan manuals are to include the plans and data describing all the subsystems integrated, and all the operating modes the vessel is designed for. Clear identification of parameter values during each mode of operation as well as during transition from one mode to another are to be included.

The applicable operation mode notations offered are listed in Section 3/Table 2.

Expected fault conditions and mitigation plans are to be identified during the risk analysis phase of the project and included in accordance with Section 3/15 of this Guide.

3.3 Operating Modes Capabilities

3.3.1 General

This section identifies and lists the different operating modes and their functionalities and arrangements needed for the vessel to be awarded the specific **HYBRID IEPS [operating mode]** notation.

The operating modes being applied for such notations are to be requested and specified on the submitted plan.

3.3.2 Key Operating Modes and Functionalities

The following table defines the different key operating modes referenced to the applicable notation offered by ABS for the hybrid electric power system installed onboard and their functionalities and arrangements.

TABLE 2
Hybrid Operating Modes (1)

	Operating Mode	*Functionalities / Arrangements*	*Enhanced Notation*
1	Low Exhaust Emission	1. Electrical power supplies the ship's consumers and main propulsion system by ESS and/or FC-PS 2. Engine driven gensets are off (e.g. at Port) 3. Boilers and incinerators operating on liquid fuel are to be off (e.g. at Port) 4. Specific time limit (vessel operating on ESS) is to be specified.	**HYBRID IEPS [LEE]**
2	Power Management	1. Typical schedule strategies: 1.1 Peak Shaving 1.2 Load Leveling/ load smoothing 2. Load sharing control 3. Load shedding/ preferential trips 4. Blackout prevention 5. The PMS is be able to bring online all available generating sources (or ETS) after a blackout and to connect them to the electrical network.	**HYBRID IEPS [PMT]**
3	Power Backup	1. The ESS is to be readily available to the ship’s electrical system during a contingency (e.g. loss of a conventional generator). 2. The ESS is to be connected to the main bus or distribution system in a specified time (e.g. in the order of seconds) that maintains the HEPS stability (not loss of HEPS’ frequency). 3. The ESS is capable to provide power backup during certain time (e.g. during failures of the conventional power generation system). The power backup mode is also known as spinning reserve mode.	**HYBRID IEPS [PBU]**

	Operating Mode	*Functionalities / Arrangements*	*Enhanced Notation*
4	PTO/PTI[(2)]	1. Power Take Off (PTO): Operating mode where a shaft generator provides electrical power flow to the ship's electrical network. 2. Power Take In (PTI): Operating mode where a shaft generator operates as a motor to boost the main propulsion engine power.	**HYBRID IEPS [PTO/PTI]**
5	Shore Connection [(3)]	1. When the vessel is provided with a shore connection installation in accordance with the *MVR Rules* or a high voltage shore connection in accordance with the ABS *HVSC Guide*. 2. The modes of operation related to the shore connection and hybrid is: *a)* The shore connection is arranged for charging the onboard ESS while providing power to the vessel's electrical consumers, And/or *b)* The on board ESS is arranged to provide power to some of the vessel's electrical consumers, while the shore connection provides electrical power to other electrical consumers on the vessel (configuration of electrical distribution system shall be monitored, with alarms, to prevent hidden failure when shore power is disconnected). 3. Operation of the vessel while connected to shore power by reducing onboard power generation, emissions, and local noise. (e.g. all combustion engines/gensets not operating).	**HYBRID IEPS [SCN]**

Notes:

1 All modes of operation are to be defined by the Owner, Designer, and or Integrator.

2 Internal combustion engine driven generator sets and shaft generators by themselves alone do not meet the criteria for HYBRID IEPS.

3 Some other conditions may be required by specific Ports/local Administrations regarding the vessel operating at berth.

Each ESS, Genset (including a shaft generator) and converters should be capable of delivering/ absorbing energy at the required rate to meet the power quality requirements (as specified for the project). For each operating mode, the following is to be specified:

- Energy/Power required
- Duty ratings
- Permissible load based on the load analysis calculation
- Lead (master) ESS or Genset, base loading as applicable
- Programmed kW/kVA load sharing between ESS and Genset(s) as defined by the power management strategy.

3.3.3 Power Management System Functionalities

i) General

In general, a PMS is to be provided in accordance with applicable Sections of the *Marine Vessel Rules* Part 4, Marine Systems and Machinery, and applicable ABS Guides.

ii) *Power Take Off / Power Take In (PTO/PTI) Functionality*

For vessels using combination of any diesel electric generators (and a shaft driven motor/ generator {PTO/PTI}), and energy storage system, and/or fuel cells, fuel consumption and emissions optimization and calculation process for sizing the HEPS (propulsion system and electric power supply system) is to be submitted to ABS for review. Consideration is to be given to maximum values of sudden loads, e.g. during changes of operating modes, and it is to be based on starting conditions and the PMS arrangements.

When it is intended that two or more shaft generators be operating in parallel, 4-8-3/3.13.3 of the *Marine Vessel Rules* is also to be complied with.

iii) *Peak-Shaving Functionality*

a) For vessels looking for a power management operating mode (PMT) and using a load management strategy as peak-shaving, the energy storage systems (ESS) is to be designed to provide sufficient electric power for the vessel's operation during a predefined period of time. The ESS capacity and such a time duration are to be identified in the basis of design (BoD) documentation.

b) Since there are several ways to peak shave, the designer/integrator is to indicate the strategy used for reducing consumption, e.g. by turning off non-essential equipment during peak hours and by the use of automatic load shedding / sharing mechanism to help reduce consumption (e.g. through the PMS).

c) Load fluctuations to the power system are to be limited to the threshold as defined in the project's Basis of Design (BoD), and demonstrated by calculations, analysis, and simulation as appropriate.

