

GUIDANCE NOTES

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Guidelines for Ships Using Integrated DC Power System

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Bei Jing

Foreword

To adapt to the rapid development of the application of integrated DC power systems on ships, China Classification Society (CCS) has developed this new edition of the Guidelines for Ships Using integrated DC power system, based on the International Maritime Organization (IMO) MSC.1/Circ.1394/Rev.2 on Generic Guidelines for Developing IMO Goal-Based Standards approved on 8 July 2019, and taking into account the scientific research achievements of the national key research and development program "Key Technologies for Typical Ships Driven by Hydrogen Energy" and the current status of industry development.

The Guidelines for Ships Using integrated DC power system are intended to specify the requirements for the design, arrangement, installation, control, monitoring and survey of integrated DC power systems, with a view to providing safe and reliable propulsion and electrical power for ships by means of integrated DC power system technology.

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CHAPTER 1 GENERAL

Section 1 GENERAL PROVISIONS

1.1.1 Application

1.1.1.1 The Guidelines for Survey of Ships Using integrated DC power system (hereinafter referred to as the Guidelines) apply to ships provided with an integrated DC power system. Unless otherwise specified, the following ships are not applicable to the Guidelines:

- (1) military vessels;
- (2) fishing vessels; and
- (3) yachts.

1.1.1.2 In addition the Guidelines, ships installed with an integrated DC power system specified in the Guidelines are to comply with the appropriate requirements of CCS Rules for Classification of Sea-going Steel Ships, Rules for the Construction of Sea-going Ships Engaged on Domestic Voyages, CCS Rules for the Construction of Inland Waterways Steel Ships, Regulations for Classification of Sea-going Ships on Domestic voyages or Regulations for Classification of Inland Waterways Ships (hereinafter referred to as CCS Rules).

1.1.1.3 As the technology of the DC integrated power system is still under development, special or novel DC integrated power systems, if not complying with the Guidelines, may be accepted by CCS as an alternative or equivalent method, provided that they have been evaluated based on the relevant theoretical calculation, test results, service experience or valid recognized standards. The equivalence of alternative designs is to be demonstrated in accordance with the CCS Guidelines for Alternative Design and Arrangements and approved by CCS. CCS does not permit the substitution of specific fittings, materials, appliances, equipment components or their types specified in this Part by operational methods or management procedures.

1.1.2 Definitions

1.1.2.1 For the purpose of the Guidelines,

(1) An **integrated DC power system** is a new shipboard power system which converts the primary energy (e.g., energy generated by fuel combustion or other reactions, wind energy and photovoltaic energy) and stored energy of the ship into DC energy and realizes the comprehensive application of energy. The system supplies the electrical energy output from sources of electrical power, including electrical energy generated from power plants and/or discharged from energy storage devices, to the whole ship loads (e.g. electric propulsion, operation loads, primary daily power loads) via the DC distribution system and daily AC distribution system, and realizes the comprehensive dispatching and use of the ship's energy by a power/energy management system (hereinafter referred to as PMS/EMS).

(2) A **centralized integrated DC power system**: The power plants, energy storage devices and loads are connected to the DC bus-bar directly or via converters. The DC bus-bar consists of two or more sections which are connected by bus-tie protective device. The protective device is switched under normal working conditions, and the system operates in a centralized mode.

(3) A **distributed integrated DC power system**: The power plants, energy storage devices and loads are connected to several sections of DC bus-bar directly or via converters. Under normal working conditions, the

bus-tie contactors or isolating switches (if any) are open, and each section of DC bus-bar is independent and operates in a distributed mode.

(4) A **power supply unit** is the ship's source of electrical power, including power plants and energy storage devices in general.

(5) A **power plant** is an arrangement to supply the ship with electrical power generated by the combustion of fuels or other reactions, which is characterized by a one-way flow of electrical power from the power plant to the distribution system under normal technical conditions. Power plants are categorized into AC power plants (e.g. AC synchronous generating sets, AC asynchronous generating sets) and DC power plants (e.g. AC rectifier generating sets, DC generating sets, fuel cells, solar photovoltaic systems).

(6) An **energy storage device** is an arrangement used for storing electrical energy or other energy, which supplies the ship with electrical power and may be charged by a power plant, energy storage device or shore power. It is characterized by a bidirectional flow of energy between the energy storage device and the distribution system under normal technical conditions, such as storage batteries (sets), supercapacitors and flywheel energy storage devices.

(7) A **DC distribution system** is a system which distributes the electrical energy supplied by power plants, energy storage devices and shore power to consuming devices via DC busbars, and realizes the conversion of power system, voltage and frequency according to the different power demands of the consuming devices. It generally includes DC switchboards, converters and electric cables.

(8) A **DC switchboard** is a combination, generally consisting of DC busbars, switchgears, protective devices and monitoring devices, which is supplied directly by power plants, energy storage devices, shore power, or by connecting to corresponding converters, to distribute DC electrical energy to the shipboard consuming loads and implement control.

(9) A **DC bus-bar** is a common DC bus-bar arranged within the DC switchboard to connect power supply units and consumers.

(10) **Single bus-bar sectioned** is a configuration in which one bus-bar is divided into two or more sections by protective devices, and connections between the bus-bar sections are made through bus-tie protective devices.

(11) A **ring bus-bar** is a bus-bar configuration formed by a single bus-bar which is closed at both ends to form a ring.

(12) A **converter** is power electronic equipment to realize the conversion of power system, voltage and frequency according to the power demands of the consuming devices, such as rectifiers (AC/DC), inverters (DC/AC), transducers (DC/AC or AC/DC/AC) and choppers (DC/DC).

(13) A **daily AC distribution system** is a distribution system to distribute the three-phase AC energy supplied by inverters, AC power plants, shore power, etc. to daily consuming loads, including AC switchboards, lighting transformers and electric cables.

(14) An **AC switchboard** is a combination, generally consisting of AC busbars, switchgears, protective devices and monitoring devices, which is supplied by inverters, AC power plants, AC shore power, etc., to distribute three-phase AC energy to the shipboard daily loads and implement control.

(15) A **monopolar DC distribution system** is a DC distribution system having only one pole (positive or negative), utilizing earth (the hull) or a metallic return as the current return path.

(16) A **bipolar DC distribution system** is a DC distribution system having two poles with opposite polarities to earth (positive and negative), where the two poles can operate independently.

(17) A **pseudo-bipolar DC distribution system** is a DC distribution system having two poles with opposite polarities to earth (positive and negative), where the two poles cannot operate independently.

(18) **Voltage deviation** is the deviation of the actual operating voltage of the power system relative to the nominal voltage of the system.

(19) **Voltage fluctuation** is the variation of the difference between the maximum and minimum voltage relative to the rated voltage within a specified time window.

(20) **Voltage ripple** is the alternating current component in the DC voltage.

(21) A **power/energy manage system** (PMS/EMS) is the power/energy management system, being an automation system to provide the functions of monitoring, control and management for getting, distributing and using the ship's power/energy.

(22) A **solid state switch** is a contactless switch using an electronic power semiconductor as the current breaking element.

(23) **Fuse pre-arcing time** is the time taken from the initiation of the current making the operation of the fuse take place to the moment the arc emerges.

(24) **Fuse arcing time** is the time taken from the initiation of the arcs to their being extinguished.

(25) **Fuse clearing time** is the sum of the pre-arcing and arcing time.

(26) **Fuse I^2t** , i.e. Joule integral, is the integral of the square of the current during a given time interval. *Pre-arcing I^2t* is the integral of I^2t during the pre-arcing time. *Clearing I^2t* is the integral of I^2t during the fuse clearing time.

(27) A **pumping voltage** is a voltage rise caused by the electric energy, which is converted from mechanical energy through an electric motor when it is in regenerative braking state, flowing back to the DC capacitor of the converter that drives the motor.

1.1.3 Goal and functional requirements

1.1.3.1 The goal of the Guidelines is to provide criteria for the design, construction and survey of installations and systems on ships provided with an integrated DC power system, and to minimise risks to the ship, crew and the environment.

1.1.3.2 In order to achieve the above goal, the design and construction of the integrated DC power system are to satisfy the following functional requirements:

(1)The safety, availability and reliability of the system should be equivalent to that of a conventional AC distribution system employing synchronous generators.

(2)The system should be capable of supplying sufficient electrical power to the ship under all operating conditions, including navigation, operations, port entry and departure, and berthing.

(3)The system should ensure the safety of the ship and personnel on board, and protect them from electrical hazards, under all normal conditions and fault conditions.

(4)The system should be designed such that the probability of failure of its relevant sub-systems is minimised, and that the manoeuvrability of the ship can be maintained or restored under a single fault condition.

(5)The electrical equipment of the system should be so constructed and installed that unintended contact with live parts is prevented under normal operation and single fault conditions.

(6)The probability and consequences of failures related to the integrated DC power system should be minimised by the design of installations and systems. Where system failures occur or risk mitigation measures fail, necessary safety actions should be initiated.

(7)The risk mitigation measures and safety measures of the installations and systems, including the control and monitoring systems, should be ensured not to result in unacceptable loss of power.

(8)The system protection should be designed such that, upon occurrence of a system fault described in

Chapter 4 of the Guidelines, the fault impact range can be limited by measures such as blocking or current limitation, with regard to the higher magnitude and faster rising rate of the peak current resulting from the characteristics of low system impedance and capacitors.

(9) Appropriately designed control and monitoring systems should be provided to realise the overall electrical power balance among the power plants, power supply units, propulsion units and daily loads of the integrated DC power system.

1.1.4 Normative references

1.1.4.1 The provisions of the relevant documents that are referred to in the Guidelines should constitute the provisions of the Guidelines. For undated references, the latest edition of the referenced document applies.

Section 2 PLANS AND DOCUMENTATION

1.2.1 Plans and documents for approval

1.2.1.1 In addition to those specified in CCS Rules, the following plans and documents are to be submitted to CCS for approval:

- (1) A power system diagram incorporating the integrated DC power system;
- (2) Calculation of short-circuit current (see 4.4.1.2 of this chapter), including DC distribution systems and AC distribution systems, applicable to ships with a parallel power-supply unit having a total power^① of more than 200 kW;
- (3) A selective protection analysis report for the integrated DC power system (see 4.4.3.1 of Chapter 4 of the Guidelines), including both the DC distribution system and the daily AC distribution system (applicable to ships with a total power of parallel power-supply units having a total power of more than 200 kW);
- (4) a monitoring and alarm item list for the integrated DC power system;
- (5) a diagram of the water cooling system for the integrated DC power system (from the cooling water suction/storage unit to the cooling water inlet of switchboards);
- (6) the mooring and sea trial programme covering the test items of the integrated DC power system (may be approved by the attending surveyor).

1.2.1.2 In addition to those specified in the relevant CCS Rules, for an integrated DC power system to be installed for the first time by the manufacturer on ships classed with CCS, the following plans and documents are to be submitted to CCS for information:

- (1) System specifications, at least including system introduction, functions of main component, principles of system protection, system control functions and description of system external interface;
- (2) Design and analysis report of electro magnetic compatibility (see 6.2.1.1 of this chapter);
- (3) Failure modes and effects analysis (FMEA) report, see Chapter 7 of the Guidelines.

1.2.1.3 In addition to those specified in CCS Rules, the following plans and documents are to be submitted to CCS for information for integrated DC power systems if previous installation of similar system on board has been approved by CCS:

- (1) The plans and documents required in 1.2.1.2 (1) to (2) of this Section;

① The total power of parallel power-supply units refers to the algebraic sum of the rated power of each power supply unit that can be connected to the DC distribution system under normal operating conditions. Where a power supply unit does not have a nominal rated power, the rated power of the converter connected in series on its branch is to be used as the basis for calculation; if no converter is connected in series on the branch, the generating power declared by the manufacturer in the electric load calculation book is to be used as the basis for calculation. The same applies hereinafter.

(2) Documentation demonstrating that the integrated DC power system is of the same type (see 4.4.5.1 of Chapter 4 of the Guidelines).

1.2.1.4 Following initial installation approval, where a DC distribution system and a daily AC distribution system of the same type (see 4.4.5, Chapter 4 of the Guidelines) are subsequently installed on ships classed with CCS, and provided they respectively comply with the provisions of 4.4.5.2 and 4.4.5.3 of Chapter 4 of the Guidelines, CCS may require additional plans and documents for approval if individual components are changed.

Section 3 PRODUCTS SURVEYS

1.3.1 General requirements

1.3.1.1 In addition to the Guidelines, products surveys are to comply with the relevant requirements of CCS Rules, regulations and products surveys guidelines.

1.3.1.2 The electrical equipment used in DC distribution system is to be manufactured and tested in compliance with international or national standards. Documents are to be submitted to demonstrate that novel equipment or novel uses for equipment, for which no standard is referred to, have an equivalence with conventional equipment.

1.3.2 DC switchboards

1.3.2.1 DC switchboards are to be surveyed by CCS and have a CCS marine product certificate.

1.3.2.2 The certification requirements for components of DC switchboard are to comply with Table 1.3.2.2.

List of Certification Requirements for Components of DC Switchboard Table 1.3.2.2

No.	Component name	Document		Approval mode				Plan approval	Remark
		C/E	W	DA	TA-B	TA-A	WA	PA	
1	Fuse	—	X	—	X ⁴	—	—	X	
2	Circuit breaker	—	X	—	X	—	—	X	
3	Isolating switch	—	X	—	X	—	—	X	
4	Solid-state switch for bus-bar connection	—	X	—	X	—	—	X	See Section 2, Chapter 3 of CCS Guidelines for Ships Using a Hybrid Power System
5	Converter	X	—	—	X	—	—	X	50 kW and above
6	Generator protection device	—	X	—	X	—	—	X	
7	Power/energy management system	—	X	—	X	—	—	X	
8	Electrical instrument	—	X	—	X	—	—	X	
9	Insulation monitoring device	—	X	—	X	—	—	X	

10	Contactor	—	X	—	X	—	—	X	
11	Electric relay	—	X	—	X ⁴	—	—	X	
12	Electric wire and cable	—	X	—	—	—	X	X	

Symbols:

- 1) C—Marine Products Certificate; E—Equivalent document; W—Manufacturer's document; X—Applicable; O—Optional.
- 2) DA—Design approval; TA-B—Type approval B; TA-A—Type approval A; WA—Works approval; PA—Plan approval;
- 3) X⁴: may be accepted subject to special agreement of CCS.

1.3.2.3 DC switchboards (including bus-bars) are to comply with IEC 61439-1 Low-voltage Switchgear and Controlgear Assemblies- Part 1: General Rules, IEC 61439-1 Low-voltage Switchgear and Controlgear Assemblies- Part 2: Power Switchgear and Controlgear Assemblies, and IEC 62271 High-voltage Switchgear and Controlgear- All Parts.

1.3.2.4 DC switchboards are to be subjected to trials at the manufacturer's works as follows:

- (1) Check of structures and wiring and if necessary, verification of degree of protection;
- (2) Check of air clearance and creepage distance;
- (3) Performance test of cooling system;
- (4) Electrical function test to check the performance of semiconductor changer, instrument, alarm, indication and display screen. The function of PMS/EMS is to be verified by test or other means;
- (5) Temperature rise test of bus-bar, only the first product is required to be tested for the mass-produced products of the same type;
- (6) Dielectric strength test;
- (7) Insulation resistance test;
- (8) Tightness test of enclosure (only for high-voltage DC switchboards).

1.3.2.5 For the factory acceptance test of a DC switchboard to be installed for the first time, additional tests according to 4.4.4.1 and 4.4.4.2 of Chapter 4 of the Guidelines are to be carried out to demonstrate the correctness of its short-circuit current simulation calculation and selective protection analysis. The tests are to be witnessed by a CCS surveyor. The error between the simulated short-circuit current peak and the tested one is generally not to exceed 20%. If the error exceeds this range, the relative error between the tested peak values measured at different short-circuit locations and the simulated ones should present a relatively consistent trend, and the analysis items listed in the selective protection analysis report (see 4.4.3.2 of Chapter 4 of the Guidelines) are to be consistent with the test results. The test report signed by the surveyor is to be uploaded to CCS's survey and certification system. Where all the above test items cannot be completed during the factory acceptance test, they are to be completed before the sea trial in accordance with a test programme approved by CCS Surveyor.

1.3.3 Power supply units

1.3.3.1 1.3.3.2 to 1.3.3.9 of this Section apply to power supply units connected to the DC distribution system.

1.3.3.2 Generating sets of a rated power of 50 kVA and above are to be subjected to unit/batch inspection, and a certificate is to be issued by CCS.

1.3.3.3 The check and test of steady short circuit specified in Table 7.1, E-04 Generators of CCS Guidelines for Survey of Marine Products may be carried out as follows: AC generators and their excitation systems are to be capable of maintaining, under steady-state short-circuit conditions, at least a maximum

short-circuit current set for their protection devices for a duration of the maximum separation time set for their protection devices.

1.3.3.4 Three-phase AC asynchronous generators are to be subjected to type testing according to Table 1.3.3.3. Unit/batch inspections, following the issue of type approval certification, are to include items 1 to 8 in the table.

Lists of Type Testing of Three-phase AC Asynchronous Generators Table 1.3.3.4

No.	Items	Technical requirements
1	External examination	Approved plans and technical documentation
2	Insulation resistance measurement	3.2.9.6, Part 4 of CCS Rules for Classification of Sea-going Steel Ships
3	Winding resistance measurement	Technical specifications
4	Overload/overcurrent test	3.2.5.1, Part 4 of CCS Rules for Classification of Sea-going Steel Ships
5	Overspeed test	Regulation 9.7 of IEC 60034-1
6	Dielectric strength test	Regulation 9.2 of IEC 60034-1
7	No-load test (no-load loss and no-load current measurement)	Regulation 4.5 of GB/T 19071.2
8	Verification of bearings	3.2.9.16, Part 4 of CCS Rules for Classification of Sea-going Steel Ships
9	Peak torque measurement	Regulation 13.1 of GB/T 1032
10	Operating curve measurement	Regulation 4.7 of GB/T 19071.2
11	Rated load test and temperature rise measurement	3.2.3, Part 4 of CCS Rules for Classification of Sea-going Steel Ships
12	Inclining test	CCS Guidelines for Type Approval Test of Electric and Electronic Products
13	Cyclic damp heat test	CCS Guidelines for Type Approval Test of Electric and Electronic Products
14	Salt spray test Ka ^①	CCS Guidelines for Type Approval Test of Electric and Electronic Products
15	Verification of degree of protection	IEC60034-5

Note: ① The products not subjected to a salt spray test are to be notified with NOT FOR OPEN DECK in the approval certificate and marine product certificate.

1.3.3.5 Generating sets do not need be subject to the parallel running test or load transfer test required in E-05 Generating Sets of CCS Guidelines for Survey of Marine Products.

1.3.3.6 Where all testing specified in E-05 Generating Sets of CCS Guidelines for Survey of Marine Products is impracticable for AC asynchronous generating sets, the testing of 8.4 (1) to (8) and (17) therein is to be carried out at the manufacturer's work, and the remaining is to be carried out during mooring test in agreement of CCS.

1.3.3.7 Lithium batteries, including high energy density super capacitors, are to be manufactured, tested and inspected according to CCS Rules for Ships Applying Battery as a Power.

1.3.3.8 Fuel cells are to be manufactured, tested and inspected according to Part 2 of CCS Guidelines for Ships Using Hydrogen Fuel.

1.3.3.9 Solar photovoltaic power generation systems are to be manufactured, tested and inspected according to CCS Guidelines for Survey of Solar Photovoltaic Systems and Lithium Iron Phosphate Battery

Systems.

1.3.4 Converters (semiconductor converters)

1.3.4.1 Converters (semiconductor converters) are to hold certificates according to Power Conversion Device in Annex 1A, Chapter 3, Part 1 of CCS Rules for Classification of Sea-going Steel Ships, or Section 1, Chapter 3 of Regulations for Classification and Survey of Ships Engaged on Domestic Voyages, or Annex 1A, Chapter 3 of Regulations for Classification of Inland Waterways Ships.

1.3.5 Propulsion control systems

1.3.5.1 Propulsion control systems are to hold certificates according to Remote Control System of Propulsion Device in Annex 1A, Chapter 3, Part 1 of CCS Rules for Classification of Sea-going Steel Ships, or Section 1, Chapter 3 of Regulations for Classification and Survey of Ships Engaged on Domestic Voyages, or Annex 1A, Chapter 3 of Regulations for Classification of Inland Waterways Ships, and may be subjected to type testing referring to E-16 of CCS Guidelines for Survey of Marine Products.

1.3.5.2 The softwares of propulsion control system are to comply with Section 6, Chapter 2, Part 7 of CCS Rules for Classification of Sea-going Steel Ships or Section 8, Chapter 2, Part 4 of CCS Rules for the Construction of Inland Waterways Steel Ships.

1.3.6 Daily AC switchboards

1.3.6.1 Daily AC switchboards are to hold certificates according to “Main Switchboard” in Annex 1A, Chapter 3, Part 1 of CCS Rules for Classification of Sea-going Steel Ships, or Section 1, Chapter 3 of Regulations for Classification and Survey of Ships Engaged on Domestic Voyages, or Annex 1A, Chapter 3 of Regulations for Classification of Inland Waterways Ships.

1.3.6.2 Daily AC switchboards are to comply with the provisions of Section 3, Chapter 3, Part 4 of CCS Rules for Classification of Sea-going Steel Ships.

1.3.6.3 For the factory acceptance test of a daily AC switchboard to be installed for the first time, additional tests according to 4.4.4.1 and 4.4.4.2 of Chapter 4 of the Guidelines are to be carried out to demonstrate the correctness of its short-circuit current simulation calculation and selective protection analysis. The tests are to be witnessed by a CCS surveyor. The error between the simulated short-circuit current peak and the tested one is generally not to exceed 20%. If the error exceeds this range, the relative error between the tested peak values measured at different short-circuit locations and the simulated ones should present a relatively consistent trend, and the analysis items listed in the selective protection analysis report (see 4.4.3.3 of Chapter 4 of the Guidelines) are to be consistent with the test results. The test report signed by the surveyor is to be uploaded to CCS's survey and certification system. Where all the above test items cannot be completed during the factory acceptance test, they are to be completed before the sea trial in accordance with a test programme approved by the CCS surveyor.

Section 4 SHIP SURVEYS

1.4.1 General requirements

1.4.1.1 All survey programmes, survey methods, types of survey, intervals between the surveys, survey conditions, preparations before survey, survey and testing requirements and preservation of the drawings and documentation, certificates, records and reports etc., are to be in compliance with CCS Rules for

Classification of Sea-going Steel Ships in case of sea-going ships, or CCS Regulations for Classification of Inland Waterways Ships in case of inland waterways ships.

1.4.2 Surveys during construction

1.4.2.1 In addition to the appropriate survey items in CCS Rules, for integrated DC power systems, the following items are to be carried out:

(1) Confirming that the operation, protection, interlock, indication, alarm and corresponding actions are in order;

(2) For two or more power supply units operating parallel contained in the electrical loading evaluation, testing is to be carried out for the operating parallel of the minimum number of power supply units. The continuity of power supply is to be verified when one unit is stopped, and one power supply unit of greater power is to be stopped in case of various rated power;

(3) Verification of the system voltage regulation performance and stability by cutting off the load of a motor with the maximum power (e.g. stopping a propulsion motor) under seagoing conditions or under operating conditions in the case of ensuring the ship power safety according to the electrical loading evaluation;

(4) Check and testing of control and monitoring system to at least verify that:

① the setting and conversion of control position (local/remote) are in order;
② the setting and conversion of control mode (manual/semi-automatic/automatic) are in order;
③ the operations, parameters and start/stop control of each power supply unit and protective device are in order;

④ the load sharing function of each power supply unit is in order;

⑤ the functions of failure indication (audible and visual alarm) and fault record opening and displaying are in order;

⑥ verifying that the system is automatically transferred into a safe condition in the case of:

(a) power failure of PMS/EMS;

(b) controller failure of PMS/EMS

(c) communication failure of PMS/EMS;

(d) other failures with a high risk level based on the FMEA analysis report.

(5) In the case of the integrated DC power system containing synchronous or asynchronous generating sets:

① verifying that the start and stop of generating set respectively performed by the local control cabinet, switchboard and PMS/EMS control panel are in order;

② simulating performance test of safety system of generating set;

③ load testing of generating set at the maximum and minimum speed for variable speed generating sets, and at the rated speed for constant speed generating sets;

④ testing of sudden load and loss of load at the maximum and minimum speed for variable speed generating sets, and at the rated speed for constant speed generating sets;

⑤ Parallel and load transfer testing is to be carried out at the maximum and minimum speeds for variable-speed generating sets, and at the rated speed for constant-speed generating sets. As far as practicable, each generating set is to be loaded to 100% of its rated load. If this is impracticable, a load equal to the total power of the propulsion motors or the load supplied by the DC distribution system to the ship's AC switchboard, whichever is greater, is to be applied, subject to agreement by CCS.;

⑥ where not all test items have been completed during the factory acceptance test for an asynchronous

generating set according to 1.3.3.6 of this Chapter, the test items of 8.4 (9) to (15) of E-05 Generating Sets of CCS Guidelines for Survey of Marine Products are also to be carried out in the surveys during construction. For the voltage adjustment range, steady-state voltage regulation rate, voltage fluctuation rate and transient voltage variation rate, the DC voltage at the converter output side is to be assessed;

⑦ verification of the pre-charge function (if any) of parallel connection of generating set together with converter;

⑧ verification of the disconnection function of generating set.

(6) In addition to the appropriate requirements of CCS Rules for Ships Applying Battery as a Power, power supply units of integrated DC power system, if containing an energy storage device, are to be subjected to the items as follows:

① check and start/stop testing of each group of energy storage device together with converter (if any);

② verification of the pre-charge function (if any) of energy storage device together with converter (if any);

③ confirming that the integrated DC power systems and energy storage devices on grid are in order where groups of storage device together with converter (if any) are integrated to the DC bus one by one;

④ check and testing of emergency stop of each group of energy storage device together with converter (if any);

⑤ check and testing of the functions of parallel operation under load and load distribution of energy storage device together with converter (if any);

⑥ check and testing of the operation, indication, interlock etc. of shore charging unit (if any);

⑦ where power supplied only by energy storage devices is presented in the electrical loading evaluation, confirming that the storage devices are capable of withstanding the sudden load and loss of load.

The testing methods as below may be used or the report is to be approved by CCS:

(a) testing of sudden load and loss of load during the mooring test to the equipment having the maximum rated power/maximum actual service power in the electrical loading evaluation, combined with the mooring test conditions;

(b) stop testing of the energy storage device having the maximum power and one propulsion motor to check the system stability.

(7) In addition to the appropriate requirements of Part 2 of CCS Guidelines for Ships Using Hydrogen Fuel, power supply units of integrated DC power system, if containing a fuel cell power installation (together with converter), are to be subjected to the items as follows:

① check and start/stop testing of each group of fuel cell power installation together with converter;

② verification of the pre-charge function (if any) of parallel connection of fuel cell power installation together with converter;

③ confirming that the integrated DC power systems and fuel cell power installations on grid are in order where groups of fuel cell power installation together with converter (if any) are integrated to the DC bus one by one;

④ check and testing of the functions of parallel operation under load and load distribution of fuel cell power installation together with converter;

⑤ confirmation of stable running of fuel cell power installation together with converter for 30 min in the condition of the minimum stable output set for PMS/EMS.

(8) Daily AC distribution systems, if supplied by an inverter, are to be subjected to:

① check and start/stop testing of inverter;

② check and testing of the operation under load of inverter;

③ testing of transferring load between the two inverters (if appropriate) and between the inverters and other AC power supply units (if any) under uninterruptible power supply;

④ starting of a motor with the maximum single power and not equipped with a soft starter, to verify the system's voltage regulating performance and stability.

(9) In addition to the appropriate requirements of CCS Rules, integrated DC power system, if containing a propulsion motor, are to be subjected to the items as follows:

① start/stop testing of the propulsion motor respectively on the bridge operating panel, in the centralized control room (if any) or at engine;

② confirmation of the function of emergency stop;

③ simulating to confirm overriding function in fault conditions;

④ confirming that anticondensation heaters are in order;

⑤ where multiple power supply units are running in parallel, stopping one in-grid power supply unit with a loading rate over 80%, to verify the power limiting function specified in 5.2.1.22 of Chapter 5 of the Guidelines is effective.

(10) In addition to the appropriate requirements of CCS Guidelines for Survey of Solar Photovoltaic Systems and Lithium Iron Phosphate Battery Systems, power supply units of integrated DC power system, if containing a photovoltaic power generation system (together with converter), are to be subjected to the items as follows:

① check and start/stop testing of each group of photovoltaic power generation system together with converter;

② verification of the pre-charge function (if any) of photovoltaic power generation system together with converter;

③ confirming that the integrated DC power system and the on-grid photovoltaic power generation system are in normal condition when each group of photovoltaic power generation system together with converter is integrated to the DC bus one by one;

④ anti-islanding protection function test of the photovoltaic power generation system together with grid-connected converter;

⑤ testing the power quality of the grid-connected operation respectively at 33%, 66% and 100% rated operating power (or at the maximum output power that can be practically achieved under current environmental conditions).

(11) Confirmation of wiring of strong and weak current, and confirming that the ground loop and cabling and other antijamming designs comply with Section 3 of Chapter 6.

1.4.3 Surveys after construction

1.4.3.1 Annual surveys: in addition to CCS Rules (if applicable), survey items are to include:

(1) General examination of electrical installations and cables of integrated DC power system in the working conditions, as far as practicable;

(2) Confirming that DC distribution system, daily AC distribution system and other electrical installations essential to the safety are in good conditions. Check of automatic supply of stand-by power supply system, if applicable;

(3) Check of insulation resistance device of continuous monitoring system, and confirming that an alarm will be given in case of abnormally low insulation resistance, if applicable;

(4) General examination of control, monitoring and safety system.

1.4.3.2 Intermediate surveys: in addition to CCS Rules (if applicable) and 1.4.3.1 of this Section, survey

items are to include:

(1) For ships with low flashpoint fuels of 6 years of age and above, a general examination of electrical installations and cables in hazardous areas is to be carried out, especially the suitability of explosion-proof lights and their associated electrical devices, and none of the following situations is to be present:

- ① electrical equipment with obvious defects;
- ② improper wiring installation;
- ③ unapproved lights and utensils;
- ④ dead-end lines.

(2) Checking whether the cable insulation has wear, ageing, cracking, discoloration, etc.

(3) Checking the reliability of connections between conductors and between conductors and equipment, such as whether bolted connections are loose, whether soldered joints are cracked, whether protective conductor connections are reliable, and whether there is corrosion or fracture.

(4) Checking whether the enclosures of electrical equipment have cracks, deformation, corrosion, rust, etc.

1.4.3.3 Special surveys: in addition to CCS Rules (if applicable) and 1.4.3.2 of this section, survey items are to include:

(1) Check of switches, instruments etc. of DC distribution system and daily AC distribution system, and check of the integrity of overcurrent protective device and fuse (by visual examination, on-resistance measurement or similar manners) to confirm the protection for their own circuits;

(2) Checking whether the rated current, breaking capacity and tripping characteristics of overcurrent protective devices (such as circuit breakers and fuses) are consistent with the drawings. DC circuit breakers and fuses are not to be replaced by AC devices;

(3) Confirmation of the availability and correct delay of protective device, if applicable;

(4) Operation test of power supply unit in parallel and not in parallel under working load to check the load distribution and transfer function;

(5) In addition, energy storage devices are to be subjected to charging and discharging tests and emergency stop function test;

(6) Fuel cell power installations (together with converters) are also to be subjected to a load test under the condition of minimum stable output power;

(7) Verification test of system alarm and safety system function as far as practicable.

CHAPTER 2 INTEGRATED DC POWER SYSTEMS

Section 1 GENERAL PROVISIONS

2.1.1 General requirements

2.1.1.1 The design of the integrated DC power system is to be reasonably determined in accordance with the nature of the load, the power capacity and the system scale.

2.1.1.2 The construction of the integrated DC power system is to be simple and clear, reduce electrical energy losses, and be easy to manage and maintain.

2.1.1.3 The selection of the DC voltage for the integrated DC power system is to fully consider the requirements of DC power supply units, DC loads and the daily AC distribution system, and the voltage levels are to be simplified as far as possible to avoid repeated voltage reduction and repeated AC/DC power conversion.

2.1.2 PQ (power quality)

2.1.2.1 During the operation of the DC distribution system, its power quality is to meet the load power demand and equipment operation requirements, and indicators such as voltage deviation, voltage fluctuation and voltage ripple are to be assessed.

2.1.2.2 In addition to compliance with 1.2.2 to 1.2.3 of Part 4 of CCS Rules for Classification of Sea-going Steel Ships or Section 3, Chapter 1, Part 3 of CCS Rules for the Construction of Inland Waterways Steel Ships, the power quality of the integrated DC power system is also to meet the requirements of Table 2.1.2.2.

Power Quality of Integrated DC Power System

Table 2.1.2.2

Equipment	Parameter	Steady State (%)	Transient	
			(%)	Recovery Time (s)
Public DC bus supplied via converters	Voltage	-10 ~ +6	-20 ~ +7	1.5
	Periodic voltage fluctuation	5	—	—
	Ripple voltage	4.5 (for frequency < 2kHz)	—	—
Dedicated DC bus supplied via converters ^①	Voltage	±30	—	—
	Periodic voltage fluctuation	—	—	—
	Ripple voltage	5 (for frequency < 10kHz)	—	—
Equipment supplied by energy storage devices: - connected to battery during charging ^② - not connected to battery during charging	Voltage Voltage	-25 ~ +30 -25 ~ +30	—	—

Notes: ①Where documentation is provided by the manufacturer to demonstrate that all equipment directly connected to the dedicated DC bus can operate without failure in the long term over the full voltage fluctuation range (including low-frequency periodic voltage fluctuations, high-frequency ripple voltage, and possible high-frequency transient voltage effects), and DC equipment not supplied by this manufacturer is not to be connected to this bus-bar.

②Different voltage fluctuations due to charging/discharging characteristics are to be considered, including the ripple

voltage from the charging equipment.

Section 2 DESIGN REQUIREMENTS FOR DC DISTRIBUTION SYSTEM

2.2.1 Bus-bar configuration

2.2.1.1 The busbar configuration of the DC distribution network is to fully achieve the functional requirements of system safety, reliability, flexibility and economy.

2.2.1.2 The busbar configuration of the DC distribution network is to consider the necessary network reconfiguration and self-restoration capability.

2.2.1.3 The DC distribution system is to select the corresponding busbar configuration based on the load characteristics, criticality and operating conditions.

2.2.1.4 Centralized topology is to meet the following requirements:

(1) The DC distribution system structure is to be simple and safe. Single busbar sectionalized and ring busbar configurations may be adopted, taking into account factors such as power supply reliability, capacity and arrangement of power supply units, and load capacity and arrangement.

(2) The DC busbar is to be subdivided into not less than 2 busbar sections. Power plants, energy storage devices and loads are to be connected to these sections, directly or via converters, as evenly as possible. Each DC busbar section is to be connected by bus-tie protective devices such as fuses, circuit breakers or solid-state switches. Under normal conditions, the bus-tie protective devices are to be closed, forming a common DC busbar to supply the loads. When a DC busbar section is faulty, the bus-tie protective device is to disconnect to isolate the fault point, and the other DC busbars are to continue to supply the loads. The bus-tie protective device is to have selectivity to ensure that the fault does not propagate further, regardless of current direction.

(3) Ring busbar configuration shall also meet the following requirements:

① The power supply branches constituting the ring busbar are to come from different power supply units or independent feeders of the same power supply unit;

② The power supply range of each busbar section is to be relatively independent. Necessary connections may be established based on the criticality of loads to ensure that each busbar section has the ability to support each other in the event of an accident;

③ The nodes of the ring busbar are not to derive an isolated secondary ring network structure;

④ The ring busbar is to support both closed-loop and open-loop operation modes. When any busbar section fails, the system is to automatically disconnect that section to ensure the remaining sections continue to operate normally;

⑤ When the power supply unit on the busbar section where the daily inverter is located fails, the loads are to be completely transferred to the adjacent busbar section;

⑥ When the power supply unit on the busbar section where the propulsion motor is located fails, at least 50% of the propulsion load is to be transferred to the adjacent busbar section;

⑦ All bus-tie protective devices are to be capable of inter-communication to ensure reliable system operation.

2.2.1.5 Distributed topology is to meet the following requirements:

(1) The DC busbar is to be subdivided into not less than 2 busbar sections. Power plants, energy storage

devices and loads are to be connected to these sections, directly or via converters, as evenly as possible. Under normal conditions, the bus-tie contactor or isolating switch (if any, measures to prevent accidental contact are to be provided) is to be open, and each DC busbar section operates independently to supply its respective loads. When a DC busbar section fails, the power supply to other DC busbars is not to be affected.

2.2.2 Wire systems of DC distribution systems

2.2.2.1 The following systems of distribution may be used for DC distribution system:

- (1) Two-wire (single-pole and metallic return) insulated or high-impedance earthed system;
- (2) Three-wire (positive pole, negative pole and neutral) insulated or high-impedance earthed system;
- (3) Two-wire (single-pole and metallic return) system with negative pole directly earthed (without using the hull as the negative return);
- (4) Three-wire (positive pole, negative pole and neutral) system with neutral directly earthed (without using the hull as the negative return).

2.2.2.2 For DC distribution systems requiring flexible power supply for equipment of different voltage levels, a bipolar or pseudo-bipolar configuration may be adopted.

2.2.2.3 For high-voltage DC distribution systems, or where high reliability of power supply is required, a bipolar configuration may be adopted.

2.2.2.4 The systems of distribution specified in 2.2.2.1(1) and (2) of this Section are to be preferentially adopted. Where electro-chemical energy storage devices such as storage batteries and super capacitors are provided, the systems specified in 2.2.2.1(3) and (4) of this Section are not to be used.

2.2.2.5 The DC distribution system is to adopt a consistent method of earthing.

2.2.2.6 System earthing is to be single-point earthing, where the neutral point or one pole of the power source is connected to the earthing arrangement at only one location.