5 Power Distribution System

5.1 Power Quality

i) In general, electrical power quality of the HEPS is to be maintained within the requirements of the applicable Rules and the standards to which the electrical power system, the components, and the equipment from which the electrical power system is constructed. In addition, consideration is to be given to the power quality requirements of consumers and appliances that are connected to and exchange energy with the power system. The requirements are specified in the ABS *Marine Vessel Rules*:

Part 4, Chapter 8, Electrical Systems

- 4-8-2/7.21 - Harmonics
- 4-8-3/1.9 - Voltage/Frequency Variations

ii) In cases where power quality operating characteristics are outside of the above limits, the electric equipment connected to the power system is to be verified as being capable of operating in the expanded power quality envelope without damage. This is typically found during a HEPS integration's modeling and simulation process prior to system/equipment installation, in this regard results from this process is expected to be submitted to ABS for review.

5.3 ESS Categorization based on Usage

The ESS can be used to serve essential loads (including emergency loads) and non-essential loads in accordance with ABS *Marine Vessel Rules* and ABS *MOU Rules*.

i) *Essential Service*. The ESS can be used for the purpose of feeding essential service loads as defined in 4-8-1/7.3.3 of *the Marine Vessel Rules*, and 4-3-1/3.5 of the *MOU Rules*.

ii) *Non-Essential Service*. The ESS can also be used for the purpose of feeding non-essential services.

The ESS is to be sized and selected accordingly to operate and provide functionality without damage, effect or degradation throughout its service life. See 3/1.5.1. Also see the specific requirements of the applicable ABS Guide.

7 Control and Instrumentation

7.1 General

The HEPS' control system as referred in this Section may be connected to an integrated control system or be a stand-alone system. It is to be designed for automatic operation and equipped with all the monitoring and control facilities required for safe operation of the system.

In general, integrated automation systems are to be designed to achieve safe and effective operation in accordance with the applicable Section 4-9-4 of the *Marine Vessel Rules*.

Redundancy criteria is to be considered, as applicable, in accordance with the applicable sections of the *MVR,* the *MOU Rules,* or other ABS Guides as appropriate for the type of vessel or installation under consideration. See references in 1/1.11.

7.3 Power Management System (PMS)

For power management system and functionalities, see 3/3.3.3.

Upon failure of the power management system, there is to be no change in the available electrical power. Failure of the power management system is to be alarmed at a manned control station. See also Section 3/ Table 4.

7.5 Energy Management System (EMS)

i) General

The HEPS vessels typically have an integrated hybrid electric power system and an energy management control system. The energy management control system is built with an operation strategy to control and supervise the different subsystems the HEPS vessel is integrated with. The EMS will have several functionalities to supply, schedule, optimize (minimize/maximize) and interact with different energy transformation device's and/or energy storage's management systems.

The energy management system may consist of monitor(s), communications equipment, controller(s), timer(s), or other device(s) that monitors and /or controls electrical loads, power production and or storage sources.

Automatic control systems are to be designed to achieve safe and effective operation in accordance with the applicable Section 4-9-3 of the *Marine Vessel Rules*.

ii) EMS and Interaction with ETD's and ESS' Management Systems

The energy management system is to consider interfaces with other system such as PMS, BMS, CMS and FC-CMSS, etc. Table 3 refers to the applicable management technologies as per ABS Guides and ABS Rules.

TABLE 3
Energy/ Power Management Systems

Example of ESS, ETD Management Systems	*Rule & Guide Reference*
Battery System Components (BMS)	2/1.3, Subsection 3/1 of *Lithium Batteries Guide*
Supercapacitor Management Systems (CMS)	Subsection 2/7, 3/1.5 of *Supercapacitor Guide*

Example of ESS, ETD Management Systems	*Rule & Guide Reference*
Fuel Cell Control, Monitoring and Safety Systems (FC-CMSS)	Section 6 of *Fuel Cell Guide*
Power Management System (PMS)	4-8-5/5.3.3 of *Marine Vessel Rules*, *Dynamic Positioning System Guide*

The following functions are to be considered during the EMS operation strategy, as a minimum:

- Control and monitoring Energy Storage System (ESS).
- Monitoring Battery, Supercapacitor, Fuel Cell Power System.
- Supervision of load sharing between ESS and other generators.
- Maintain energy supply to the essential service loads and propulsion loads, as applicable.
- Failure of the energy management system is to be alarmed at a manned control station, alarms and safeguards are to be fitted in accordance with Section 3/Table 4.
- Upon failure of the power management system, the available electrical power is to remain unchanged. Failure of the power management system is to be alarmed at a manned control station.

7.7 Control, Monitoring, Alarm and Safety Systems

i) The HEPS is to be monitored and provided with audible and visual alarms as a minimum in a normally attended location, such as the following spaces, as applicable:

a) Vessel's navigation bridge (or offshore manned control station)

b) Engine control room (or offshore propulsion centralized control station)

c) Cargo control room

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

iii) The safety system is to be designed such that failure of any of the system's components will not cause unsafe operation of the system or the equipment.