2.2.2.7 Protective earthing is to ensure that all exposed conductive parts of electrical equipment (such as equipment enclosures, metal wiring conduits, metal supports) are properly connected to the earthing arrangement. The protective earthing conductor of each equipment connected to the earthing arrangement is to be capable of being disconnected independently, and the removal of the earthing conductor of one equipment is not to affect the protective earthing function of other equipment. The connection between the protective earthing conductor and the earthing arrangement is to be reliable and only capable of being disconnected using tools (such as a screwdriver or spanner). Plug-in type, snap-fit type or other connection methods that can be disconnected without tools are not to be used. Screws used for connecting protective earthing conductors are not to serve any other purposes concurrently, such as fixing equipment enclosures, wiring conduits or other components.

2.2.3 Insulated distribution systems and high-impedance earthed distribution systems

2.2.3.1 For the insulated system and the high-impedance earthed system, an insulation monitoring device is to be provided to continuously monitor the insulation resistance of the DC distribution system and give an audible and visual alarm in case of abnormally low insulation resistance.

2.2.3.2 For the insulated system and the high-impedance earthed system, where the switchgear of the distribution branch will not be disconnected upon the occurrence of the first earth fault, the system is to be designed so that the switchgear is capable of disconnecting the fault current in the event of a second earth fault (on a pole different from the first earth fault) before the first earth fault is cleared.

2.2.3.3 Double earth faults are to be included in the scope of short-circuit protection. It is to be assumed that the earth fault occurs under the most adverse earth fault scenario, and the short-circuit protection is to

have the capability to selectively isolate at least one fault point.

2.2.3.4 High impedance earthed systems are to achieve the following functions by selecting the resistance to earth:

- (1) Limitation on the fault currents and overvoltage levels in case of single-pole earth fault to the short-time continuous operation of the system and the safety of personnel and equipment in the fault;
- (2) The current flowing through the resistance to earth is to ensure triggering of the monitoring, alarm or protection of the system earthing.

2.2.4 Earthed distribution system

2.2.4.1 Distribution circuits are to be provided with a DC residual current device (RCD), and the operating current of the RCD is not to exceed 80 mA.

2.2.5 Main source of electrical power

2.2.5.1 The number and capacity of power supply units serving as the ship's main source of electrical power are to comply with 2.1.1.1, Part 4 of CCS Rules for Classification of Sea-going Steel Ships or 3.1.2, Part 3 of CCS Rules for the Construction of Inland Waterways Steel Ships.

2.2.5.2 The design of auxiliary systems (such as cooling systems, lubrication systems and monitoring systems) is not to cause the power supply units serving as the ship's main source of power in 2.2.5.1 of this Section and the standby power supply units to become inoperative simultaneously. The auxiliary systems supporting the main source of power and the associated control systems are to be designed as independently as possible and isolated from each other to reduce common cause failures. In particular, the cooling system is to be designed with reference to 4.1.1.6, Chapter 4 of the CCS Rules for Ships Using Battery Power.

2.2.5.3 Power supply units connected to the DC busbars and operating in parallel are to automatically achieve load sharing and ensure that the output power of each power supply unit operating in parallel does not exceed its own maximum available power under all operating conditions. This may be achieved by:

- (1) one power supply unit regulating the DC busbar voltage, while all other power supply units regulate the current based on pre-set values or the PMS/EMS;
- (2) load sharing based on the voltage droop characteristics of the power supply unit itself (or simulated through a converter);
- (3) a combination of the above methods.

2.2.5.4 The grid connection of the DC distribution system is generally not to rely entirely on the PMS/EMS for stability control such as load sharing and source-grid coordination, but is to ensure operational stability through the inherent characteristics of the power system and the adaptability of the equipment itself (such as converters or voltage regulators).

2.2.5.5 When the method of 2.2.5.3(1) of this Section is used for parallel operation and load sharing, the system is to be provided with a power supply unit of appropriate capacity operating in voltage mode, to ensure that the total output power of all power supply units is suitable for the steady-state and transient demands of the current load power, and to avoid serious impacts on the operation of the integrated DC power system. Meanwhile, appropriate measures are to be taken to ensure that, should any power supply unit used for regulating the DC busbar voltage fail, the remaining power supply units can continue to operate normally.

2.2.5.6 When the method of 2.2.5.3(2) of this Section is used for parallel operation and load sharing, consideration is to be given to the impedance difference between the converter voltage sensor and the DC busbar, to prevent the load sharing deviation from exceeding the system safety margin.

2.2.5.7 Appropriate measures are to be taken to ensure the stability of the DC distribution system. The

rapid power supply capability of the power supply units serving as the main power source is to be compatible with the magnitude and speed of high-power load impacts, so that the system voltage can be maintained within the range required in 2.1.2 of this Chapter when large power loads are connected.

2.2.5.8 Power supply units operating in parallel are to be capable of supplying the loads under reasonably foreseeable conditions (including rated current, starting current, inrush current and fault current) to ensure effective operation of the protective devices.

2.2.6 Requirements for shore power or other external power to DC distribution system

2.2.6.1 Shore power or other external power, having a power system and voltage appropriate to the bus-bar of DC distribution system, may be directly connected to the bus-bar via circuit breakers or other protective devices. If not, an appropriate converter is required.

2.2.6.2 An interlock is necessary where shore power or other external power not in parallel with power supply unit (including short-time load transfer in parallel) is connected to the bus-bar directly or via a converter, to prevent serious impacts on the DC distribution system operation due to improper connection.

Section 3 DESIGN OF DAILY AC DISTRIBUTION SYSTEM

2.3.1 General requirements

2.3.1.1 The power supply and distribution and insulation monitoring of daily AC distribution system are to comply with 2.4.1 and 2.4.2, Part 4 of CCS Rules for Classification of Sea-going Steel Ships or 2.1.1, Part 3 of CCS Rules for the Construction of Inland Waterways Steel Ships, if applicable.

2.3.1.2 Daily AC distribution systems may be connected to DC distribution systems via inverters, and also may be provided with an AC power plant and connected to shore power. Where DC distribution systems and daily AC distribution systems have really different insulation classes, an isolating transformer is to be provided.

2.3.1.3 Power supply units of daily AC distribution system mainly include AC synchronous generating sets and inverters connected to DC distribution system. The number and capacity of AC power supply unit are to comply with 2.1.1.1, Part 4 of CCS Rules for Classification of Sea-going Steel Ships or 3.1.2, Part 3 of CCS Rules for the Construction of Inland Waterways Steel Ships.

2.3.1.4 The design of auxiliary systems (such as cooling systems, lubrication systems and monitoring systems) is not to cause the power supply units in 2.3.1.3 of this Section and the standby power supply units to become inoperative simultaneously. The auxiliary systems supporting this power source and the associated control systems are to be designed as independently as possible and isolated from each other to reduce common cause failures.

2.3.1.5 The main busbar of the daily AC distribution system is to be subdivided into at least two independent sections and designed with reference to the applicable requirements of 2.2.1.4(2) or 2.2.1.5(1) of this Chapter, depending on whether they normally operate in parallel. Where all essential services (such as steering gear, fire pumps, bilge pumps, control power supplies for essential equipment, etc.) among the ship's daily loads are directly supplied by the DC distribution system, the main busbar of the daily AC distribution system need not be subdivided.

2.3.2 Design requirements for inverters in daily AC distribution system

2.3.2.1 Where power supply is switched between inverters operating in parallel, and between inverters

and AC generating sets, it is to be ensured that the switch is smooth without impact and under uninterruptible power supply to daily AC loads.

2.3.2.2 Where a daily AC distribution system is supplied by inverter alone, the inverter is to employ constant voltage and constant frequency control under normal conditions. In case of a short-circuit fault of the AC system, the inverter is to be capable of immediately switching from constant voltage-frequency control to constant current-frequency control, to supply a short-circuit current of a specified amplitude and constant frequency to the daily AC distribution system, with a duration of no less than 0.5 s, for use in identification and breaking the short-circuit fault by the protective devices of the daily AC distribution system.

2.3.2.3 Where a daily AC distribution system is supplied by inverters and AC synchronous generating sets in parallel, the AC synchronous generating set may regulate the AC bus voltage and the inverter may regulate the current according to the PMS/EMS, or the inverters and the AC synchronous generating sets may realize paralleling based on AC droop characteristics. When necessary, regardless of whether the AC synchronous generating set is in service or not, the inverters are to be capable of providing reliable constant voltage and constant frequency power supply to the daily AC distribution system.

2.3.3 Design requirements for shore power or other external power to daily AC distribution system

2.3.3.1 Shore power or other external power, having a power system and voltage appropriate to the bus-bar of daily AC distribution system, may be directly connected to the bus-bar via circuit breakers or other protective devices. If not, an appropriate transformer or converter is required.

2.3.3.2 An interlock is necessary where shore power or other external power not in parallel with power supply unit (including short-time load transfer in parallel) is connected to the bus-bar, to prevent serious impacts on the operation of daily AC DC distribution system due to improper connection.

CHAPTER 3 ELECTRICAL INSTALLATIONS

Section 1 GENERAL PROVISIONS

3.1.1 General requirements

3.1.1.1 The design of electrical installations is to ensure no safety risks to personnel and equipment under all operating conditions. The safety measures which may be taken include, but are not limited to:

- (1) enclosure IP protection degree appropriate for the intended location of installation;
- (2) integrity of equipment enclosures (including openings such as doors);
- (3) equipotential bonding / earthing;
- (4) isolation.

Section 2 GENERATORS

3.2.1 General requirements

3.2.1.1 In addition to the requirements of this Section, generators are also to comply with the relevant requirements of Section 2, Chapter 3, Part 4 of CCS Rules for Classification of Sea-going Steel Ships.

3.2.1.2 The rated power, overload capacity and dynamic performance of the prime mover of the generator are to meet the power demand required by the transitional changes of working conditions of electrical equipment caused by manoeuvring, navigational environment and weather conditions.

3.2.1.3 When the method of 2.2.5.3(2), Chapter 2 of the Guidelines is used for grid connection, the characteristics of the automatic voltage regulator of the generator are to ensure that, during parallel operation, the load of the generator set and other power supply units is distributed as proportionally as possible according to their rated power.

3.2.2 Bearings and lubrication

3.2.2.1 Bearings are to be adequately lubricated to ensure continuous and sufficient lubrication under normal and severe sailing conditions (e.g. heel, trim).

3.2.2.2 The bearing structure is to take effective measures to prevent excessive lubricating liquid from leaking out and penetrating into the interior of the generator.

3.2.2.3 For forced-lubrication type bearings, an alarm signal is to be triggered in the event of oil supply failure (oil pump failure, loss of pressure in the bearing oil supply line) or abnormal temperature rise of the bearing (generally, bearing lubricating oil temperature not exceeding 70°C, or not exceeding 80°C when rolling bearings are used). If the temperature rises to a dangerous level, immediate shutdown is to be effected.

3.2.2.4 Reliable measures are to be taken to avoid harmful currents between the shaft and the bearing, so as to prevent bearing damage.

3.2.2.5 Sliding bearings are to be designed as a structure that can be readily replaced.

3.2.2.6 Split sliding bearings are to be provided with temperature monitoring devices, whose temperature measuring elements are preferably arranged at the lower bearing bush position and effectively reflect the actual temperature of the bearing bush.

3.2.2.7 Rolling bearings are to have sufficient preload.

3.2.3 Cooling

3.2.3.1 For generators equipped with forced air cooling devices, air duct systems, air filters or liquid coolers, the cooling effect is to be continuously monitored (e.g. windings temperature of each phase), and an alarm is to be triggered when the temperature exceeds the set value. The temperature set value is to be determined according to the equipment characteristics and is not to be higher than the upper limit of the permissible operating temperature.

3.2.3.2 For generators using closed-cycle cooling (with heat exchanger), it is to be possible to monitor the flow or pressure of the primary coolant and the secondary coolant, or to monitor the temperature difference between the inlet and outlet of the heat exchanger.

3.2.3.3 For generators equipped with liquid-cooled heat exchangers, a leakage monitoring device is to be provided.

3.2.3.4 If a liquid-cooled electrical machine has the function of switching to a pure air-cooled operation mode, the maximum design capacity of the generator is to be correspondingly reduced under pure air-cooled conditions.

3.2.4 Protection

3.2.4.1 Protective measures (such as converters with current limiting function or short-circuit protective devices) are to effectively protect the generator so that it can withstand the impact caused by short circuits in the DC distribution system.

3.2.4.2 In the event of a short-circuit between the AC synchronous generator set and the converter, or an internal fault in the converter, the electrically excited generator is to be capable of achieving the protection function by means of differential protection or switching off the excitation to stop output. Permanent magnet synchronous generators are to be provided with corresponding protection, such as achieving the protection function through the blowing of fuses on the stator winding, and also be capable of stopping the operation of the prime mover.

3.2.4.3 The generator protection unit and/or its converter are to be provided with a fault current detection device.

3.2.4.4 The protection of the generator protection unit is to be coordinated with the protection actions of the integrated DC power system.

3.2.4.5 The protection of the generator is to cover the entire speed range.

3.2.5 Special requirements for synchronous generators

3.2.5.1 The steady-state and transient regulation performance of the excitation system (including the automatic voltage regulator) of synchronous generators is to comply with standards accepted by CCS.^①

3.2.5.2 Synchronous generators are generally to adopt a self-excitation mode, with their excitation system supplied by the generator itself, and the voltage build-up process of the generator is not to rely on other power supply units.

3.2.5.3 Where other power supply units are independent and redundant to each other, and at least include one set of emergency power source (if any), they are permitted to supply power to the excitation and/or control circuits of the synchronous generator (including the voltage build-up process).

3.2.5.4 Upon tripping of the protective device of the excitation system of the synchronous generator set, the synchronous generator outlet circuit breaker is to be automatically disconnected (time delay may be provided), and an audible and visual alarm is to be initiated locally and at the manned position.

① Refer to IEC 60092-301 Electrical installations in ships – Part 301: Equipment – Generators and motors.

3.2.5.5 The internal protection functions of the excitation system are to be coordinated with the selectivity of the power system protection.

3.2.5.6 The control system of the excitation system is to be reasonably arranged to avoid harmful voltage rises caused by the operation of protective devices, grid connection/disconnection operations of power supply units, or faults in the excitation system.

3.2.5.7 Special requirements for AC rectifier generators integrating an AC synchronous generator and an uncontrolled rectifier:

(1) Sufficient creepage distance and electrical clearance are required between the positive and negative poles of the rectifier components, and between live parts and earth (generator frame);

(2) The overall structure is to meet the requirements of shock resistance and vibration resistance in the marine environment;

(3) The centralized cooling system is to ensure that the junction temperature of the diode/thyristor, the temperature of the rotor windings and the excitation device are within the permissible limits;

(4) When water cooling is used for the rectifier diode/thyristor, the water circuit and the frame are to be connected with insulated pipes to prevent electric leakage;

(5) The withstand capability of the rectifier diode/thyristor against short-circuit current is to be compatible with the holding time specified in 1.3.3.3, Chapter 1 of the Guidelines.

3.2.6 Special requirements for asynchronous generators

3.2.6.1 The voltage control characteristics of the asynchronous generator together with the converter performing its voltage control function, under steady-state and transient conditions, are to comply with the requirements for DC generators in standards^① accepted by CCS.

3.2.6.2 The asynchronous generator is to have its electrical energy conversion and control performed by an independent converter.

3.2.6.3 The asynchronous generator is to have the following functions:

(1) together with the energy storage system (if any), be capable of restoring the ship's power supply from a total loss of power state;

(2) be capable of providing sufficient fault current, or adopt alternative protection schemes, to achieve selectivity of the integrated DC power system protection.

3.2.7 Special requirements for variable speed operation generators

3.2.7.1 Variable speed operation generators are to be capable of operating and grid-connected generating within the entire speed range (or at speed points) specified by the manufacturer.

3.2.7.2 The speed governor of the prime mover of the variable speed operation generator is to be capable of being controlled both locally and from the manned position.

Section 3 FUEL CELLS

3.3.1 General requirements

3.3.1.1 In addition to the requirements of this Section, fuel cells are also to comply with the relevant requirements of Chapter 4, Part 2 of CCS Guidelines for Ships Using Hydrogen Fuel.

3.3.1.2 The composition of the main power source of the DC distribution system is to be reasonably designed according to the dynamic response indicators provided by the fuel cell manufacturer, so as to

achieve the requirements of 5.2.1.8, Chapter 5 of the Guidelines.

3.3.1.3 When the operating condition of the fuel cell changes such that the maximum actual output power capability may become lower than the rated power, the current actual maximum available power is to be provided to the PMS/EMS.

3.3.1.4 When a fuel cell is connected to the distribution system, measures are to be taken to ensure that energy can only flow unidirectionally from the power supply unit into the distribution system to prevent reverse power from damaging the equipment. A unidirectional DC/DC converter may be used to connect to the distribution system.

3.3.1.5 When a short circuit occurs on the main busbar, protective measures are to be provided to ensure that the fuel cell will not be endangered.

3.3.1.6 Protective devices are to be provided as overload and short-circuit protection for the fuel cell. In the event of overload or short circuit in the line between the fuel cell and the chopper, the protection function is to be achieved by means of the protective devices inside the fuel cell high voltage box. During any time-delay tripping time / fuse clearing time of the protective devices, the fuel cell is to be capable of withstanding the mechanical stress and thermal effects produced by the short-circuit current.

3.3.1.7 The short-circuit current of the fuel cell power installation is to be sufficient to cause the short-circuit protective device of its own branch to operate.

3.3.1.8 The fuel cell converter is preferably of an isolated type.

Section 4 ENERGY STORAGE DEVICES

3.4.1 General requirements

3.4.1.1 Multiple energy storage devices intended for parallel operation are to be connected to the DC bus-bar via converters and protective devices.

3.4.1.2 Where each energy storage device always operates independently (i.e., not in parallel operation), or other measures are adopted to prevent the formation of circulating currents between the energy storage devices that are sufficient to affect the safety of the energy storage devices (e.g., parallel operation cannot be executed when the voltage difference between the energy storage devices is too large), and the system functional requirements can be satisfied, they may be directly connected to the DC bus-bar via protective devices, thereby exempting from the requirements of 3.4.1.1 of this Section.

3.4.1.3 Energy storage devices connected to the DC bus-bar in the manner specified in 3.4.1.2 of this Section are to have inertia support capability compatible with the system. When switching energy storage devices or during instantaneous load fluctuations, the voltage fluctuation range and duration of the bus-bar and the battery are to comply with the short-time transient requirements for power quality specified in Table 2.1.2.2, Chapter 2 of the Guidelines. Equipment connected to the DC distribution system is to remain capable of normal operation and not endanger the safety of ship navigation. The system is to be capable of achieving natural recovery and stable operation through the discharge characteristics of the energy storage devices.

3.4.1.4 The system earthing method of the energy storage device is to be consistent with the system earthing method of the DC distribution system and the charging system.

3.4.1.5 The energy storage device (together with its management system) is to be capable of transmitting the necessary information to the converter charging the energy storage device, to ensure that each battery cell does not exceed the voltage, current and temperature limits specified by the manufacturer during the charging process.

3.4.1.6 An alarm is to be given when the energy storage device discharges to the lower operating limit specified by the manufacturer. When the limit value endangering the battery safety is reached, the discharge is to be automatically stopped, and the connection to the converter or DC bus-bar is to be disconnected (if applicable).

3.4.1.7 Internal faults of the energy storage device are not to affect the rest of the integrated DC power system.

3.4.1.8 A single-point earth fault inside the energy storage device is not to cause a short circuit.

3.4.1.9 Upon a fault, the energy storage device is to be capable of being isolated from the DC distribution system. This may be achieved by a circuit breaker with isolating function, or a converter equipped with an isolator.

3.4.1.10 The energy storage device (together with its management system) is to be capable of transmitting the necessary information to the PMS/EMS to realize energy optimization and charge/discharge management.

3.4.1.11 The inrush current level at the start-up of the energy storage device is to be compatible with the current-carrying capacity of the equipment in the distribution system to which it is connected.

3.4.1.12 The start-up time of the energy storage device is to meet the power restoration time requirements of 4.2.2.5(5) and 4.3.2.4(2), Chapter 4 of the Guidelines. In hot standby state, the time from the receipt of the PMS/EMS control signal by the energy storage device to the discharge power first reaching 90% of the rated power is not to exceed 0.2 s, and the time to the discharge power reaching 100% of the rated power with the power deviation constantly controlled within $\pm 1\%$ of the rated power is not to exceed 1 s.

3.4.2 Protection

3.4.2.1 In the event of a short circuit in the line between the energy storage device and the corresponding chopper (if any), or between the energy storage device and the DC switchboard, the protection function is to be achieved by the blowing of fuses inside the high voltage box or near the installation location.

3.4.2.2 Each series-connected battery cluster is to be provided with an independent protective device to limit the internal short circuit of a battery cell or single string.

3.4.2.3 In general, the failure of a single battery string is not to cause the entire battery group to be taken out of operation. If this is necessary due to special operating conditions, approval by CCS is to be obtained.

3.4.2.4 The protection function activated by the battery management system is not to be overridden.

3.4.3 Special requirements for storage batteries

3.4.3.1 In addition to the provisions of 3.4.3.2 to 3.4.3.7 of this Section, lithium-ion storage batteries are also to comply with the relevant requirements of CCS Rules for Ships Using Battery Power.

3.4.3.2 Only storage batteries of the same model and manufactured on the same production line are permitted to be connected within the same battery system. Subsequent repair and replacement are also to be evaluated, and batteries with performance close to that of the original equipment are to be adopted.

3.4.3.3 Measures are to be provided to allow only authorized personnel to open and enter the battery cabinet or module.

3.4.3.4 Except for the power supply, control and communication cables of the battery system itself, and the ancillary systems necessary to maintain the normal operation of the battery system, electrical equipment (including cables) essential for maintaining the ship in a normal operational state and satisfying normal habitability conditions is not to be arranged in the battery compartment.

3.4.3.5 Battery systems used to achieve the redundancy required by 2.2.5.1, Chapter 2 of the Guidelines are not to be installed in the same battery cabinet or battery compartment.

3.4.3.6 An emergency stop device for stopping the operation of the storage battery is to be provided outside the battery space, in close proximity.

3.4.3.7 The emergency stop device is to be a hardwired circuit independent of the control and monitoring system.

3.4.4 Special requirements for supercapacitors

3.4.4.1 In addition to the provisions of 3.4.4.2 to 3.4.4.9 of this Section, supercapacitors are also to comply with the relevant requirements of CCS Rules for Ships Using Battery Power.

3.4.4.2 The voltage drop caused by the charging current of the supercapacitor is not to cause instability of the integrated DC power system.

3.4.4.3 When the supercapacitor discharges in parallel with other power supply units, it is not to cause overvoltage in the integrated DC power system and overspeed of the generator.

3.4.4.4 An emergency stop device is to be provided outside the supercapacitor space, in close proximity.

3.4.4.5 The emergency stop device is to be a hardwired circuit independent of the control and monitoring system.

3.4.4.6 Where the supercapacitor supplies power to the ship's propulsion and steering gear, an additional emergency stop device is to be provided at the propulsion remote control position.

3.4.4.7 Warning signs indicating operational risks are to be provided at appropriate locations on the installation.

3.4.4.8 Devices such as interlocking mechanisms are to be provided to prevent electric shock to personnel during normal operation, maintenance, testing, repair and replacement.

3.4.4.9 The front panel of the supercapacitor installation is to be provided with insulated handrails or handles. If rear operation is required, they are also to be provided at the rear of the rack/assembly.

Section 5 PHOTOVOLTAIC POWER GENERATION SYSTEMS

3.5.1 General requirements

3.5.1.1 In addition to the requirements of this Section, photovoltaic power generation systems are also to comply with the relevant requirements of Section 2, Chapter 2 of CCS Guidelines for Survey of Solar Photovoltaic Systems and Lithium Iron Phosphate Battery Systems.

3.5.1.2 The key electrical performance parameters (such as open-circuit voltage, short-circuit current, peak power, etc.) of each photovoltaic module in the same photovoltaic module string are to be consistent.

3.5.1.3 Photovoltaic combiner boxes are to be provided with lightning protection.

3.5.1.4 The voltage, array orientation and installation inclination angle of photovoltaic module strings connected to the same converter are to be consistent.

3.5.1.5 For a grid-connected photovoltaic power generation system connected to a DC distribution system, the capacity of the grid-connected photovoltaic power generation system may be higher than 10% of the total capacity of the power supply units on grid in the DC distribution system, provided that one of the following requirements is met:

(1) documentation can be provided to demonstrate that when it is put into / disconnected from the DC distribution system under reasonably foreseeable operating conditions, the system power quality can still

meet the requirements of 2.1.2, Chapter 2 of the Guidelines;

(2) the photovoltaic power generation system is capable of accepting the management and dispatch of the PMS/EMS;

(3) the photovoltaic power generation system is to have the capability to limit the rate of change of output power. The output power change rate and the maximum power limit are not to exceed the limits currently given by the PMS/EMS; however, the output power decrease rate of the photovoltaic power generation system caused by a rapid decrease in solar irradiance is not subject to this limitation.

3.5.1.6 A grid-connected photovoltaic power generation system connected to a daily AC distribution system is to meet the following requirements:

(1) the design of the photovoltaic power generation system is to ensure the safe and stable operation of the daily AC distribution system;

(2) the voltage deviation and harmonic content at the connection point are to comply with the relevant requirements for power quality in the relevant CCS rules;

(3) after the connection of the grid-connected photovoltaic system, the short-circuit current at each busbar node of the daily AC distribution system under the maximum operating mode is not to exceed the breaking current limit of the circuit breaker;

(4) the photovoltaic power is to be consumed locally in the daily AC distribution system as a priority. Under the most unfavourable situation, the power fed back to the DC distribution system through the daily AC inverter is not to exceed 80% of the rated value of each equipment and cable in the inverter branch.

3.5.2 Protection

3.5.2.1 The photovoltaic power generation system is to be capable of detecting the voltage deviation of the DC distribution system and safely disconnecting the photovoltaic power generation system from the DC distribution system when the deviation exceeds the limits.

3.5.2.2 When the DC distribution system to which the photovoltaic power generation system is connected loses voltage, the photovoltaic power generation system is to be disconnected from the DC distribution system (time delay is permitted) to prevent islanding effect.

3.5.2.3 If the photovoltaic power generation system stops operating due to voltage exceeding the limits, a certain time delay is to be set before the photovoltaic power generation system restores power supply after the voltage of the DC distribution system recovers.

3.5.2.4 Short-circuit protection is to be provided for the photovoltaic power generation system with respect to the DC distribution system. In the event of a short circuit, the converter is to have a current limiting function.

3.5.2.5 A mechanical switch with a visible break is to be provided at the point of connection between the photovoltaic power generation system and the DC distribution system.

3.5.2.6 Reverse power protection is to be provided for the photovoltaic power generation system.

Section 6 CONVERTERS

3.6.1 General requirements

3.6.1.1 This Section applies to converters directly connected to the DC bus-bar, such as generator rectifiers, converters for energy storage device connection, transducers (for propulsion or operation) and inverters (for daily use).

3.6.1.2 In addition to the requirements of this Section, converters are also to comply with the relevant requirements of Section 8, Chapter 3, Part 4 of CCS Rules for Classification of Sea-going Steel Ships.

3.6.1.3 The technical performance of the converter such as harmonics, power factor and ripple is to meet the requirements of the connected AC/DC grid.

3.6.1.4 Converters used to supply AC loads are to be capable of providing reactive power within their rated power operating range.

3.6.1.5 Converters are generally to have a certain short-time overload capability, with the reliable working time at 110% rated power being preferably not less than 1 min.

3.6.1.6 The power components of the converter are to be easy to replace and maintain.

3.6.1.7 The converter control system is to ensure that the power components do not exceed the permissible current limits under normal operating conditions.

3.6.1.8 The converter is to have a fault diagnosis function and be capable of indicating the possible fault location under abnormal conditions.

3.6.1.9 For a DC distribution system where the converter load ratio is higher than 70% and the parallel mode of 2.2.5.3(2), Chapter 2 of the Guidelines is not adopted, the converters are to be capable of avoiding negative impedance oscillation through reasonable control.

3.6.1.10 Converters are to be capable of withstanding the possible voltage or current peaks on the DC bus-bar. Conditions occurring under normal and reasonably foreseeable abnormal situations are to be considered, for example, voltage peaks caused by short circuits and the operation of protective devices, and current peaks of converters caused by the restoration of power supply in non-fault areas.

3.6.1.11 Converters are to have the function of preventing reverse power flow from the DC bus-bar to the generator. Where converters capable of bidirectional energy flow are used (such as converters for energy storage connection, transducers or inverters also serving as rectifiers), the magnitude of power permitted to flow bidirectionally through the converter is to be evaluated to ensure the safe operation of the DC distribution system and its connected electrical equipment.

3.6.1.12 The protective devices of the converter branch are to be provided with operating status monitoring function. Appropriate measures are to be provided to suppress the switching overvoltage and switching overcurrent generated when the converter is connected to the grid, which is not to cause the shutdown of the converter or damage to the protective devices of its branch.

3.6.1.13 When the DC bus-bar voltage is very low, if the inrush current during the start-up process of the converter is so large as to pose a safety hazard, a pre-charge circuit is to be provided for limitation.

3.6.1.14 Power supply unit converters are generally to obtain power from the power supply unit side, and load converters are generally to obtain power from the DC bus-bar side.

3.6.1.15 The converter cabinet door is only to be permitted to be opened when the internal capacitor voltage is lower than 50 V. If this condition cannot be met, the cabinet door is to be opened only with a tool or key, and warning signs are to be provided according to 6.5.2 of IEC 61800-5-1.

3.6.2 Cooling

3.6.2.1 Where the converter is force-cooled, a monitoring device for the operating status of the cooling system is to be provided. In the event of a cooling system failure, protective measures are to be taken to prevent damage to the converter, and an alarm signal is to be triggered. The alarm signal may be realized through the monitoring of the coolant flow or the monitoring of the temperature of the semiconductor components. Flow monitoring may be replaced by monitoring the temperature difference between the inlet and outlet.

3.6.2.2 Converters of 100 kW and above are to adopt liquid cooling systems as far as practicable.

3.6.2.3 Converters using liquid-cooled radiators are to be provided with a coolant leakage monitoring device.

3.6.2.4 Where the power components are liquid-cooled, the liquid cooling branch of each converter is to be independent of each other.

3.6.2.5 A single failure in the converter cooling system is not to cause tripping of all converters in the integrated DC power system, and the ship is to maintain basic manoeuvring capability.

3.6.3 Protection

3.6.3.1 Converters are to be provided with overvoltage and undervoltage protection, and are to meet the following requirements:

(1) when the voltage rises to 130% of the rated voltage (or other values specified by the manufacturer) and above, it is to operate after a time delay of 5 ms;

(2) when the voltage drops to 70% of the rated voltage (or other values specified by the manufacturer) and below, it is to operate after a time delay of 1 ms, and be compatible with the selectivity protection requirements of the system. The operating time of the daily inverter is also to meet the provisions of 4.3.1.4, Chapter 4 of the Guidelines.

3.6.3.2 In the event of a direct short-circuit fault at the output terminal of the converter, the power components are not to be damaged.

3.6.3.3 Power supply unit converters are generally to have both instantaneous and inverse-time overcurrent protection functions, and adjustment of the inverse-time protection characteristics is to be permitted. The short-circuit fault ride-through function specified in 2.3.2.2, Chapter 2 of the Guidelines may be regarded as a special form of inverse-time overcurrent protection.

3.6.3.4 If the design of the generator rectifier can prevent reverse current flow from the DC bus-bar to the generator set, it may replace the generator reverse power protection.

3.6.3.5 Load converters (such as transducers and daily inverters) are to be capable of controlling the current to ensure that no components are damaged in the event of overload inside the load converter, in the AC side feeder line or in the load. Where necessary, a backup short-circuit protective device is to be provided between the DC bus-bar and the load converter.

3.6.3.6 Where necessary, the converter of the power supply unit is to have a fault current limiting function. The effective value of the fault current and the current limiting time are to be greater than the fault characteristic current value and duration required for fault location by the protective relay (the tripping time of the circuit breaker or the clearing time of the fuse). The converter is to have an automatic switching function for the current limiting operation mode. When its operating current exceeds the normal operating current range, the converter is to automatically enter the current limiting operation mode; when its operating current recovers from the fault current to the normal operating current, the converter is to automatically exit the current limiting operation mode.

3.6.4 Special requirements for frequency converters driving propulsion motors

3.6.4.1 The design of the frequency converter is to be based on the rated torque of the propulsion motor, and the shutdown protection is not to be triggered when subjected to the short-time overload of the propulsion motor and the resulting power fluctuations.

3.6.4.2 The frequency converter is to have a starting current control function and ensure that the power components are not damaged when starting under the locked-rotor condition of the propulsion motor.

3.6.4.3 Energy storage devices, braking resistors or similar measures are to be used to absorb or suppress the braking energy of the propulsion motor (e.g., the energy generated when the propeller is switched from full ahead to full astern), to prevent damage to the electrical equipment of the DC distribution system due to excessive pumping voltage and tripping of protective devices due to reverse power. Alternatively, documentation may be submitted to demonstrate that the recovery of the propulsion motor braking energy will not cause pumping voltage of the DC bus-bar. During the normal motoring operation of the propulsion motor, the pumping voltage suppression circuit is not to be activated. At the end of the operation of the pumping voltage suppression circuit, the DC bus-bar voltage is not to drop too low to avoid causing system instability.

3.6.4.4 The frequency converter may drive the propulsion motor by means of speed control or torque control, and is to limit the output torque of the frequency converter or the maximum speed of the propulsion motor to ensure the safety of ship navigation and equipment.

3.6.4.5 When the frequency converter supplies power to a permanent magnet motor, the switching device with breaking capacity required in 3.7.6.1 of this Chapter is to be capable of automatically breaking in the event of an inverter fault.

Section 7 PROPULSION MOTORS

3.7.1 General requirements

3.7.1.1 In addition to the requirements of this Section, propulsion motors are also to comply with the relevant requirements of Section 2, Chapter 3, Part 4 of CCS Rules for Classification of Sea-going Steel Ships.

3.7.1.2 The configuration and number of motors together with the corresponding converters are to meet the requirements of 2.2.1.1, Chapter 2, Part 8 of CCS Rules for the Construction of Inland Waterways Steel Ships or 15.2.1.6 to 15.2.1.8, Chapter 15, Part 8 of CCS Rules for Classification of Sea-going Steel Ships.

3.7.1.3 The enclosure protection degree of propulsion motors is to be not lower than IP23. The enclosure protection degree of high-voltage (AC with phase-to-phase rated voltage exceeding 1 kV, or DC with pole-to-pole rated voltage exceeding 1.5 kV) motors is to be not lower than IP44.

3.7.1.4 The design of a motor supplied by a converter is to meet the harmonic characteristic requirements and leave sufficient margin for the additional temperature rise caused by total harmonic distortion.

3.7.1.5 The motor and shafting are to be capable of withstanding all load conditions. The effects of torsional excitation generated by electrical components on the system are to be considered and proven through torsional vibration calculations to ensure that all stresses do not exceed the design stresses. Special consideration is to be given to the maximum alternating torque that may be generated during asymmetrical faults (such as two-phase short circuits) and the maximum peak torque that may be generated during symmetrical faults (such as three-phase short circuits).

3.7.1.6 For a propulsion motor with an independent excitation circuit, its excitation circuit is to be supplied from the same switchboard section or power supply unit as the stator winding supply.

3.7.1.7 Propulsion motors are to be capable of withstanding a direct short circuit at the output terminal under all operating conditions.

3.7.1.8 The cables of different propulsion motors are to be routed away from each other. The cable installation is to ensure that any single electrical fault, local fire and the subsequent actions of safety systems

will not cause a total loss of the ship's propulsion capability.

3.7.2 Bearings and lubrication

3.7.2.1 For the bearings and lubrication system of the propulsion motor, in addition to meeting the technical requirements for generator bearings in 3.2.2 of this Chapter, when a forced lubrication system is used, its bearings are to be provided with redundant pump sets.

3.7.3 Cooling

3.7.3.1 For the cooling system of the propulsion motor, in addition to meeting the technical requirements for generator cooling systems in 3.2.3 of this Chapter, the following requirements are to be met:

- (1) it is to be ensured that the cooling system operates effectively under all load and speed conditions;
- (2) the temperature monitoring device for the windings and the cooling medium is to trigger an alarm when the temperature exceeds the set limit value;
- (3) in the event of a failure of the propulsion motor cooling system, it is to be possible to maintain basic propulsion capability for a short time when necessary, allowing the operator to override and take emergency intervention measures (if applicable).

3.7.4 Anti-condensation

3.7.4.1 Propulsion motors are to be provided with electric heating devices, the design of which is to ensure that the internal temperature is always at least 3°C higher than the ambient temperature.

3.7.5 Protection

3.7.5.1 The overcurrent protection setting values of the main circuit and the excitation circuit (if any) are to avoid the instantaneous overcurrents generated during ship manoeuvring, severe weather conditions or navigation in ice.

3.7.5.2 The short-circuit and overcurrent protection of the propulsion motor may be realized by the converter.

3.7.5.3 When a short-circuit fault occurs in the DC distribution system, consideration is to be given to the possibility that the propulsion motor may discharge to the short-circuit point through the antiparallel diodes of the frequency converter before the protective devices of the DC distribution system operate, so as to avoid damage to the propulsion motor and the frequency converter.

3.7.5.4 Propulsion motors are to be provided with overspeed protection devices. The setting range of the overspeed protection device is to be compatible with the dynamic characteristics of the ship's propulsion system.

3.7.5.5 The structural design of the propulsion motor is to be capable of withstanding the limit speed corresponding to the setting value of the overspeed protection device without sustaining mechanical damage.

3.7.6 Special requirements for permanent magnet motors

3.7.6.1 Measures are to be provided to reliably isolate the permanent magnet motor from the converter supplying it. In addition, one or more of the following measures, including but not limited to, are to be provided to prevent the high voltage generated at the electrical port of the propulsion motor by the energy fed back by the propulsion motor in non-propulsion states (e.g., when the ship is being towed) from endangering personnel safety:

- (1) shaft locking device, braking device or other equivalent measures capable of fixing the main shaft

under towing conditions;

(2) decoupling of the motor shaft from the main shaft to ensure that the motor shaft remains stationary.