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

v) The sensors are to be designed to withstand the local environment. The enclosure of the sensor and the cable entry are to be in accordance with the applicable sections of the *Marine Vessel Rules* and *MOU Rules*, for the space in which they are located.

vi) A list of monitored parameters, as a minimum, for alarm & shutdown is provided in Table 4 below.

TABLE 4
List of Alarms and Shutdown

Systems	*Monitored Parameters*		*A & D*	*Auto Shut down* [1]	*Notes [A = Alarm; D = Display; x = applies]*
Energy Storage System[3][4]	A1	State of Charge (SOC) – low	x		
	A2	Charging/Discharging - failure	x	x	
	A3	Current – high	x	x	
	A4	Overload	x	x	
	A5	Voltage – high and low	x	x	
	A6	Frequency – high and low (only AC systems) [5]	x	x	
	A7	Cooling or fan - failure	x	x	
	A8	Emergency Stop [2]	x	x	See 5/1.7.iv)
	B1	Cooling medium pressure – low or, temperature – high	x		For subsystem having a cooling system.
	B2	Ventilation - failure	x	x	For subsystem having a ventilation system
	B3	Transformer - failure	x	x	For subsystem having a transformer
	B4	Converter - failure	x	x	For subsystem having a converter
	B5	ESS room or space – high ambient temperature	x		
	B6	ESS (cell, module) – high temperature	x	x	Alternative arrangements can be accepted on risk assessment basis
Shaft Generator	C1	Shaft Generator -failure	x	x	See 4/1.5
Energy Management System (EMS)	D1	Failure System	x		See Table 3 of 3/7.5
Battery Management System (BMS)	D2	Failure System	x		See Table 3 of 3/7.5, if fitted
Supercapacitor Management Systems (CMS)	D3	Failure System	x		See Table 3 of 3/7.5, if fitted
Fuel Cell Control, Monitoring and Safety Systems (FC-CMSS)	D4	Failure System	x	x	See Table 3 of 3/7.5, Section 6/ Table 1 of ABS *Fuel Cell Guide*, if fitted
Power Management System (PMS)	D5	Failure System	x		See Table 3 of 3/7.5, if fitted

Notes:

1 An arrangement is made for starting a standby generator (or energy source) and connecting it to the switchboard, in accordance with 4-8-2/3.11 of the *Marine Vessel Rules* to prevent loss of power.

2 The emergency stop circuit is to be hard-wired and independent of any control system signal.

3 Grouped alarms may be allowed. Refer to the specific ABS Guide (Lithium Battery or Supercapacitor).

4 The ESS room or 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.

5 The high and low frequency trip settings are to be defined and applied in accordance with the designer's and manufacturer's instructions/recommendations.

9 Electrical Protection System

In general, the HEPS protection and control system is to be in accordance with the different requirements as specified in the ABS *Marine Vessel Rules*.

Also, specific protection requirements for each technology can be found in the applicable ABS Guide.

Protection against fault conditions (e.g. short circuits) are also to take into account the following:

i) For protection zones defined by power electronic devices (PEMs), the ABS *Guide for DC Power Distribution System* can be used as reference. Other protection methods will also be acceptable provided coordination and selectivity is achieved.

ii) Due to different converter configurations used in the AC and DC distribution system, methods of calculations of fault currents and protection coordination methodologies are based on steady and transient states as needed. Application of standards and/or other modeling and simulation approaches are to be documented and submitted to ABS for review.

Operational tests are to be carried out including but not limited to the testing of protective devices (over current, under-voltage, and preferential tripping, etc.), electrical interlocks, synchronization of generators, ESS and other alternative generating sources. See also 4-8-3/5.11.4 of *the Marine Vessels Rules*.

11 Equipment Earthing

Protection against electrical shock, exposed metal parts of electrical equipment earthing requirements are to be in accordance with the applicable sections of *the Marine Vessel Rules* (4-8-4/23).

13 Degree of Protection

Enclosures and assemblies are to be constructed of steel or other suitable incombustible, moisture resistant materials and reinforced as necessary to withstand the mechanical, electro-magnetic and thermal stresses which may be encountered under both normal and fault conditions. Enclosures are to be of the closed type. The degree of protection of the enclosure is to be in accordance with the applicable requirements as per Section 4-8-3/TABLE 2, and 4-8-4/1.3 of the *Marine Vessels Rules*.

15 HEPS Risk Assessment

15.1 General

i) A risk assessment is to be conducted to identify risks associated with the design, installation and safe operation of the electrical power system as new and conventional technologies are integrated onboard. The risk assessment is to demonstrate the vessel's safety and the continuity of power supply in case of failure of any part of the system. The risks are to be analyzed using acceptable and recognized risk analysis techniques.

ii) Loss of function, component damage, fire, explosion, and electric shock are to be considered as a minimum. The analysis should identify risks that can be eliminated wherever possible.

iii) Risks which cannot be eliminated are to be mitigated, as necessary. Identification of risks, and means by which they are mitigated, are to be documented to the satisfaction of ABS and to the flag Administration if required.

iv) Properly performed studies done early in the design process to identify hazards, risks and failure modes and allow for them to be resolved, and to enhance safety and performance are to be included. Consideration should be given to aligning these studies with modeling and simulation efforts.