3.7.6.2 In the event of an internal short-circuit fault in a permanent magnet motor, the power supply to its three-phase windings is to be cut off by a circuit breaker.

3.7.6.3 Under steady-state short-circuit current conditions, the permanent magnet synchronous motor is to ensure that:

(1) the motor body is not thermally damaged;

(2) the temperature rise of the current-carrying parts (including cables, slip rings, etc.) does not exceed the limits specified by the manufacturer.

3.7.7 Maintainability

3.7.7.1 Access for maintenance is to be provided to enable inspection, disassembly and replacement of the stator and rotor windings.

3.7.7.2 A shafting support device is to be provided so that the rotating shaft can be fixed during bearing inspection and replacement.

3.7.7.3 Sufficient maintenance space is to be provided to enable the conditions for slip ring surface polishing, as well as the adjustment and replacement of brushes, rotating rectifiers and protective devices.

3.7.7.4 The coupling is to be of a monobloc structure, and its design is to enable integral disassembly and assembly without axial movement of the driving shaft and the driven shaft, or without disassembly of the magnetic pole components.

Section 8 HARMONIC FILTER DEVICES

3.8.1 General requirements

3.8.1.1 Where harmonic filter devices for suppressing harmonic distortion in the daily AC distribution system grid are provided, they are to meet the requirements of this Section.

3.8.1.2 Each independent filter circuit is to be provided with overcurrent and short-circuit protective devices, and a fault monitoring function for the filter device is to be provided.

3.8.1.3 An alarm signal is to be triggered when the protective device of the filter circuit operates.

3.8.1.4 The filter device is to adopt a three-phase integral structure, with independent protective devices provided for each phase. When the protective device of any phase operates, the entire filter group is to be automatically cut off.

3.8.1.5 In addition to overcurrent protection, an independent current unbalance detection system is to be provided to issue a warning in case of abnormality.

3.8.1.6 A single failure in the filter system is not to cause failure of the daily AC distribution system.

3.8.1.7 The design of the filter device is to cover all possible grid operating conditions, and self-resonance is not to occur under any combination of load conditions and power plants.

3.8.1.8 The enclosure design of the harmonic filter device is to comply with the requirements for main switchboards in the relevant rules.

CHAPTER 4 SYSTEM PROTECTION

Section 1 GENERAL PROVISIONS

4.1.1 General requirements

4.1.1.1 The protection of the integrated DC power system is to minimize the possibility of power interruption and equipment damage.

4.1.1.2 When the bus-tie protective device is closed, partial disturbances (such as voltage dips caused by short circuits) are permitted to propagate to adjacent busbars, but the duration and severity of the disturbance in adjacent sections are to be evaluated according to the application scenario and ship operational requirements.

4.1.1.3 A single busbar sectionalized system is to be capable of ensuring that a fault on one busbar section does not affect the operation of adjacent busbar sections.

4.1.1.4 Each distribution branch of the integrated DC power system is to be provided with an isolating switch or similar means to prevent injury to personnel due to inadvertent contact with live parts when equipment is under maintenance. The isolating switch may be located as required and is to be provided with corresponding marking nearby to indicate which electrical connection has been disconnected.

4.1.1.5 In addition to the requirements of this Chapter, the system protection is to comply with Section 5, Chapter 2, Part 4 of CCS Rules for Classification of Sea-going Steel Ships or Section 3, Chapter 2, Part 3 of CCS Rules for the Construction of Inland Waterways Steel Ships. For certain specific applications (e.g., navigating in torrent reaches, or ships equipped with a dynamic positioning system), the specific requirements of the relevant rules (such as 2.2.13, Chapter 2, Part 8 of CCS Rules for the Construction of Inland Waterways Steel Ships, Chapter 11, Part 8 of CCS Rules for Classification of Sea-going Steel Ships, etc.) are also to be complied with.

Section 2 PROTECTION DESIGN OF DC DISTRIBUTION SYSTEM

4.2.1 General requirements

4.2.1.1 The DC distribution system may use protective devices such as air circuit breakers, moulded-case DC circuit breakers, solid-state switches and DC fuses, combined with the protection strategy design, to achieve fast breaking and isolation of system short-circuit faults, allowing the non-faulty parts of the system to resume normal operation without expanding the fault scope. Converters may also serve as part of the protection function implementation.

4.2.1.2 Bus-tie protection is to be implemented using protective devices capable of simultaneously breaking all insulated poles. As an alternative, a main protective device plus a backup protective device may be used for bus-tie protection, where the main protective device is to be capable of breaking at least the single pole of a single-pole system, and the positive and negative poles of a two-pole or pseudo two-pole system; the backup protective device is to be capable of breaking all insulated poles (including positive pole, negative pole, neutral line and metallic return); after the protective device operates, all insulated poles are to be automatically disconnected from the busbar (e.g., by means of a DC contactor on the line).

4.2.1.3 A power supply unit whose operation relies heavily on the DC bus-bar voltage stability, e.g.,

an asynchronous generating set (including its rectifier), should not use a DC circuit breaker as its protective device.

4.2.1.4 Where the necessary current and adequate sustaining time cannot be provided to maintain the operation of the protective device of the DC distribution system, the branch of a power supply unit (and its converter) is not to use a DC circuit breaker as its protective device.

4.2.1.5 Power supply units (including converters) are to be provided with overload and short-circuit protection functions:

(1) the overload protection setting value of the protective device is to be configured based on the rated current of the power supply unit (including the converter) and avoid the inrush current during startup or grid-connection of the power supply unit (including the converter);

(2) in the event of an internal short-circuit fault in the power supply unit (including its converter), it is to immediately stop operation and disconnect from the DC bus-bar, and this is not to affect the normal operation of other power supply units in parallel with it;

(3) the operating time of the protective device between the converter of the power supply unit and the DC bus-bar is to be compatible with the converter topology. For example, during a short circuit, it is to be possible to limit the duration of the short-circuit current fed by the power supply unit through the main circuit diode of the boost chopper to the short-circuit point, or to limit the magnitude and duration of the constant short-circuit current output to the short-circuit point through converter current limiting control, so as to prevent equipment damage.

4.2.1.6 Except for necessary maintenance, the isolating switch on the distribution branch of the DC distribution system is to remain in the connected state, unless a branch is in a fault condition, or documentary evidence can be submitted to demonstrate that the isolating switch to be disconnected will not affect the selectivity protection of the system.

4.2.1.7 The load branches of the DC distribution system are to be provided with instantaneous short-circuit protection. In the event of a short-circuit fault on the load branch, the protective device at the load input end is to operate instantaneously with priority; after isolating the fault, all other distribution branches are to continue normal power supply.

4.2.2 Selective protection principles

4.2.2.1 Unless otherwise specified in 4.2.2.2 to 4.2.2.6 of this Section, the short-circuit selective protection of the DC distribution system is to comply with 2.5.4, Part 4 of CCS Rules for Classification of Sea-going Steel Ships or 2.3.1.1, Part 3 of CCS Rules for the Construction of Inland Waterways Steel Ships.

4.2.2.2 The protection of the DC distribution system is to be coordinated with that of the daily AC distribution system. Adjacent protection zones are to overlap, and no protection dead zone is to exist.

4.2.2.3 Each electrical installation within the DC distribution system is to be provided with complete internal protection according to its different characteristics in accordance with the requirements of Chapter 3 of the Guidelines, to ensure reliable clearance of internal faults of the equipment.

4.2.2.4 In the event of a short-circuit fault on one section of the multi-section DC bus-bar:

(1) the power supply units and load devices on this section and adjacent bus-bar sections are not to be damaged;

(2) the protective device is to be capable of local reset; if a fuse is used, its construction and arrangement are to facilitate replacement;

(3) if a centralized topology is adopted for the system, the bus-tie protective device is to be disconnected within not more than 0.4 s at the latest; the duration and severity of the fault impact on adjacent bus-bar

sections are to be limited, and it is not to cause operation of the protective devices of any branch on adjacent bus-bar sections or stoppage of equipment. If operation of protective devices on adjacent sections and equipment stoppage are unavoidable, the operation to restore power supply and equipment operation on adjacent bus-bar sections is to be automatically executed immediately;

(4) if a centralized topology is adopted for the system, the bus-tie protective device is recommended to be a solid-state switch (operating and isolating the fault within tens or hundreds of microseconds); if other types of bus-tie protective devices are used, documentary evidence is to be submitted to demonstrate that the same safety and reliability as described in (3) above can be achieved under all operating conditions;

(5) if a distributed topology is adopted for the system, the protective devices of all branches of power supply units on grid on the faulty bus-bar section are to operate, and the power supply to other non-faulty bus-bar sections is not to be affected;

(6) for periodically unattended machinery spaces, automatic starting of the standby power source and automatic connection to the switchboard is to be achievable.

4.2.2.5 In the event of a short-circuit fault at the output terminal of any power supply unit (including its converter):

(1) separate short-circuit protection is to be provided to limit the impact of the short circuit on the equipment of the faulty branch;

(2) the short-circuit protection is to be capable of completing the operation of the protective device of the distribution branch of the faulty power supply unit within not more than 0.6 s;

(3) other power supply units and load devices on this section and adjacent bus-bar sections are not to be damaged;

(4) except for the bus-tie protective device, the protective devices of other branches of the local and adjacent bus-bar sections are not to operate (excluding cases such as automatic shedding of non-essential loads);

(5) if the power supply unit of the faulty branch is the only on-grid power supply source for the DC distribution system, and the DC distribution system loses power due to the short-circuit fault and protection operation, the standby power supply unit is to be automatically started within 30 s after the loss of power (where conditions permit, e.g., when a battery group is used as the standby power supply unit, it is preferably to be automatically started within 0.5 to 20 s after loss of power) to restore the power supply of the DC distribution system, with the maximum duration not exceeding 45 s;

(6) if there are other power supply units operating in parallel in the DC distribution system, in principle, apart from the operation of the protective device of the distribution branch where the faulty power supply unit is located (in the case of a circuit breaker, it is to be instantaneous reverse current protection), it is not to cause the operation of protective devices of any other branch (excluding cases such as automatic shedding of non-essential loads). If it is considered necessary due to factors such as limiting the scope of fault impact, operation of the bus-tie protective device is permitted to reduce the impact on adjacent bus-bar sections;

(7) if there are other power supply units operating in parallel in the DC distribution system, the duration and severity of the fault impact on this section and adjacent bus-bar sections are to be limited; during the operation of the protective device of the distribution branch where the faulty power supply unit is located, the non-faulted equipment on this section and adjacent bus-bar sections is not to shut down or have its corresponding circuit breaker trip due to DC undervoltage; after the completion of the operation of the protective device of the distribution branch where the faulty power supply unit is located, as the supply voltage recovers, the non-faulted equipment is to automatically return to normal operation; daily inverters are to have the low voltage ride-through capability required by 4.3.1.4 of this Chapter, so that during the operation

of the protective device of the distribution branch of the faulty power supply unit, the AC daily load is not interrupted;

(8) for periodically unattended machinery spaces, automatic starting of the standby power source and automatic connection to the switchboard is to be achievable.

4.2.2.6 In the event of a short-circuit fault at the input terminal of any load (including its converter):

(1) separate short-circuit protection is to be provided to limit the impact of the short circuit on the system or equipment, and the power supply units of this section and adjacent bus-bar sections are to remain continuously available;

(2) the short-circuit protection is to be capable of completing the operation of the protective device of the faulty load branch within not more than 0.2 s;

(3) other power supply units and load devices on this section and adjacent bus-bar sections are not to be damaged;

(4) in principle, apart from the immediate operation of the protective device of this load branch (in the case of a circuit breaker, it is to be instantaneous), it is not to cause the operation of protective devices of any other branch. If it is considered necessary due to factors such as limiting the scope of fault impact, operation of the bus-tie protective device is permitted to reduce the impact on adjacent bus-bar sections;

(5) the duration and severity of the fault impact on this section and adjacent bus-bar sections are to be limited; during the operation of the protective device of the faulty load branch, the non-faulted equipment on this section and adjacent bus-bar sections is not to shut down or have its corresponding circuit breaker trip due to DC undervoltage; after the completion of the operation of the protective device of the faulty load branch, as the supply voltage recovers, the non-faulted equipment is to automatically return to normal operation; daily inverters are to have the low voltage ride-through capability required by 4.3.1.4 of this Chapter, so that during the operation of the protective device of the faulty load branch, the AC daily load is not interrupted.

Section 3 PROTECTION DESIGN OF DAILY AC DISTRIBUTION SYSTEM

4.3.1 General requirements

4.3.1.1 A protective device is to be provided at the output of an AC power supply unit, having the functions of overload and short-circuit protection.

4.3.1.2 Where an inverter is used alone as the power supply source for the daily AC distribution system, in the event of an AC short-circuit fault, it is to be switched to constant current output mode according to the requirements of 2.3.2.2, Chapter 2 of the Guidelines. The effective value of the constant current output is to be more than twice the rated RMS AC current of the inverter (set based on the principle of achieving instantaneous operation of the protective devices of the essential daily load distribution branches). If the constant current output duration exceeds 0.5 s and the short-circuit fault is still not broken and isolated, the inverter control signals are to be immediately blocked to limit the inverter output.

4.3.1.3 Where inverters and AC synchronous generating sets are arranged in parallel as the power supply source for the daily AC distribution system, in the event of an AC short-circuit fault, the short-circuit current is to be provided mainly by the AC synchronous generating sets, and the inverters may operate with constant current output during the short circuit by referring to 4.3.1.2 of this Section.

4.3.1.4 If the faults specified in 4.2.2.5 and 4.2.2.6 of this Section would cause the DC bus-bar voltage to drop below the inverter undervoltage protection shutdown threshold, the inverter is to have a low voltage ride-through function. The low voltage ride-through time is to be as compatible as possible with the response time of the short-circuit protection operation, so that the AC daily load is not interrupted during the blowing of the fuse and the instantaneous protection operation specified in 4.2.2.5(6) and 4.2.2.6(4) of this Chapter. In general, the inverter is to be capable of maintaining uninterrupted power supply to the AC daily load within 30 ms when a DC side voltage drop or power loss occurs at a load rate not exceeding 50%.

4.3.1.5 Loads are to be provided with short-circuit protection functions, and essential loads are also to be provided with overload protection functions.

4.3.1.6 The protection design of the daily AC distribution system is to achieve total selective protection for essential electrical equipment and loads.

4.3.2 Selective protection principles

4.3.2.1 Unless otherwise specified in 4.3.2.2 to 4.3.2.5 of this Section, the selection of short-circuit protective devices and the design of the selective protection strategy for the daily AC distribution system are to comply with the requirements of 2.5.3 to 2.5.4, Part 4 of CCS Rules for Classification of Sea-going Steel Ships or 2.3.1 and 2.3.3, Chapter 2, Part 3 of CCS Rules for the Construction of Inland Waterways Steel Ships.

4.3.2.2 When a fault occurs in the daily AC distribution system, the fault is to be selectively cleared by the protective devices on the AC side, avoiding shutdown of the daily inverter as far as possible, and is not to cause maloperation of the protection of the DC distribution system.

4.3.2.3 In the event of a short-circuit fault on the AC bus-bar:

(1) the power supply units and load devices on this bus-bar section are not to be damaged;
(2) the protective devices of the distribution branches of the power supply units supplying power to the AC bus-bar are to operate;

(3) if a short-circuit fault occurs on one bus-bar section and there are power supply units supplying power on other AC bus-bar sections, the bus-tie protective device is to be disconnected with priority, to avoid the operation of protective devices on any branch of the other bus-bar sections and the stoppage of equipment.

4.3.2.4 In the event of a short-circuit fault at the output terminal of any power supply unit:

(1) separate short-circuit protection is to be provided to isolate the short-circuit fault and limit the impact of the short circuit on the system or equipment;

(2) if the power supply unit is the only on-grid power supply source in the daily AC distribution system, and the AC bus-bar loses power due to the short-circuit fault and protection operation, the standby power supply unit is to be automatically started within 30 s after the loss of power (where conditions permit, it is preferably to be automatically started within 0.5 to 20 s after loss of power) to restore the power supply of the daily AC distribution system, with the maximum duration not exceeding 45 s;

(3) if there are other power supply units operating in parallel in the daily AC distribution system, the short-circuit fault and protection operation are not to cause loss of power to all AC bus-bars. It is recommended to use differential protection or similar methods so that the protective device of the distribution branch where the faulty power supply unit is located operates with priority, and it is not to cause the operation of protective devices of any other branch (excluding cases such as automatic shedding of non-essential loads).

4.3.2.5 In the event of a short-circuit fault at the input terminal of any load:

(1) the protective device of this load distribution branch is to be automatically disconnected immediately (instantaneous operation) to ensure fast clearing of the short-circuit fault without causing power

interruption to the AC bus-bar and operation of protective devices of other branches.

Section 4 SHORT-CIRCUIT CURRENT CALCULATIONS AND CHOICE OF PROTECTIVE DEVICES

4.4.1 Short-circuit current calculations

4.4.1.1 The short-circuit current values at various points of the integrated DC power system may be calculated according to Annex 1 of the Guidelines or standards accepted by CCS, and compared with the time-current characteristic curves of the overcurrent protective devices to determine the setting values of the protective devices.

4.4.1.2 Short-circuit current calculations are to be carried out for the integrated DC power system and a calculation report is to be submitted, including the simulation model, calculation method and calculation results, and the calculated values of the maximum short-circuit current and the minimum short-circuit current are to be submitted.

4.4.1.3 The short-circuit current contribution of each power supply unit is to be calculated based on the electrical model and characteristic operating parameters provided by the manufacturer. For energy storage devices, the effects of factors such as the actual state of charge and ageing conditions are also to be considered.

4.4.1.4 The selectivity of the protective device operation for the integrated DC power system is to be determined based on the principles of 4.2.2 and 4.3.2 of this Chapter, so as to determine the setting values of fuses, semiconductor devices and circuit breakers.

4.4.1.5 In the first design stage, the consistency between the simulation results of the short-circuit calculations and selective protection analysis and the test results is to be compared according to the requirements of 1.3.2.5 and 1.3.6.3, Chapter 1 of the Guidelines.

4.4.2 Selection of protective devices

4.4.2.1 Integrated DC power systems and their electrical components are to comply with the following requirements:

- (1) being suitable for the environmental conditions of the location;
- (2) the rated voltage being compatible with the nominal voltage of the circuit where it is installed;
- (3) the rated current being not less than the calculated current of the circuit;
- (4) meeting the requirements for dynamic stability and thermal stability under short-circuit conditions;
- (5) protective devices used to break short-circuit currents meeting the requirements for making capacity and breaking capacity under short-circuit conditions.

4.4.2.2 The selection of conductors and protective devices for the DC distribution system is to comply with the requirements of 4.4.2.4 to 4.4.2.9 of this Section.

4.4.2.3 The selection of conductors and protective devices for the daily AC distribution system is to comply with 2.5.3, Section 5, Chapter 2, Part 4 of CCS Rules for Classification of Sea-going Steel Ships or Section 3, Chapter 2, Part 3 of CCS Rules for the Construction of Inland Waterways Steel Ships.

4.4.2.4 Conductors and bus-bars:

- (1) the continuous permissible current of conductors and bus-bars is not to be less than the continuous working current of the circuit;
- (2) the short-circuit current used for checking the dynamic stability and thermal stability of conductors

and bus-bars is to meet the requirements of the maximum prospective short-circuit current at the installation location.

4.4.2.5 Selection of DC isolating switches:

(1) the rated voltage of the isolating switch is not to be less than the maximum working voltage of the system;

(2) the rated current of the isolating switch is to be greater than any load current that may occur in operation;

(3) the short-circuit current used for checking the dynamic stability and thermal stability of the isolating switch is to meet the requirements of the maximum prospective short-circuit current at the installation location. During the duration of the short-circuit current in the circuit, the time-current characteristic curve of the short-circuit current is to be within the current withstand curve of the isolating switch, i.e., the isolating switch does not weld, ignite or explode under the action of the short-circuit current.

4.4.2.6 Selection of fast-acting fuses:

(1) the rated voltage of the fast-acting fuse is not to be less than the maximum working voltage of the system;

(2) the rated current of the fast-acting fuse is to be greater than any load current that may occur in operation;

(3) the breaking current used for checking the fast-acting fuse is not to be less than the maximum prospective short-circuit current to be broken at the installation location;

(4) the pre-arcing I^2t value of the fast-acting fuse is to comply with: the system short-circuit current and its total I^2t value are to be calculated under each typical fault in the maximum/minimum operation mode respectively; when the fuse of the fault circuit blows, the total I^2t value of the short-circuit current of each non-fault circuit is to be, as far as possible, less than half of the pre-arcing I^2t value of its fast-acting fuse;

(5) the total I^2t value of the fast-acting fuse is to comply with: the system short-circuit current and its total I^2t value are to be calculated under each typical fault in the maximum/minimum operation mode respectively; when the fuse of the fault circuit blows, the time-current characteristic curve of the circuit is to be within the current withstand curve of the isolating switch of this circuit;

(6) fast-acting fuses are to be provided with alarm contacts;

(7) fast-acting fuses are to be of the bolted type; when other types of fuses are used, documentation is to be provided to prove that the increased contact resistance caused by this installation method will not affect the selectivity of the system.

4.4.2.7 Selection of DC circuit breakers:

(1) DC circuit breakers are to have the functions of overcurrent protection, electrical isolation and DC arc extinguishing;

(2) the rated voltage of the DC circuit breaker is not to be less than the maximum working voltage of the system;

(3) the rated current of the DC circuit breaker is to be greater than any load current that may occur in operation;

(4) when checking the breaking capacity of the DC circuit breaker, it is advisable to take the short-circuit current at the actual breaking time of the circuit breaker as the checking condition;

(5) the rated short-circuit making current of the DC circuit breaker is not to be less than the maximum peak short-circuit current;

(6) in distribution systems where both the upstream and downstream protective devices are circuit breakers, the short-circuit current settings and/or short-time delay settings of the upstream and downstream

circuit breakers are to be coordinated to ensure protective selectivity of the upstream and downstream circuit breakers under the same fault current. If the circuit breaker is set only based on the instantaneous value of the short-circuit current, the short-circuit current setting of the upstream circuit breaker is to be greater than the maximum short-circuit current that may flow through the downstream circuit breaker; if the circuit breaker is also provided with a short-time delay trip device, the total breaking time of the downstream circuit breaker is to be less than the return time of the upstream circuit breaker. The following principles may be adopted:

① the bus-tie circuit breaker of the DC bus-bar is provided with short-time delay protection. In the event of a short-circuit fault, the bus-tie circuit breaker is to be capable of operating to isolate the fault, ensuring that the impact of the short-circuit fault on the non-fault side bus-bar and loads complies with the provisions of 4.2.2.4 and 4.2.2.5 of this Chapter;

② the output circuit breaker of the DC power supply unit is preferably provided with short-time delay protection and instantaneous reverse current protection. The delay time of the short-time delay protection is to be greater than the protection return time of the bus-tie circuit breaker; the instantaneous reverse current protection is used for fast isolation of faults when a short circuit occurs between the DC power supply unit and the DC bus-bar;

③ the load input circuit breaker is provided with instantaneous protection for fast isolation of faults and protection of load equipment from large short-circuit current shocks.

(7) within the time required for selective protection, the circuit breaker is to be capable of carrying the short-circuit current at the installation point without breaking;

(8) the rated current of the DC circuit breaker connected to the energy storage device is to be selected according to the charge and discharge current of the energy storage device, and the safety of the protection operation is to be checked according to the discharge current at the early stage of the fault, and it is to be coordinated with the protective devices of the upstream and downstream circuits (if any).

4.4.2.8 Selection of solid-state switches:

(1) the rated voltage of the solid-state switch is not to be less than the maximum working voltage of the system;

(2) the rated current of the solid-state switch is to be greater than any load current that may occur in operation;

(3) the solid-state switch is to be capable of withstanding the maximum peak voltage between any pair of terminals, and overvoltage absorption devices are to be provided if necessary;

(4) the control circuit of the solid-state switch is to have interlock and delay functions to prevent short circuits between the positive and negative poles caused by the bidirectional power electronic switch;

(5) the solid-state switch is to be capable of withstanding overcurrents that may occur during normal operation;

(6) the solid-state switch is to be capable of reliably breaking the short-circuit current, and the di/dt during breaking is not to exceed the limits specified in the product technical documentation.

4.4.2.9 Selection of DC contactors (load switches):

(1) the rated voltage of the DC contactor is not to be less than the maximum working voltage of the system, and it is to have the capability to withstand transient overvoltages of the DC distribution system;

(2) the rated current of the DC contactor is to be greater than any load current that may occur in operation, and the 1 min overload capacity is not to be less than 1.5 times the rated current;

(3) the breaking capacity of the DC contactor is not to be less than the maximum prospective overload current, and it is to have at least the capability to support one reclosing function;

(4) the short-circuit current used for checking the dynamic stability and thermal stability of the DC

contactor is to meet the requirements of the maximum prospective short-circuit current at the installation location. During the duration of the short-circuit current in the circuit, the time-current characteristic curve is to be within the current withstand curve of the DC contactor, i.e., the DC contactor does not weld, ignite or explode under the action of the short-circuit current.

4.4.3 Selective protection analysis

4.4.3.1 A selective protection analysis is to be carried out for the integrated DC power system and the analysis report is to be submitted.

4.4.3.2 The selective protection analysis of the DC distribution system is to analyze, one by one, the operation of the system protective devices and the scope of system impact when the faults specified in 4.2.2.4, 4.2.2.5 and 4.2.2.6 of this Chapter occur in the DC distribution system. Based on the short-circuit current calculations and the selection of protective devices, the fault clearance, the operation of non-fault branches, whether the bus-bar loses power, and the bus-bar voltage fluctuations are to be analyzed to confirm compliance with the short-circuit protection principles of 4.2.2 of this Chapter.

4.4.3.3 The selective protection analysis of the daily AC distribution system is to be based on the constant current output of the inverters and the time-current characteristic curves of the protective devices, and is to analyze, one by one, the operation of the system protective devices and the scope of system impact when the faults specified in 4.3.2.3, 4.3.2.4 and 4.3.2.5 of this Chapter occur in the daily AC distribution system. A coordination analysis of the protective devices at all levels is to be carried out to confirm compliance with the short-circuit protection principles of 4.3.2 of this Chapter.

4.4.4 Test and verification for initial installation of the system

4.4.4.1 For an integrated DC power system that has obtained CCS approval in principle (with a design approval document or an approval in principle certificate) and for which all or part of the tests specified in 4.4.4.2 of this Section have been carried out during the approval process, the tests specified in 4.4.4.2 of this Section that have already been completed during the approval in principle need not be repeated.

4.4.4.2 The following tests are to be carried out for the integrated DC power system:

(1) Short circuit between the positive and negative poles of the DC bus-bar of the DC distribution system. Under this fault condition, the bus-tie protective device (if any) connecting the faulty bus-bar section operates, the DC power supply unit shuts down or the protective device of its distribution branch operates; the non-fault bus-bar section is not affected or automatically restores power supply and equipment operation immediately after the operation of the bus-tie protective device; the power supply units and load devices are not damaged.

(2) Short circuit between the positive and negative poles at the output terminal of the power supply unit (including converter) of the DC distribution system. Under this fault condition, the protective device of the distribution branch of the faulty power supply unit is to operate; the DC distribution system is to be able to restore power supply within 45 s (when the faulty power supply unit is the only on-grid power supply source); the DC distribution system does not lose power, the non-fault equipment does not shut down due to undervoltage, and the daily inverter is to ensure uninterrupted power supply to the AC load during the low voltage ride-through period (when there are other power supply units operating in parallel); the power supply units and load devices are not damaged.

(3) Short circuit between the positive and negative poles at the input terminal of the load device (including converter) of the DC distribution system. Under this fault condition, the protective device of the faulty load branch is to operate; the daily inverter is to ensure uninterrupted power supply to the AC load

during the low voltage ride-through period; the power supply units and load devices are not damaged.

(4) Three-phase short circuit of the AC bus-bar of the daily AC distribution system. Under this fault condition, the bus-tie protective device (if any) connecting the faulty AC bus-bar section operates, the AC power supply unit shuts down or the protective device of its distribution branch operates; if the non-fault AC bus-bar section is supplied by a power supply unit, power supply and equipment operation can be automatically restored immediately after the operation of the bus-tie protective device; the power supply units and load devices are not damaged.

(5) Three-phase short circuit at the output terminal of the power supply unit of the daily AC distribution system. Under this fault condition, the protective device of the distribution branch of the faulty power supply unit is to operate; the daily AC distribution system is to be able to restore power supply within 45 s (when the faulty power supply unit is the only on-grid power supply source); the daily AC distribution system does not lose power (when there are other power supply units operating in parallel); the power supply units and load devices are not damaged.

(6) Three-phase short circuit at the input terminal of the load of the daily AC distribution system. Under this fault condition, the protective device of the faulty load branch is to operate, and the AC bus-bar and other load power supplies are not affected; the power supply units and load devices are not damaged.

If the above tests cannot be completed before installation on board due to equipment compatibility reasons, they are permitted to be carried out during mooring and sea trials.

When the DC distribution system adopts a distributed topology, the tests and verification specified in (1) above need not be carried out.

When only three-phase AC synchronous generating sets are used as the power supply source for the daily AC distribution system, the tests and verification specified in (4)-(6) above need not be carried out.

When each bus-bar section of the daily AC distribution system operates independently, the tests and verification specified in (4) above need not be carried out.

4.4.5 Test and verification for systems of the same type

4.4.5.1 "Same type" means that there are no fundamental changes in the system topological structure, protection principles and control logic. When applying for testing and verification to be carried out as a same-type system, documentary evidence is to be provided. The documentation is to include the following information of the first-built ship: ship identification number, system schematic diagram (may be a single-line diagram), short-circuit current calculation report, selective protection analysis report, and test verification details, and is to prove item by item its high consistency with the first-built system in accordance with 4.4.5.2 and 4.4.5.3 of this Section.

4.4.5.2 A DC distribution system meeting the following conditions may be considered as a same-type DC distribution system:

- (1) the number of DC bus-bar sections has not changed;
- (2) the types of protective devices of the DC distribution system branches (such as DC circuit breakers, fast-acting fuses, solid-state switches), and the manufacturer of fast-acting fuses has not changed or been replaced;
- (3) the types of power supply units in the DC distribution system have not been increased;
- (4) the specifications of converters in the DC distribution system have not changed;
- (5) the number of branches on each bus-bar section of the DC distribution system that can serve as short-circuit power sources (see 2.1.2, Section 2, Annex 1 of the Guidelines) has not decreased;
- (6) no fundamental change has occurred in the protection strategy of the DC distribution system (see

4.2.2 of this Chapter);

(7) the simulation/modelling calculation method used for calculating the short-circuit current is to be consistent with that used for the first-built system.

4.4.5.3 A daily AC distribution system meeting the following conditions may be considered as a same-type AC distribution system:

- (1) the number of AC bus-bar sections has not changed;
- (2) the main protection functions of the daily inverter (see 2.3.2, Chapter 2 of the Guidelines) and its manufacturer have not changed or been replaced;
- (3) the number of daily inverters put into operation under normal operating conditions has not changed;
- (4) no fundamental change has occurred in the protection strategy of the AC distribution system (see 4.3.1.4 and 4.3.2 of this Chapter);

(5) the simulation/modelling calculation method used for calculating the short-circuit current is to be consistent with that used for the first-built system.

4.4.5.4 For a same-type integrated DC power system that has been approved for initial installation and is subsequently installed on ships classed with CCS, the tests specified in 4.4.4.2 of this Section that were completed during the initial installation need not be carried out. The tests for such systems are also to meet the relevant requirements of the flag State administration (if any).

CHAPTER 5 CONTROL AND MONITORING

Section 1 GENERAL PROVISIONS

5.1.1 General requirements

5.1.1.1 The control and monitoring of the integrated DC power system are to be provided based on the system design principle and the functions of each equipment component, so as to ensure the continuity of power supply of the ship's power grid and the reliable operation of the ship's propulsion system.

5.1.1.2 Status monitoring is to be carried out for each power supply unit, DC switchboard, AC switchboard, converter, propulsion motor, protective device, etc. in the integrated DC power system, and the faulty sub-system or equipment is to be indicated.

5.1.1.3 The design of the control system is to satisfy the following requirements:

(1) the control system architecture is to achieve maximum system availability, reliability, maintainability and fault tolerance;

(2) the network topology is to adopt a redundant star or redundant ring structure as far as possible;

(3) the integrated DC power system is to be controllable under all sailing conditions and ship manoeuvring conditions, even when a single failure occurs in any system;

(4) failure of automatic control functions is not to render local manual control inoperative;

(5) the system is to have a self-diagnostic function and is to give an alarm in the event of a system or power supply failure;

(6) the ship's propulsion or manoeuvring capability is not to be affected by failure or maloperation of other shipborne control systems;

(7) the propulsion control system is to perform only propulsion-related functions and is not to interfere with other systems;

(8) the electromagnetic compatibility of the control system is to satisfy the requirements of Chapter 6 of the Guidelines.

5.1.1.4 The control system is to be provided with necessary interlocking protective devices to prevent damage caused by maloperation.

5.1.1.5 Safety actions are to limit the scope and consequences of fault effects and follow the fail-safe principle.

5.1.1.6 All remote and local operable positions are to be provided with emergency stop devices independent of the control system. The emergency stop devices are to be provided with protection against inadvertent activation.

5.1.1.7 The PMS/EMS is to be independent of the propulsion control system.

5.1.2 Monitoring and alarm requirements

5.1.2.1 The integrated DC power system is to be provided with at least the alarms and display items required in Table 5.1.2.1. These items are to be set in the engine control room (or locally if there is no control room). Alarms and displays equivalent to those in the table may be provided subject to CCS approval. Safety action alarms, group alarms for generators, propulsion motors and propulsion frequency converters, as well as the display of some essential parameters and data, are to be provided on the navigation bridge.

Monitoring and Alarm Items of Integrated DC Power System

Table 5.1.2.1

System	Monitored Parameters	Without additional notation			BRC, MCC, AUT-0 notation			Remarks
		Alarm	Display	Auto shutdown	Alarm	Display	Auto shut down	
Generator	Bearing lub. oil inlet pressure – low or bearing temperature – high	√	√	√	√	√	√	Prime mover automatic shutdown
	Voltage limit alarm (high/low)		√		√	√		Read all phases; not applicable to asynchronous generators
	Frequency or speed limit alarm (high/low)		√		√	√		For AC generators only
	Current		√			√		Read all phases; not applicable to asynchronous generators
	Power		√			√		Display consumed power and available propulsion power in wheelhouse and centralized control room (where fitted)
	Stator windings temperature – high	√	√		√	√		Read all phases; generator power >500 kW
	Generator circuit breaker – open/close					√		Applicable to direct connection to the DC bus without semiconductor converter
	Generator running		√			√		
	Failure of on-line generator				√			
	Standby generator change-over				√			
	Generator cooling medium temperature – high	√			√	√		Where applicable
	Generator cooling pump or fan motor failure				√			Where applicable
	Generator cooling water leakage	√			√			Where applicable
	Field voltage and current		√			√		Not applicable to asynchronous generators and permanent magnet synchronous generators
	Commutating pole windings temperature – high	√	√		√	√		For DC generators only
Propulsion motor	Bearing lub. oil inlet pressure – low or bearing temperature – high	√	√	√	√	√	√	
	Voltage limit alarm (high/low)		√		√	√		To read all phases. For propulsion motor controlled by frequency converter, the output of frequency converter may be taken as an alternative
	Field voltage					√		Not applicable to asynchronous motors and permanent magnet synchronous motors without external excitation power supply
	Frequency limit alarm (high/low)				√	√		For AC propulsion motors only. For propulsion motor controlled by frequency converter, the output frequency of frequency converter may be taken as an alternative
	Armature current		√			√		Read all phases

System	Monitored Parameters	Without additional notation			BRC, MCC, AUT-0 notation			Remarks
		Alarm	Display	Auto shutdown	Alarm	Display	Auto shut down	
System	Field current		√			√		Not applicable to asynchronous motors and permanent magnet synchronous motors without external excitation power supply
	Stator windings temperature – high	√			√	√		Read all phases; only for AC motors with power >500 kW
	Motor switch – open/close					√		Applicable to direct connection to the DC bus without semiconductor converter, and to isolated on-off states of permanent magnet synchronous motor in 3.7.6.1
	Motor running		√			√		
	Motor overspeed	√	√	√	√	√	√	Automatic shutdown only for DC propulsion motors
	Failure of on-line motor				√			
	Standby motor change-over				√			
	Motor cooling medium temperature – high	√			√	√		Where applicable
	Cooling pump or fan motor failure				√			Where applicable
	Commutating pole current		√			√		For DC propulsion motors only
	Differential protection or similar protection function	√			√			Motor rated power ≥1500 kW
	Shaft locking device, brake device or device capable of decoupling motor shaft from the main shaft		√			√		Only for permanent magnet synchronous motors
Converter	Input voltage limit alarm (high/low)	√	√		√	√		Alarm before protection action
	Input current limit alarm (high)	√			√			Alarm before protection action
	Output voltage		√			√		Applicable to power supply converters, including daily inverters
	Output current		√			√		Applicable to power supply converters, including daily inverters
	Output frequency		√			√		Applicable to daily inverters
	Overload (overcurrent)	√			√			Alarm before protection device operates
	Pre-charge failure	√			√			Where fitted
	Charge and discharge indication		√			√		Applicable to energy storage device converters
	Communication status with BMS (normal/fault)	√	√	√	√	√	√	Applicable to energy storage device converters
	External emergency stop request	√		√	√		√	Where fitted
	Distribution switch – open/close position					√		
	Converter cooling medium temperature – high	√	√		√	√		Where applicable

System	Monitored Parameters	Without additional notation			BRC, MCC, AUT-0 notation			Remarks
		Alarm	Display	Auto shutdown	Alarm	Display	Auto shut down	
	Converter cooling pump or fan motor failure	√			√			Where applicable
	Converter cooling water leakage	√			√			Where applicable
	Converter power device/power module temperature – high				√		√	Alarm before shutdown protection action
	Inter-phase reactor temperature – high				√	√		Where fitted
	Filter circuit protection trip	√			√			Where applicable
AC/DC switchboard	Bus-bar voltage limit alarm (high/low)	√	√		√	√		Each independent section
	Bus-bar frequency limit alarm (high/low)	√	√		√	√		Only for AC daily switchboards
	Automatic power reduction/load shedding operation	√			√			
	Main switch automatic closing failure				√			
	Main switch automatic tripping				√			
	Load sharing failure				√			Set when automatic load sharing function is adopted
	Bus-bar insulation resistance (normal/abnormal)	√			√			Each independent section
	Switchboard cooling system common fault	√			√			Where applicable
	Switchboard cooling system medium leakage				√			Where applicable
	Power/energy management system common fault				√			
Others	Field circuit earthing fault	√			√			May be omitted in brushless excitation systems and excitation circuits of motors rated less than 500 kW
	Main propulsion circuit earthing fault		√			√		

5.1.2.2 A battery management system is to be provided when an energy storage device is used as the power source of the integrated DC power system. The management system for lead-acid batteries and similar types is to have at least the monitoring function for voltage, discharge current, battery temperature and battery internal resistance. The management system for lithium batteries (including energy-type supercapacitors) is to comply with the requirements of the CCS Rules for Ships Using Battery Power.