15.3 Risk Assessment Techniques

i) The use of 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 the ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*.

ii) Several risk assessment techniques may be applied. At the early design stages, a Hazard Identification (HAZID) technique may be conducted to identify potential hazards that could result in consequences to personnel, the environment, and assets. A Hazard and Operability (HAZOP) study may also be conducted to identify and evaluate hazards that may represent risks to personnel or equipment. A Failure Mode and Effects Analysis (FMEA) may also be used to demonstrate that any single failure will not lead to an undesirable event.

17 Emergency Source of Power

i) In general, conventional diesel engine driven emergency generators are to comply with applicable Sections of the *Marine Vessel Rules,* and the *MOU Rules*.

ii) When an ESS (e.g. lithium batteries) is being proposed as an emergency source of electric power, consideration will be given on a case-by-case basis, provided all requirements Subsection 4-8-2/5 of the *Marine Vessel Rules* are complied with, or 4-8-3-2/5.3 of the *MOU Rules, as applicable,* are complied with.

19 Modeling and Simulation

Modeling and Simulation may be considered as an alternative approach to some of the physical testing requirements.

A test plan is to be submitted for review and approval showing which items will be validated by physical tests and which ones will be validated by simulation tests.

Model Based Systems Engineering (MBSE), when used in lieu of traditional practices (i.e. Documents Based Systems Engineering), is to meet industry typical requirements for this type of simulation/modeling process.

19.1 General

i) Modeling and simulation of the HEPS offers the capability of providing the information that would normally be obtained from traditional system studies and additional information about operation, configuration, and power quality.

ii) For model verification and validation, acceptable techniques such as these below are acceptable:

- Explore Model Behavior
- Graphical comparison of data
- Confidence intervals
- Hypothesis Tests

19.3 Documents to be submitted

i) Model of the HEPS that has been developed in a simulation space that supports the functional mockup interface (FMI) standard.

ii) Report of the results of the execution of the simulation of the HEPS model depicting steady state operation, switching operation, transient operation, and fault operation of the power system. The simulation results should be provided in a format that will be capable of comparison to simulation performed independently on alternative simulation software.

iii) Short circuit analysis that may be part of the simulation above.

iv) Power, energy, and load flow analysis that may be part of the simulation above.

v) Power quality analysis that may be part of the simulation required above.

vi) Protection scheme that includes a protective device coordination study that may be part of the simulation above.

19.5 Computer Based System Simulation Testing

When computer-based system simulation testing is conducted as an alternative approach or to supplement the approach to some of the physical testing requirements, the following methods are acceptable. The application of these methods are to be described in the test plan:

i) Model in the Loop (MIL)

Model In the Loop (MiL) testing shall be conducted when, both a numerical model of the multi-physics system and a model of its automation and manual control functions have been verified and validated. In MIL test approach the model and its environment are simulated without any physical hardware components. MIL approach cannot reveal faults that are caused by the target controller or by the processor architecture.

ii) Software in the Loop (SIL)

During Software In the Loop (SiL) Testing, virtual (emulated) PLCs, with dedicated interfaces to the simulated multi-physics models, shall be considered for deployment of the executable code. Combining the various multi-physics models of connected systems onboard with their actual control and automation logic through SiL can offer a higher fidelity virtual testing. This level is essentially a test of the coding system. In SIL test approach, the model and its virtual (emulated) PLCs are simulated without any physical hardware components. SIL approach cannot reveal faults that are caused by the target controller or by the processor architecture.

iii) Hardware in the Loop (HIL)

During Hardware in the Loop (HiL) Testing, the control and automations software is fully integrated into the final controller hardware and can only interact with the simulated multi-physics system through the actual I/Os of the controller. The simulated multi-physics system also runs on a real-time computer with I/O simulations to "trick" the controller into believing that it is installed on the actual physical system. In this case, the only difference between the final application and the HiL environment is the fidelity of the simulated multi-physics system model and the test vectors that are being used. HIL level of testing can reveal faults that are caused by the target compiler or by the processor architecture.

iv) The following, is also to be included in the test plan and submitted for our review:

1) test purpose

2) test setup including models' parameters

3) expected results and acceptance criteria

Notes:

1 For software upgrades it is recommended to do a regression testing.

2 Regression testing is re-running functional and non-functional simulation tests to ensure that previously developed and tested software still performs after a change.

19.7 Integration Simulation testing

i) Intra-system integration testing is to be performed between system and sub-system software modules before being integrated on board.

ii) The simulation tests can follow one of the computer-based systems simulation testing methods mentioned in 3/19.5 above as applicable.

iii) Functional and failure testing of the integrated systems identified in 4-9-3-A2/11 and 4-9-3-A2/15 of the *Marine Vessel Rules* may be demonstrated by modeling and simulation tests.

SECTION 4 Equipment and Installation

1 Electrical Equipment

1.1 General

In addition to the specific requirements in this Section of this Guide, the following references are also to be taken into account:

i) In general, electrical equipment is to be designed, constructed and tested to a national, international or other recognized standard and in accordance with the applicable requirements of Part 4 Chapter 8 of the *Marine Vessel Rules,* or applicable requirements of Part 4 Chapter 3 of the *MOU Rules*.

ii) Computer based systems where used for control, monitoring and safety systems are to comply with the applicable provisions of Section 4-9-3 of the *Marine Vessel Rules*.

iii) ABS may consider other industry standards and practices for electrical equipment, on a case-by-case basis, with justifications through novel features and/or comparative analyses to be provided to demonstrate equivalent level of safety to the recognized standards.

iv) For yachts, see Appendix 2/11.

1.3 Transformers and Converters

Application: Transformers and Converters used in the HEPS (e.g. as part of ESS, FC-PS, etc.) are to be designed, constructed, and tested as follows:

i) Transformers

Transformers are to be designed, constructed, and tested in accordance with 4-8-2/3.7, 4-8-3/7 and 4-8-5/3.3.3, 4-8-5/3. of the *Marine Vessel Rules* as applicable.

ii) Power electronic converters (PEC)

Power electronic converters are typically considered “two port” devices capable of providing unidirectional or bidirectional conversions with independent control of the input/output frequency and input/output voltage ratio. A transformer may be included with the PEC.

Converters are to be designed, constructed, and tested in accordance with 4-8-2/3.7, 4-8-3/5.9, 4-8-3/8 and 4-8-5/3.7.5 of the *Marine Vessel Rules* as applicable.

1.5 Shaft Generators (SG)

i) General

Shaft generators (SG) are used to generate electric power (in PTO mode) and support the ship’s service loads if the prime mover has sufficient load margin. The SG is typically driven by slow or medium speed engines (ships’ conventional propulsion power system). In some cases, the shaft generator may also be used to boost the propulsion system (used as a motor in PTI mode).

ii) Shaft generators (constant and variable speed drives) are also to comply with 4-8-2/3.5 of *the Marine Vessel Rules* as appropriate.

iii) Operating mode (PTO/PTI), see Section 3/Table 2 Item 4.

iv) Materials

For material tests of power takeoff generators and power-take-in motors, please see 4-8-5/6.17.1 of the *Marine Vessel Rules*.

v) Gears

When the shaft generator is driven through a reduction gear, the gear box is to be designed, constructed and tested in accordance with Section 4-3-1 of the *Marine Vessels Rules* as applicable.

vi) Shaft Generators - Performance Tests

Shaft generators are to be tested at the factory as per 4-8-3/3.17 of the *Marine Vessel Rules*.

vii) Shaft Generators Installed on Board Yachts

- Shaft generators are to comply with 4-6-2/3.3 of the *ABS Guide for Building and Classing Yachts*.
- See also Appendix 2/ Table 1, for shaft generators certification requirements, and Appendix 2/11.

3 Hazardous Area Installation

3.1 Hazardous Area Classification and Requirements

The following requirements as per the referenced Guides in Table 1, as applicable, are also to be met.

TABLE 1
Hazardous Area Classification

Applicable System	*Rule & Guide Reference*
Battery System Installation	Paragraph 3/3.3 of *Lithium Battery Guide*
Supercapacitor Systems Installation	Paragraph 3/3.9 of *Supercapacitor Guide*
Fuel Cell Power Systems Installation	Subsections 5/3, 5/4 of *Fuel Cell Guide*

SECTION 5 Tests and Trials

1 Surveys During Construction

1.1 General

This Subsection pertains to surveys during fabrication at the manufacturer's facility and installation and testing of hybrid electric power systems (HEPS) onboard. For surveys at the manufacturer's facility, the scope of the survey will be confined to those items that are supplied by the manufacturer.

1.3 Surveys at Manufacturer's Facility

See Section 2/Table 1 and Table 2 of this Guide for certification requirements of HEPS. Survey requirements for equipment components at the manufacturer's facility are summarized in the relevant sections of the applicable Rules/Guides.

i) The manufacture, testing, inspection, and documentation of the HEPS is to be in accordance with applicable ABS Rules, recognized standards and the requirements given in this Section.

ii) At the option of the manufacturer, each machine design or type may be enrolled in the ABS Type Approval Program in accordance with the provisions of 1-1-A3/5.1 of the ABS *Rules for Conditions of Classification (Part 1)*. The details of the ABS approval may be posted on the ABS website, http://www.eagle.org/typeapproval.

1.5 Tests for Control, Monitoring and Safety System

i) Equipment in association with control, monitoring and safety systems of the hybrid electric power generating plant for vessels and offshore installations are to be performance tested in accordance with 4-9-9/13 of the *Marine Vessel Rules*, as applicable.

ii) Indications of parameters necessary for the safe and effective operation of the control, monitoring and safety system are to be tested and verified according to 3/7.7, as applicable.

iii) Simulation testing for verification of the systems/equipment integration may be performed as per 3/19.7 of this Guide.

1.7 Onboard Testing

i) General

- Onboard testing is to verify that functionality has been achieved with all systems in operation.
- The hybrid electric power system installations, as appropriate, are to be examined and tested to the satisfaction of the attending Surveyor in accordance with the approved test plans.
- Table 1 shows references to the applicable requirements for the electrical equipment installed on board the vessel, as given in Section 4-8-4 of the *Marine Vessel Rules*, and in the applicable ABS Guides.
- For yachts, please see Appendix 2/13.1.3.

i)

TABLE 1
Electrical Equipment Installation and Test(1)