Section 2 DESIGN REQUIREMENTS FOR PMS/EMS

5.2.1 General requirements

5.2.1.1 A PMS/EMS is to be provided for the integrated DC power system to ensure adequate power supply under normal operating conditions of the ship.

5.2.1.2 The PMS/EMS is to be capable of automatically managing the power supply units to ensure that sufficient power generation capacity is maintained during ship navigation. When the ship is in a condition

requiring high maneuverability (e.g., berthing/unberthing), this condition information is to be sent to the PMS/EMS automatically or manually. In this case, the PMS/EMS is not to automatically disconnect power supply units based on load rate.

5.2.1.3 The PMS/EMS is to be capable of achieving structural optimization and energy consumption control of the integrated DC power system (including specific fuel oil consumption of prime movers and charge/discharge cycles of energy storage devices).

5.2.1.4 The PMS/EMS is to provide the operator with the operating status of all power supply units, propulsion devices, protective devices and isolating switches, including converters and necessary auxiliary systems.

5.2.1.5 The PMS/EMS is to provide the operator with operating status monitoring, operation mode switching, fault indication and prompts for alternative solutions during faults.

5.2.1.6 The PMS/EMS is to be capable of automatically performing start/stop management of power supply units, grid connection/disconnection of power supply units, load power distribution, automatic shedding of non-essential loads, power/energy reserve analysis, and heavy load inquiry.

5.2.1.7 Failure of any PMS/EMS function is not to affect the local control of power supply unit start/stop management, grid connection/disconnection, and load power distribution.

5.2.1.8 Load power distribution is to consider the voltage steady-state fluctuation and transient response capability of different power supply units.

5.2.1.9 An alarm is to be triggered when the load distribution deviation exceeds the safety margin of the power supply units.

5.2.1.10 Minor faults of power supply units may initiate a pre-alarm and delayed shutdown by the PMS/EMS, with a function to allow manual intervention before shutdown, and it is to meet the requirements of 3.4.2.4, Chapter 3 of the Guidelines.

5.2.1.11 Automatic starting of the standby main power supply unit is to take place under the following conditions:

- (1) main bus-bar loss of power (initial on-grid load should be limited in this case);
- (2) sustained voltage dip exceeding the limits specified in Table 2.1.2.2, Chapter 2 of the Guidelines, provided that voltage dips with a duration shorter than 1.5 s are not to immediately trigger automatic starting of the standby power supply unit;
- (3) sustained frequency dip in the daily AC distribution system exceeding the limits specified in Table 2.1.2.2, Chapter 2 of the Guidelines;
- (4) anticipated shutdown of a running unit (such as delayed shutdown);
- (5) high load rate or overload of a power supply unit;
- (6) increase in power demand (such as a start signal for a high-power load) which is anticipated to result in a high load rate or overload of a power supply unit;
- (7) failure of a power plant or energy storage device.

5.2.1.12 When the ship is in a state powered only by a single power supply unit, the standby power supply unit is to be automatically made ready, and if necessary, sequential control for preheating and cooling is to be set.

5.2.1.13 A power supply unit that is in a shutdown state due to its own fault is not to be automatically reconnected to the integrated DC power system.

5.2.1.14 The PMS/EMS is to be capable of monitoring the standby readiness of power supply units and is to permit automatic starting and running only when its standby readiness is completed.

5.2.1.15 If several power supply units are provided with automatic start, the PMS/EMS is to be capable

of controlling the starting sequence. When the number of unsuccessful starts of a certain power supply unit exceeds the permissible number of starts for the starting device, the PMS/EMS is to be capable of giving an alarm and automatically switching to start the next power supply unit in sequence.

5.2.1.16 The number of pre-charge attempts by each power supply unit for a de-energized DC bus-bar is not to exceed 1.

5.2.1.17 If a variable-speed generating set is installed, the PMS/EMS is to consider the difference in available power at different operating speeds of the variable-speed generating set when calculating the current system load rate.

5.2.1.18 If a fuel cell power installation is installed, the PMS/EMS is to be capable of adjusting its grid-connected number according to the load demand, and endeavour to operate it in the high-efficiency operating range as far as possible, provided that the minimum stable power of the fuel cell power installation is satisfied.

5.2.1.19 The PMS/EMS is to be capable of calculating in real time the available power and available energy according to the state of charge of the energy storage system. When the average load rate of the power supply units exceeds 90%, a new power supply unit is to be put into operation or the propulsion power is to be appropriately limited.

5.2.1.20 The PMS/EMS is to control the charging and discharging of the energy storage system. When the energy storage system supplies power to the ship's propulsion and steering systems, it is also to monitor the available capacity and available power of the energy storage device, and be capable of estimating the remaining time/range under the current operating conditions.

5.2.1.21 When performing disconnection of a power supply unit, overloading of the remaining on-grid power supply units is to be prevented.

5.2.1.22 The PMS/EMS, switchboard or converter is to have a power limiting function. When the ship's power station operating under heavy load experiences a shutdown of one or more power supply units due to a fault, causing the remaining on-grid power supply units to face unacceptable overload, and the fault deteriorates too rapidly for manual intervention, the PMS/EMS, switchboard or converter is to immediately limit the propulsion power and issue an alarm to prevent total blackout. The power limitation is to continue until sufficient main power supply units are put into operation. After that, the PMS/EMS, switchboard or converter may release the limitation and adjust the propulsion load to the target power value. The power limitation function is not to be lost due to PMS/EMS failure.

5.2.1.23 The PMS/EMS is to be capable of monitoring the failures of the integrated DC power system. When the power supply to the systems and equipment on the non-fault section lines is interrupted, it is to be capable of automatically carrying out the measures such as those specified in 4.2.2.4(3), 4.2.2.5(7), 4.2.2.6(5) and 4.3.2.4(2) of the Guidelines to restore the power supply to systems and equipment.

5.2.1.24 A fault in the PMS/EMS itself is to be capable of being alarmed at the manned position, and is not to cause loss of power to the main power supply or failure of the propulsion and steering systems.

Section 3 PROPULSION CONTROL SYSTEMS

5.3.1 General requirements

5.3.1.1 Under all sailing conditions, it is to be possible to exercise full control over the speed, direction and pitch (if applicable) of the propeller from the navigation bridge.

5.3.1.2 In the event of a failure of the propulsion control system, the system is to maintain the current propulsion speed and direction unchanged until the propeller is transferred to local control mode.

5.3.1.3 The remote control system is to achieve independent control of each propeller from the navigation bridge. After a total blackout, it is to be possible to restart the propulsion system from the navigation bridge.

5.3.1.4 When multiple propellers are under combined control, automatic switching to independent control is to take place when the control function at any location is abnormal.

5.3.1.5 The remote control system and the local control are to be independent of each other. When the remote control system fails, functions abnormally or loses power, the local control function of the propulsion is to be maintained or recoverable, and vice versa.

5.3.1.6 Local control of the propeller is to be achieved at the converter or propulsion motor location, and the local control has the highest priority.

5.3.1.7 The communication between the local control of each propeller and the main controller is to ensure that the local control can still obtain the necessary display and alarm information in the event of any single failure.

5.3.1.8 Unless it may cause serious damage or total failure of the integrated DC power system, an override function is to be permitted to avoid shutdown of the propulsion system.

5.3.1.9 The propulsion control system is to be provided with interlocks. Starting is to be prevented when there is a fault that may lead to shutdown or the process of starting the propulsion motor may cause damage to the equipment. At least the following interlock functions are to be included:

- (1) shaft locking device not released;
- (2) frequency converter cooling system failure;
- (3) propulsion motor cooling system failure (may be overridden);
- (4) excitation device (if applicable) fault;
- (5) serious frequency converter fault;
- (6) DC switchboard not ready;
- (7) emergency stop function activated;
- (8) propulsion motor speed setpoint not reset to zero;
- (9) propulsion motor bearing lubricating oil pressure too low (if applicable);
- (10) cooling medium electrical conductivity too high (if applicable);
- (11) protective devices of power supply units and propulsion system operated.

5.3.1.10 The propulsion control system or the frequency converter control system is to be capable of quickly limiting the propulsion motor power to cooperate with the PMS/EMS or switchboard in realizing the power limiting function of 5.2.1.22 of this Chapter.

CHAPTER 6 ELECTROMAGNETIC COMPATIBILITY

Section 1 GENERAL PROVISIONS

6.1.1 General requirements

6.1.1.1 Unless otherwise specified, this Chapter applies to the arrangement and installation of all electrical installations of the integrated DC power system.

6.1.1.2 The electrical and electronic installations of the integrated DC power system are to comply with the relevant requirements of the standards^① accepted by CCS.

6.1.1.3 The design objective of the electromagnetic compatibility of the integrated DC power system is to ensure the self-compatibility of the system, i.e., all system devices are to be capable of working cooperatively while ensuring the performance of the integrated DC power system.

6.1.1.4 The integrated DC power system is to be compatible with other systems (communication, navigation, intelligence, etc.) in the ship's electromagnetic environment, and the fluctuations of transient voltage, common mode voltage and current generated by it under all operating conditions are not to cause maloperation of other systems.

6.1.1.5 The integrated DC power system is to consider all interference effects generated by converters within the system.

6.1.1.6 The design of cables and wiring, transformers and protective devices of the daily AC distribution system is to consider the additional losses and heating effects caused by the harmonic current distortion level.

Section 2 DESIGN AND ANALYSIS REQUIREMENTS FOR ELECTROMAGNETIC COMPATIBILITY

6.2.1 General requirements

6.2.1.1 The design and analysis of electromagnetic compatibility is to be carried out before the integrated DC power system is installed on board. The integrated DC power system is to be analyzed and evaluated according to the standards^① no lower than those accepted by CCS, with separate assessment of the effects of external electromagnetic environment on the system and the interaction among the strong and weak electrical devices within the system (self-compatibility), and the design and analysis report is to be developed to guide the electromagnetic compatibility anti-interference design to ensure the safety and reliability of the ship systems.

6.2.1.2 The design and analysis report of electromagnetic compatibility is to cover at least the system description, electromagnetic environment analysis, electromagnetic compatibility characteristics of primary equipment (systems), main electromagnetic compatibility design measures and expected effects, etc. Reference may be made to the template in Annex 2. In general, the report is to include:

- (1) electromagnetic environment analysis of the integrated DC power system, which is to consider all

^①Refer to IEC 60533 Electrical and Electronic Installations in Ships – Electromagnetic Compatibility (EMC) – Ships with a Metal Hull.

foreseeable electromagnetic environments relevant to the integrated DC power system throughout its life cycle, including the electromagnetic environment within the integrated power system and the ship's electromagnetic environment faced by the integrated power system, for use in establishing the standard limits followed by each device in the system;

(2) the electromagnetic compatibility characteristics of the primary equipment (systems) of the integrated DC power system, including the interference characteristics and immunity characteristics of the primary equipment (systems). Measured data is the preferred choice; where measured data is unavailable, analysis and calculation results based on the equipment operating principles may also be used. On the basis of these data provided by the equipment manufacturer, an electromagnetic interference matrix is to be established in the electromagnetic compatibility analysis report based on these data to predict the electromagnetic compatibility risks in the system;

(3) electromagnetic compatibility design measures used to eliminate electromagnetic compatibility risks. These measures include system layout, cable routing, filtering design, shielding design, earthing design, etc. It is to be ensured that these measures are embedded in the products without producing negative effects on the integrated DC power system and other ship systems, and the potential risks associated with their installation, arrangement, operation, maintenance and software updates are to be considered. Illustrative block diagrams for the installation locations and design requirements, etc., of these measures are to be provided in the electromagnetic compatibility analysis and design report. This item may be divided into equipment-level electromagnetic compatibility design measures and system-level electromagnetic compatibility design measures, and may be completed jointly by the equipment manufacturer and the ship design institute.

6.2.1.3 The risks are to be eliminated as far as possible from the overall design such as spatial layout and frequency allocation. Risks that cannot be completely eliminated through the overall design are to be assessed in combination with electromagnetic compatibility tests to ensure that the risks are controllable.

Section 3 DESIGN PRINCIPLES FOR ANTI-INTERFERENCE

6.3.1 Arrangement and cable routing

6.3.1.1 When arranging equipment, strong and weak current equipment is to be arranged in separate zones in compartments containing high-power equipment. Sensitive electronic equipment is not to be arranged near equipment that may become sources of electromagnetic interference, such as generators, motors, rectifiers, transducers, inverters, transformers, and switchgear cabinets.

6.3.1.2 Cabling is to comply with the relevant requirements of Chapter 2, Part 4 of CCS Rules for Classification of Sea-going Steel Ships or Chapter 11, Part 3 of CCS Rules for the Construction of Inland Waterways Steel Ships. High-power cables are to be arranged symmetrically in bundles to reduce the radiated interference generated outward by the cables; weak current signal lines are to be shielded and earthed at both ends, and when passing through high-voltage (≥ 1000 V) and high-power (≥ 100 kW) environments, optical fibre transmission is preferably to be used.

6.3.1.3 Power cables are to be kept away from signal control cables. The signal control cables of electronic equipment are to be not less than 1 m away from other heavy-current equipment that may cause interference, and not less than 0.13 m away from fluorescent lamps. If the above cable separation distances cannot be met due to space limitations, protective measures such as shielding and perpendicular cross routing are to be taken for the signal cables. If, in special cases, strong and weak current cables cannot be separated, measures such as frequency division and time division operation are to be taken in the system design to avoid

interference.

6.3.1.4 Cables not related to the frequency converter are to be kept away from the frequency converter to avoid interference from the output of the propulsion frequency converter.

6.3.1.5 Motor (variable frequency) cables are to be routed independently of other cables. Motor (variable frequency) cables, frequency converter input cables and control cables are to be installed in different cable trays to avoid long parallel runs of motor (variable frequency) cables and other cables, thereby reducing electromagnetic interference generated by the output voltage transients of the propulsion frequency converter.

6.3.1.6 Motor (variable frequency) cables are to be as short as possible. If longer cables need to be installed, a du/dt filter is to be installed at the output of the frequency converter. Single-core cables are not to be used for motor (variable frequency) cables.

6.3.1.7 The use of three single-core cables is to be avoided as far as possible for other three-phase AC systems, and measures are to be taken to reduce the electromagnetic effect among grouped single-core cables. The effect of one three-core cable may be achieved by transposing the three single-core cables at intervals not exceeding 15 m; transposition is not required where the cable length is less than 30 m.

6.3.1.8 Cable installation is to avoid proximity to single-core AC cables. Magnetic materials are not permitted to be installed between cables of different phases of the same circuit. The distance between single-core AC cables and parallel magnetic materials is to be greater than 76 mm.

6.3.1.9 Where DC and AC cables are installed in parallel, the minimum separation distance is to be not less than 300 mm; where they cross, insulating barrier plates are to be used for separation, and the distance is to be not less than 100 mm. If the DC voltage exceeds 1 kV, the separation distance is to be increased by an additional 20%.

6.3.2 Isolation and filtering

6.3.2.1 The auxiliary power supply of the electric propulsion system is to avoid using the same power adapter (switching mode power supply) as communication and navigation equipment. Where necessary, isolation and filtering measures are to be taken for suppression.

6.3.2.2 An isolation transformer is preferably to be added at the output end of the AC inverter. For the DC power supply, except for supplying relays, contactors and indicator lights, special power consumption is to use switching mode power supplies for isolation.

6.3.3 Shielding

6.3.3.1 High-power equipment cabinets are to be made of metal sheets. The metal sheet material may be selected according to the nature of the interference (magnetic field, electric field) to be shielded, so as to provide corresponding shielding effectiveness. Electromagnetic compatibility shielding seals are preferably to be used between the cabinet door and the cabinet body to ensure a continuous conductive interface and reduce the leakage of electromagnetic fields. Waveguide ventilation panels or shielding mesh are preferably to be installed inside larger openings such as air inlets and display screens. The waveguide ventilation panels and shielding mesh, etc., are to have good electrical connection with the cabinet body. High-power input and output cables are to be connected to the cabinet body through glands, and their shielding layers are to be connected to the cabinet body through the glands.

6.3.3.2 Power cables on ships are to be installed as close as possible to the metal hull or bulkheads, and the metal bulkheads and decks are to be utilized for shielding as far as possible.

6.3.3.3 Armoured shielded cables are to be used for power cables as far as possible, and their installation is to minimize the interference caused by the power cables and reduce mutual induction and

coupling.

6.3.3.4 Twisted-pair cables with shielding layer and metallic armour layer are preferably to be selected for essential control and communication cables. The lay length of the twisted-pair cables is preferably to be less than 50 mm.

6.3.3.5 Shielded cables are to be used for control cables for analogue signals and low-voltage digital signals. For analogue signals, twisted-pair, double-shielded wires are to be used, and separate shielded twisted wires are to be used for each signal; different analogue signals are not to use the same common return wire. Low-voltage digital signal wires are preferably to use double-shielded cables; single-shielded multiple-pair twisted-pair cables may also be used. Switching signals of higher voltage and other relay signals are to be connected using twisted-pair wires and routed in separate cable conduits or trays. Analogue signals and digital signals are to use separate shielded cables.

6.3.3.6 Cable shielding layers are to be connected inside junction boxes or cable entry boxes. Except for the outer conductor of coaxial cables, the cable shielding layer is not to be used as a return conductor for the working circuit.

6.3.4 Earthing

6.3.4.1 Earthing connections are to comply with the following requirements:

- (1) low high-frequency impedance;
- (2) length as short as possible (low inductance);
- (3) connectors and conductors secured against vibration;
- (4) corrosion protection;
- (5) easy access for routine inspection.

6.3.4.2 The metal of all earthing contact surfaces is to be clean and free from paint, oxides or other insulating coatings. Anti-corrosion spray or compound is preferably to be applied to each contact point before final assembly.

6.3.4.3 Solid metal bars of minimum length are to be used for earthing instead of flexible braided straps, to keep the earth loop as short as possible.