Item	*Marine Vessel Rules and Guide Reference*
Degree of Enclosure	4-8-4/1.3 of *Marine Vessel Rules*
Inclination	4-8-4/1.7 of *Marine Vessel Rules*
Generators and Motors	4-8-4/3 of *Marine Vessel Rules*
Accumulator Batteries	4-8-4/5 of *Marine Vessel Rules*
Switchboard and Distribution Boards	4-8-4/7 of *Marine Vessel Rules*
Motor Controllers and Motor Control Centers	4-8-4/9 of *Marine Vessel Rules*
Cable	4-8-4/21 of *Marine Vessel Rules*
Equipment Earthing	4-8-4/23 of *Marine Vessel Rules*
System Earthing	4-8-4/25 of *Marine Vessel Rules*
Electrical Equipment in Hazardous Areas	4-8-4/27 of *Marine Vessel Rules*
Shipboard Tests	4-8-4/29 of *Marine Vessel Rules*
Battery System Testing Requirements	Section 3 of *Lithium Battery Guide*
Transformers	4-8-3/7.3.5 of *Marine Vessel Rules*
Convertors	4-8-3/8.7 of *Marine Vessel Rules*
Supercapacitor System Testing Requirements	Section 3 of *Supercapacitor Guide*
Fuel Cell Power System Testing Requirements	Sections 6, 7 and 8 of *Fuel Cell Guide*

Note:

1 For units which are designed to the *MOU Rules* corresponding requirements of the *MOU Rules* are to be applied.

ii) Commissioning Test Plan

A Test Plan is to be submitted to ABS at the start of the plan review process. The test plan is to identify all equipment and systems, including details of performance tests and trials for all operating modes, including testing of all automatic functions of the system including the power and energy management systems. Tests for the control, monitoring and safety system are to be included to verify the system complies with 3/7.7, as applicable.

iii) Fuel Containment Inspection/Survey Plan

An inspection/survey plan for the fuel containment system (as applicable) is to be developed and submitted for approval by ABS. The inspection/survey plan is to identify components/systems to be examined and/or validated during each survey during the vessel's operating life.

iv) Operating Mode Trials Plan

- Each operating mode is to be subjected to trials in accordance with the approved trials plan required to be submitted for review before the trials. The trials plan is to specify the duration of tests and to include trials in all possible modes for full load testing, half load testing, reversing tests, maneuvering, and any other trials that may be applicable to the vessel, such as dynamic positioning etc. During the trial, all functions of components, equipment, subsystems used in control, monitoring and safety systems of hybrid electric power systems are to be tested in accordance with the provisions in 3/7.7 of this Guide.

- The trails plan is to include disconnection (emergency stop) of the energy storage system (ESS) (see Section 3/Table 4, item A8), as applicable for each operating mode. In the event of loss of the power supply provided by the ESS, the vessel's electrical supply system is to maintain power to equipment necessary for propulsion and steering and for the safety of the vessel.
- Operating modes testing are to be witnessed by Surveyor during harbor and Sea-trial.

1.9 Initial Survey

1.9.1 Surveys During Installation

i) In general, the equipment is to be installed in accordance with the manufacturer's requirements as per the installation approved plans, and the ABS Rules as applicable

ii) All certified safe systems (as applicable) and instrumentation and control panels are to be verified to be in compliance with approved drawings.

iii) Electrical wiring and connections are to be in accordance with applicable Rules requirements of Section 4-8-4 of the *Marine Vessel Rules*, and Section 4-3-3 of the *MOU Rules*, and checked for continuity and proper workmanship.

iv) Instrumentation is to be tested to confirm proper operation as per its predetermined set points.

v) The Commissioning Test Plan is to be followed and verified by the Surveyor

1.9.2 Surveys During Trials

During the initial trials, the HEPS is to be confirmed for its satisfactory operation, including associated controls, alarms and shutdowns. The tests are to be conducted in accordance with the Operating Mode Trials Plan as per 5/1.7 of this Guide.

3 Surveys After Construction

3.1 General

Surveys after construction are to be carried out in accordance with the ABS *Rules for Surveys After Construction (Part 7)* for *Marine Vessel Rules* or *MOU Rules for Offshore* units as applicable.

Annual or Special surveys after construction are to be carried out to for systems and equipment as referred to in 5/3.3 of below, as applicable.

3.3 Annual Surveys

The Hybrid Electric Power System (HEPS) operating and maintenance records are to be examined to identify any issues with the HEPS.

If a hybrid fuel system is installed, the Hybrid Fuel Containment Inspection/Survey Plan is to be referenced and the fuel containment system examined.

The overall HEPS is to be verified in acceptable condition and operational in all modes through a review of the vessel's documentation and system testing in accordance with the Operating Mode Trials Plan when deemed necessary.

3.5 Special Surveys

Dock trials are to be conducted to verify the proper operation of the HEPS in all operational modes. Testing conducted is to be done using the Operating Mode Trials Plan as guidance.

3.7 Surveys for Existing Vessels Obtaining HYBRID IEPS Notation

3.7.1 Initial Survey

All vessels subjected to modifications and retrofits with hybrid electric power systems as detailed in this Guide are to be examined and tested in accordance with the approved plans and 5/1.1 through 5/1.9 to verify compliance and to the satisfaction of the attending Surveyor.

APPENDIX 1 Table for Cross References to existing ABS Guides

1 General

1.1 Battery System Design and Construction

The provisions of this Section apply to vessel battery energy storage systems. The following references in Table 1 are applicable to vessels designed, constructed, or retrofitted with a lithium battery system used as an additional source of power with a capacity greater than 25 kWh. When batteries are being used as the main source of power, the additional requirements set forth in Section 4 of *Lithium Batteries Guide* are to be met.

TABLE 1
Lithium Battery System Components

Battery System	***Lithium Batteries Guide Reference***
Battery System Components	Paragraph 2/1.3, Subsection 3/1
Battery Chargers	Subsections 2/3, 3/1
Battery Management Systems	Subsections 2/5, 3/1
Battery System Installation	Section 3
Battery System Used as Main Source of Electrical Power	Section 4
Battery System Surveys	Section 5

1.3 Supercapacitor System Design and Construction

The provisions of this Section apply to vessel supercapacitor energy storage systems. The following references in Table 2 are applicable to vessels designed, constructed, or retrofitted with a supercapacitor system used as an additional source of power with a capacity greater than 50 Wh.

TABLE 2
Supercapacitor System Components

Supercapacitor System	***Supercapacitor Guide Reference***
Supercapacitor Cells/Modules	Subsection 2/3, 3/1.1, 3/1.3
Supercapacitor Chargers	Subsection 2/5, 3/1.5
Supercapacitor Management Systems	Subsection 2/7, 3/1.5
Supercapacitor Converters	Subsection 2/5, 3/1.5
Supercapacitor System Testing and Installation	Section 3
Supercapacitor System Surveys	Section 4

1.5 Fuel Cell Power System Design and Construction

The provisions of this Section apply to vessel fuel cell power systems using a gaseous fuel as well as liquid fuels. The following references in Table 3 are applicable to vessels designed, constructed, or retrofitted with a fuel cell used for auxiliary and main electric power systems.

TABLE 3
Fuel Cell Power System Components

Fuel Cell Power System	*Fuel Cell Power System Guide Reference*
Materials	Subsection 2/2
Fuel Cell Module	Subsection 2/4
Arrangements and Installation	Section 3
Fire Safety	Section 4
Electrical Systems	Section 5
Control, Monitoring and Safety Systems	Section 6
Fuel Cell Power System Surveys	Sections 7 and 8

APPENDIX 2 Hybrid Electric Power Systems Installed Onboard Yachts

1 General

1.1 Application

The provisions of this Appendix apply to the design, construction, and testing of hybrid electric power systems intended for installation on yachts. Compliance with the requirements in this Appendix is to be verified by ABS.

3 Plan and Data to be submitted

i) All plans and data as requested by 2/1.3 and 2/1.5 of this Guide are to be submitted.

ii) All plans and data as required by 4-6-2/1, 4-6-3/1, 4-6-4/1.3 and 4-6-5/3.1.2 of the ABS *Guide for Building and Classing Yachts* are to be submitted.

5 Certification

The following Table 1 provides the applicability of the certification requirements for certain equipment and components as referred to in Part 4 and applicable Chapters and Sections of the ABS *Guide for Building and Classing Yachts*.

See also Section 2/ Table 2 of this Guide.

TABLE 1
Hybrid Electric Power System Certification for Yacht

No.	*Equipment*	*d*	*m*	*s*	*t*	*obs*	*g*	*Yacht Guide Reference*
1	Propulsion Generators and Motors	X	X	X	X	X		see 4-6-4/3,4-6-4/Table 1, 4-6-5/3.17.5
2	Switchboards (Propulsion, Main and Emergency)	X		X		X		see 4-6-4/7
3	Motor Controllers ≥ 100 kW (135 hp)	X		X		X		see 4-6-4/7.17
4	Battery Charging and Discharging Boards for Essential, Emergency or Transitional Source of Power	X		X		X		see 4-6-4/7.19
5	Power Transformers and Converters of Low Voltage					X	X	see 4-6-4/9, 4-6-4/10, 4-6-4/11
6	Power Transformers and Converters for High Voltage Systems Exceeding 1 kV	X		X		X		see 4-6-5/1.11.3
7	Circuit Breakers and Fuses	X				X		see 4-6-4/11
8	Certified Safe Equipment	X			X	X		see 4-6-3/9

No.	*Equipment*	*d*	*m*	*s*	*t*	*obs*	*g*	*Yacht Guide Reference*
9	Shaft Generators (motors)	X		X	X	X	X	4-6-2/3.3, 4-1-1/Table 3c, (as appropriate based on rating)

Symbol	*Meaning*
d	DESIGN REVIEW – (Design Review Required)
m	MATERIAL TESTING – (Material Testing is to be witnessed by an ABS Surveyor)
s	MANUFACTURING SURVEYS – (Product is to be inspected during fabrication by an ABS Surveyor)
t	TYPE/PROTOTYPE – (Testing conducted on an actual sample or a prototype model is required, as applicable)
obs	ON BOARD SURVEYS – Operational, hydrostatic non-destructive testing, or other required tests are to be witnessed by an ABS surveyor after installation on board the yacht
g	MANUFACTURER'S DOCUMENTATION – (Manufacturer should supply documentation to guarantee that the material or the equipment complies with an acceptable Standard, (e.g., Standard tests reports, Ex Certification, etc.)

7 Onboard Documentation

See Subsection 2/5 of this Guide, as applicable.

9 System Design

See Section 3 of this Guide, as applicable.

11 Electrical Equipment and Installation

i) In general, see applicable Sections of Part 4 Chapter 6 of the ABS *Guide for Building and Classing Yachts.*

ii) See also Section 4 of this Guide, as applicable.

iii) Material for gears and gear units is to be designed in accordance with 4-3-1/3 of the *Marine Vessel Rules*.

13 Tests and Trials

13.1 Surveys During Construction

13.1.1 Surveys at Manufacturer's Facility

See Appendix 2/Table 1 and Section 2/Table 2 of this Guide for certification requirements for Yachts. Survey requirements for equipment components at the manufacturer's facility are summarized in the applicable sections of the ABS *Guide for Building and Classing Yachts.*

i) The manufacture, testing, inspection, and documentation of the HEPS is to be in accordance with applicable ABS Rules, recognized standards and the requirements given in this Section.

ii) At the option of the manufacturer, each machine design or type may be enrolled in the ABS Type Approval Program in accordance with the provisions of 1-1-A3/5.1 of the ABS *Rules for Conditions of Classification (Part 1)*. The details of the ABS approval may be posted on the ABS website, http://www.eagle.org/typeapproval.

13.1.2 Tests for Control, Monitoring and Safety System

i) Equipment in association with control, monitoring and safety systems of the hybrid electric power generating plant for Yachts installations are to be performance tested in

accordance with 4-7-2/Table 1 of the ABS *Guide for Building and Classing Yachts*, as applicable.

ii) Indications of parameters necessary for the safe and effective operation of the control, monitoring and safety system are to be tested and verified according to 3/7.7 of this Guide, as applicable.

iii) Simulation testing for verification of the systems/equipment integration may be performed as per 3/19.7 of this Guide.

13.1.3 Onboard Testing

i) General

- Onboard testing is to verify that functionality has been achieved with all systems in operation.
- The hybrid electric power system installations, as appropriate, are to be examined and tested to the satisfaction of the attending Surveyor in accordance with the approved plans.
- All requirements applicable electrical equipment installation on board vessels are given in Section 4-6-3 of the ABS *Guide for Building and Classing Yachts*.

ii) Commissioning Test Plan

A Test Plan is to be submitted to ABS at the start of the plan review process. The test plan is to identify all equipment and systems, including details of performance tests and trials for all operating modes, including testing of all automatic functions of the system including the power and energy management systems. Tests for the control, monitoring and safety system are to be included to verify the system complies with 3/7.7, as applicable.

iii) Fuel Containment Inspection/Survey Plan

An inspection/survey plan for the fuel containment system (as applicable) is to be developed and submitted for approval by ABS. The inspection/survey plan is to identify components/systems to be examined and/or validated during each survey during the vessel's operating life.

iv) Operating Mode Trials Plan

- Each operating mode is to be subjected to trials in accordance with the approved trials plan required to be submitted for review before the trials. The trials plan is to specify the duration of tests and to include trials in all possible modes for full load testing, half load testing, reversing tests, maneuvering, and any other trials that may be applicable to the vessel, such as dynamic positioning etc. During the trial, all functions of components, equipment, subsystems used in control, monitoring and safety systems of hybrid electric power systems are to be tested in accordance with the provisions in 3/7.7 of this Guide.
- The trails plan is to include disconnection (emergency stop) of the energy storage system (ESS) (see Section 3/Table 4, item A8), as applicable for each operating mode. In the event of loss of the power supply provided by the ESS, the vessel's electrical supply system is to maintain power to equipment necessary for propulsion and steering and for the safety of the vessel.
- Operating modes testing are to be witnessed by Surveyor during harbor and Sea-trial.

13.1.4 Initial Survey

i) Surveys During Installation

- In general, the equipment is to be installed in accordance with the manufacturer's requirements as per the installation approved plans, and the ABS *Guide for Building and Classing Yachts* as applicable as applicable
- All certified safe systems (as applicable) and instrumentation and control panels are to be verified to be in compliance with approved drawings.
- Electrical wiring and connections are to be in accordance with applicable *s* requirements of Section 4-6-2 of the ABS *Guide for Building and Classing Yachts* and checked for continuity and proper workmanship.
- Instrumentation is to be tested to confirm proper operation as per its predetermined set points.
- The Commissioning Test Plan is to be followed and verified by the Surveyor

ii) Surveys During Trials

During the initial trials, the HEPS is to be confirmed for its satisfactory operation, including associated controls, alarms and shutdowns. The tests are to be conducted in accordance with the Operating Mode Trials Plan as per Appendix 2/13.1.3 iv) of this Guide.

13.3 Surveys After Construction

13.3.1 General

Surveys after construction are to be carried out in accordance with the ABS *Rules for Surveys After Construction (Part 7)* for *Marine Vessel Rules* as applicable.

Annual or Special surveys after construction are to be carried out to for systems and equipment as referred to in Appendix 2/13.3.2 of below, as applicable.

13.3.2 Annual Surveys

The Hybrid Electric Power System (HEPS) operating and maintenance records are to be examined to identify any issues with the HEPS.

If a hybrid fuel system is installed, the Hybrid Fuel Containment Inspection/Survey Plan is to be referenced and the fuel containment system examined.

The overall HEPS is to be verified in acceptable condition and operational in all modes through a review of the vessel's documentation and system testing in accordance with the Operating Mode Trials Plan when deemed necessary.

13.3.3 Special Surveys

Dock trials are to be conducted to verify the proper operation of the HEPS in all operational modes. Testing conducted is to be done using the Operating Mode Trials Plan as guidance.

13.3.4 Surveys for Existing Vessels Obtaining HYBRID IEPS Notation

Initial Survey

All Yachts subjected to modifications and retrofits with hybrid electric power systems as detailed in this Guide are to be examined and tested in accordance with the approved plans and Appendix 2/13.1 to verify compliance and to the satisfaction of the attending Surveyor.