6.3.4.4 The connection between the earthing conductor and the equipment or hull is to be made by bolting or welding.

6.3.4.5 Heavy-current equipment (such as frequency converters, propulsion motors) and weak-current equipment (such as controllers, switches) are to be earthed at separate points with single-point earthing nearby, and the earthing points are to be designed with corrosion protection. The signal circuits in electronic equipment are to be earthed and completely independent from the heavy-current circuits to prevent interference from heavy-current equipment on weak-current equipment. Cables of AC circuits are not to be installed close to or in parallel with signal earth wires at close distance; the distance is not to be less than 0.3 m, and crossings are preferably to be made at right angles.

6.3.4.6 For weak-current equipment arranged in different compartments, if the possibility that the large distance between compartments causes a potential difference at the signal earth cannot be excluded, they are preferably to be interconnected using optical fibres or digital communication interfaces to avoid the effects caused by potential differences and spatial electromagnetic field interference.

6.3.4.7 Metal doors, protective covers, etc., are to be connected to their respective housings using short, independent, and as flexible as possible conductors.

6.3.4.8 For armoured shielded power cables, the inner shielding layer is to be earthed at one end to suppress capacitive coupling; the armour layer serves as the outer shielding layer and is to be earthed at both

ends or multiple ends to suppress inductive coupling; insulation is to be provided between the two shielding layers. Both the inner shielding layer and the metallic armour layer can suppress radiated coupling and strong magnetic field coupling.

6.3.4.9 Multi-core symmetrical cables with armour and shielding layer are to be selected for motor (variable frequency) cables, and 360-degree earthing is to be ensured at both ends. The unshielded portion of the motor cable is to be as short as possible.

6.3.4.10 Except for branch circuits which are already earthed at the power supply terminal, all metal protective coverings of cables are to ensure their electrical continuity over the entire length, and are to be effectively connected to the metal hull at both ends of the cable; metal braids or sheaths are to be terminated at the sealing gland or fitting where the cable enters the equipment enclosure, and are to have a good electrical connection with the enclosure.

6.3.4.11 The installation at the cable entry position is to minimize electromagnetic interference as far as possible (e.g., by earthing the cable shielding layer at the cable gland), to limit the effects caused by the high-frequency ripple current generated by the converter.

6.3.4.12 The shielding layer of signal cables is to be earthed at a single point.

6.3.4.13 Electrical continuity is to be maintained between cable trays and between cable protective conduits, and they are to have as many electrical connections to the hull as possible.

6.3.4.14 To prevent the effects of common mode interference, an isolation transformer required in 2.3.1.2, Chapter 2 of the Guidelines is preferably to be provided between the daily AC distribution system and the DC distribution system, or an isolation transformer is to be used to supply power to critical weak-current equipment.

CHAPTER 7 FAILURE MODES AND EFFECTS ANALYSIS

Section 1 GENERAL PROVISIONS

7.1.1 General requirements

7.1.1.1 A failure modes and effects analysis (FMEA) is to be carried out for the integrated DC power system. The FMEA technique may be used to analyze whether a single failure will lead to unacceptable consequences.

7.1.1.2 The FMEA of the integrated DC power system is to consider all foreseeable failures and risks associated with the integrated DC power system throughout its life cycle. It is to be ensured that safety measures can cover the effects on the ship arising from any reasonably foreseeable failures of the power plants, energy storage devices, converters, DC switchboards, AC switchboards, propulsion motors, PMS/EMS, etc. In particular, potential risks associated with their installation, arrangement, operation, maintenance and software updates are to be considered, including but not limited to:

- (1) any normal and reasonably foreseeable abnormal operating conditions, such as starting, normal shutdown, non-operation and the effects of protection on the system;
- (2) the effects of equipment layout, arrangement and location on the system;
- (3) mechanical, electrical and human failures due to short circuits, earth faults, fire (if applicable), flooding (if applicable), cooling failure and operation beyond the design operating parameters;
- (4) failures of power plants, energy storage devices, protective devices, motors, converters, bus-bars, etc.;
- (5) failures of power supply, control power supply, cooling/auxiliary heating systems, communication systems, etc.

7.1.1.3 The FMEA is to analyze and record each component of the integrated DC power system according to standards^① no lower than those accepted by CCS. It is to cover at least the failure of a single core component, heating/cooling system failure, control power supply failure, earth fault, short-circuit fault, loss of power source, effects of human operation, effects of weather, fire, explosion, other unexpected chemical reactions and power outages. The assessment is to ensure that risks are eliminated as far as possible. Risks that cannot be eliminated are to be mitigated as far as possible.

7.1.1.4 When categorizing the probability of occurrence of a single failure, the following principles may be referred to for the integrated DC power system:

- (1) occasionally occurs: may occur several times during the service life of the product;
- (2) sometimes occurs: may occur at a certain time during the product service period (e.g., commissioning period, first half year of the service period or near the end of the service period);
- (3) rarely occurs: unlikely to occur but possible;
- (4) extremely rarely occurs: extremely unlikely to occur (in most cases, such failures have never been found in actual projects).

7.1.1.5 When categorizing the severity of a single failure, the following principles may be referred to for the hybrid power system:

- (1) catastrophic: after the failure occurs, it causes a serious failure of the power supply or propulsion and steering system, making it impossible to maintain power supply or continue to maintain the ship's

^① Refer to IEC 60812 Failure mode and effects analysis (FMEA and FMECA).

propulsion/steering power; the ship is in an uncontrollable or near-uncontrollable state, resulting in catastrophic effects;

(2) severe: after the failure occurs, it causes a failure of the power supply or propulsion and steering system, resulting in reduced power supply capability or reduced propulsion/steering power, leading to a degradation of the ship's dynamic performance level and producing severe effects;

(3) critical: after the failure occurs, it results in the loss of redundancy of the power supply or propulsion/steering system, but normal power supply or propulsion/steering can still be maintained, without producing severe effects;

(4) minor: after the failure occurs, it does not affect the normal power supply of the power supply or propulsion/steering system and its redundancy, producing only minor effects.

7.1.1.6 If the analysis conclusion indicates that the probability of occurrence and the severity of a specific failure of the integrated DC power system are very high, the redundancy of the power supply units may be increased by increasing the number of bus-bar sections or the number of power supply branches on each bus-bar section. The following methods may be used to evaluate the reliability indicators of the integrated DC power system, identify weak points affecting the reliability of power supply, and propose targeted improvement schemes, such as optimizing the maintenance strategy and increasing the frequency of maintenance, so as to improve the system reliability.

(1) Perform system definition based on elements such as the grid structure and typical operating modes of the integrated DC power system;

(2) Based on the analysis purpose and system failure criteria, determine the undesired event related to the system, which is recorded as the top event;

(3) Identify the direct, necessary and sufficient causes (bottom events) that lead to the occurrence of the top event, take all direct causes as input events, and establish a standardized fault tree^① based on the actual logical relationships of these events^②;

(4) The failure rate of the bottom events may be estimated using historical data of similar equipment from the manufacturer. Under the condition that all bottom events are mutually independent, indicators such as the probability of propulsion motor shutdown, the mean down time of propulsion motor, the probability of propulsion motor derating operation, the mean derating operation time of propulsion motor, the probability of daily load derating operation, and the mean derating operation time of daily load may be selected as important indicators for quantitative calculation according to actual needs.

① Refer to GB/T 7829 Fault Tree Analysis Procedure.

CHAPTER 8 SUPPLEMENTARY REQUIREMENTS FOR SMALL SHIPS USING INTEGRATED DC POWER SYSTEM

Section 1 GENERAL PROVISIONS

8.1.1 Application

8.1.1.1 This Chapter applies to ships of less than 20 m in length^① provided with an integrated DC power system.

8.1.1.2 In addition to the requirements of this Chapter, the ships are also to comply with the relevant requirements of CCS Rules for Classification of Small Sea-going Steel Ships or CCS Rules for the Construction of Inland Waterways Small Ships.

8.1.2 Plans and documentation

8.1.2.1 The plans and documents to be submitted for approval for the ship are to comply with the requirements of 1.2.1.1, Chapter 1 of the Guidelines.

8.1.2.2 The plans and documents to be kept on board for reference are to comply with the requirements of 1.2.1.2(1), Chapter 1 of the Guidelines.

8.1.3 Product surveys

8.1.3.1 Product surveys are to comply with the requirements of Section 3, Chapter 1 of the Guidelines.

8.1.4 Ship surveys

8.1.4.1 Surveys during construction

(1) Functional verification of the integrated DC power system is to comply with the requirements of 1.4.2.1(1), Chapter 1 of the Guidelines.

(2) Verification of the control and monitoring system is to comply with the requirements of 1.4.2.1(4), Chapter 1 of the Guidelines.

(3) Verification of the generating sets is to comply with the requirements of 1.4.2.1(5)①-③ and ⑤-⑧, Chapter 1 of the Guidelines.

(4) Verification of the energy storage device is to comply with the requirements of 1.4.2.1(6)①-⑥, Chapter 1 of the Guidelines.

(5) Verification of the fuel cell power installation is to comply with the requirements of 1.4.2.1(7)①-④, Chapter 1 of the Guidelines.

(6) Verification of the daily AC inverter is to comply with the requirements of 1.4.2.1(8)①-②, Chapter 1 of the Guidelines.

(7) Verification of the propulsion motor is to comply with the requirements of 1.4.2.1(9)①-④, Chapter 1 of the Guidelines.

(8) Verification of the photovoltaic power generation system is to comply with the requirements of 1.4.2.1(10)①-④, Chapter 1 of the Guidelines.

① Where the Technical Regulations for Survey of Inland Waterways Small Ships and the Technical Regulations for Survey of Coastal Small Ships adjust the length range of small ships, the relevant provisions of the new length range in the scope of application of the two regulations are to be followed.

8.1.4.2 Surveys after construction:

- (1) Annual surveys are to comply with the requirements of 1.4.3.1(1)-(4), Chapter 1 of the Guidelines.
- (2) Special surveys are to comply with the requirements of 1.4.3.3(1)-(7), Chapter 1 of the Guidelines.

8.1.5 Design of DC distribution system

8.1.5.1 The system of distribution is to comply with the requirements of 2.2.2, Chapter 2 of the Guidelines.

8.1.5.2 Insulated distribution systems and high-resistance earthed distribution systems are to comply with the requirements of 2.2.3, Chapter 2 of the Guidelines.

8.1.5.3 Earthed distribution systems are to comply with the requirements of 2.2.4, Chapter 2 of the Guidelines.

8.1.6 Design of daily AC distribution system

8.1.6.1 The daily AC inverter is to comply with the requirements of 2.3.2.2 and 2.3.2.3, Chapter 2 of the Guidelines.

8.1.7 Electrical installations

8.1.7.1 Generators are to comply with the requirements of Section 2, Chapter 3 of the Guidelines.

8.1.7.2 Fuel cells are to comply with the requirements of Section 3, Chapter 3 of the Guidelines, except for 3.3.1.2 and 3.3.1.3.

8.1.7.3 Energy storage devices are to comply with the requirements of Section 4, Chapter 3 of the Guidelines, except for 3.4.1.12 and 3.4.3.5.

8.1.7.4 Photovoltaic power generation systems are to comply with the requirements of Section 5, Chapter 3 of the Guidelines, except for 3.5.1.5.

8.1.7.5 Converters are to comply with the requirements of Section 6, Chapter 3 of the Guidelines, except for 3.6.1.5 and 3.6.1.8.

8.1.7.6 Propulsion motors are to comply with the requirements of Section 7, Chapter 3 of the Guidelines, except for 3.7.1.2 and 3.7.6.

8.1.8 System protection

8.1.8.1 The integrated DC power system is to comply with the requirements of 4.1.1.1 to 4.1.1.4, Chapter 4 of the Guidelines.

8.1.8.2 DC distribution system:

(1) Protective devices and protection functions are to comply with the requirements of 4.2.1.1 to 4.2.1.7, Chapter 4 of the Guidelines.

(2) The short-circuit protection principles are to be capable of achieving:

① In the event of a short-circuit fault on the DC bus-bar of a single bus-bar system:

(a) the power supply units and load devices are not to be damaged;

(b) the protective device is to be capable of being reset locally. If a fuse is used, its construction and arrangement are to facilitate replacement;

(c) The protective devices of all distribution branches of the power supply units on grid are to operate.

② In the event of a short-circuit fault on one bus-bar section of a single bus-bar sectionalized system:

(a) The requirements of 4.2.2.4(1), (2) and (5), Chapter 4 of the Guidelines;

(b) If a centralized topology is adopted for the system, the bus-tie protective device is to be

automatically disconnected. The duration and severity of the fault impact on the adjacent bus-bar sections are to be limited, and it is not to cause the operation of protective devices of any branch on the adjacent bus-bar sections and the stoppage of equipment. If the operation of protective devices on the adjacent bus-bar sections and equipment stoppage are unavoidable, the bus-tie protective device is to be disconnected within 1.5 s, and the power supply and equipment operation on the adjacent bus-bar sections are to be restored automatically or manually.

③ In the event of a short-circuit fault at the output terminal of any power supply unit (including converter):

(a) The requirements of 4.2.2.5(1), (3), (4) and (6), Chapter 4 of the Guidelines;

(b) If the power supply unit of the faulty branch is the only on-grid power supply source for the DC distribution system, and the DC distribution system loses power due to the short-circuit fault and protection operation, the standby power supply unit is to be automatically or manually started after the loss of power;

(c) If there are other power supply units operating in parallel in the DC distribution system, the duration and severity of the fault impact on this section and adjacent bus-bar sections are to be limited. During the operation of the protective device of the distribution branch of the faulty power supply unit, the non-faulted equipment on this section and adjacent bus-bar sections is not to shut down or have its corresponding circuit breaker trip due to DC undervoltage. The operation of the protective device of the distribution branch of the faulty power supply unit is to be completed within 2 s, and the non-faulted equipment is to be restored to normal operation automatically or manually.

④ In the event of a short-circuit fault at the input terminal of any load (including converter):

(a) The requirements of 4.2.2.6(1), (3) and (4), Chapter 4 of the Guidelines;

(b) The duration and severity of the fault impact on this section and adjacent bus-bar sections are to be limited. During the operation of the protective device of the faulty load branch, the non-faulted equipment on this section and adjacent bus-bar sections is not to shut down or have its corresponding circuit breaker trip due to DC undervoltage. The operation of the protective device of the faulty load branch is to be completed within 1 s, and the non-faulted equipment is to be automatically restored to normal operation.

8.1.8.3 Daily AC distribution system:

(1) Protection functions are to comply with the requirements of 4.3.1.1 to 4.3.1.3, 4.3.1.5 and 4.3.1.6, Chapter 4 of the Guidelines.

(2) The short-circuit protection principles are to be capable of achieving:

① In the event of a short-circuit fault on the AC bus-bar:

(a) The requirements of 4.3.2.3(1) and (2), Chapter 4 of the Guidelines;

(b) If the daily AC distribution system has multiple AC bus-bar sections and a short-circuit fault occurs on one bus-bar section, where there are power supply units supplying power on the other AC bus-bar sections, the bus-tie protective device is to be disconnected with priority to avoid the operation of protective devices on any branch of the other bus-bar sections and the stoppage of equipment.

② In the event of a short-circuit fault at the output terminal of any power supply unit:

(a) The requirements of 4.3.2.4(1) and (3), Chapter 4 of the Guidelines;

(b) If the power supply unit is the only on-grid power supply source in the daily AC distribution system and the AC bus-bar loses power due to the short-circuit fault and the operation of the protective device, the standby power supply unit is to be automatically or manually started after the loss of

power.

③ In the event of a short-circuit fault at the input terminal of any load:

(a) The requirements of 4.3.2.5, Chapter 4 of the Guidelines.

8.1.8.4 Short-circuit current calculations and the selection of protective devices are to comply with the requirements of 4.4.1.1 to 4.4.1.4 and 4.4.2, Chapter 4 of the Guidelines.

8.1.9 Control and monitoring

8.1.9.1 The general requirements for control and monitoring are to comply with the requirements of 5.1.1, Chapter 5 of the Guidelines, except for 5.1.1.7.

8.1.9.2 The control station is to be provided with at least the alarms and display items required in Table 8.1.9.2.

Monitoring and alarm for small ships

Table 8.1.9.2

System	Monitored Parameter	Alarm	Display	Auto Shutdown	Remarks
Generator	Bearing lub. oil inlet pressure – low or bearing temperature – high	√	√	√	Prime mover automatic shutdown
	Voltage		√		To read all phases; not applicable to asynchronous generators
	Current		√		To read all phases; not applicable to asynchronous generators
	Power		√		Display consumed power and available propulsion power on the navigation bridge and in the centralized control room (if any)
	Excitation voltage and current		√		Not applicable to asynchronous generators and permanent magnet synchronous generators
	Generator running		√		
Propulsion Motor	Bearing lub. oil inlet pressure – low or bearing temperature – high	√	√	√	
	Voltage (high/low)		√		To read all phases. For propulsion motor controlled by frequency converter, the output of the frequency converter may be used as an alternative.
	Armature current		√		To read all phases
	Excitation current		√		Not applicable to asynchronous motors and permanent magnet synchronous motors without external excitation power supply
	Motor running		√		

System	Monitored Parameter	Alarm	Display	Auto Shutdown	Remarks
Converter	Input voltage limit alarm (high/low)	√	√		Alarm before protective action
	Input current limit alarm (high)	√			Alarm before protective action
	Output voltage		√		Applicable to power supply unit converters, including daily inverters
	Output current		√		Applicable to power supply unit converters, including daily inverters
	Output frequency		√		Applicable to daily inverters
	Pre-charge fault	√			If any
	Charge/discharge indication		√		Applicable to energy storage device converters
	Communication status with BMS (normal/fault)	√	√	√	Applicable to energy storage device converters
	External emergency shutdown request	√		√	If any
Switchboard	Bus-bar voltage limit alarm (high/low)	√	√		Each independent section
	Bus-bar frequency limit alarm (high/low)	√	√		Only applicable to daily AC switchboard
	Bus-bar insulation resistance (normal/abnormal)	√			Each independent section

8.1.9.3 The PMS/EMS is to comply with the requirements of 5.2.1.1 to 5.2.1.10, Chapter 5 of the Guidelines.

8.1.9.4 The propulsion control system is to comply with the requirements of 5.3.1.1 to 5.3.1.9, Chapter 5 of the Guidelines.

ANNEX 1 SHORT-CIRCUIT CURRENT CALCULATIONS AND PROTECTION CHECK METHODS

Section 1 GENERAL PROVISIONS

1.1 General requirements

1.1.1 This Annex applies to the short-circuit current calculations and protection check of shipboard integrated DC power systems.

1.1.2 This Annex provides a universally applicable method of short-circuit modelling, simulation calculation and protection check for reference. The calculation results may be used to:

- (1) check the short-circuit making capacity and short-circuit breaking capacity of the selected protective devices;
- (2) check the electrodynamic stability and thermal stability of bus-bars and other components;
- (3) check the accuracy of the protection design and setting of the integrated DC power system;
- (4) provide a basis for selecting appropriate current-limiting equipment when necessary, to ensure that the short-circuit current is limited to within the breaking capacity of the protective devices.

1.1.3 The designer may adopt other calculation methods according to the specific situation, provided that the short-circuit calculations are ensured to agree with the test results of 4.4.4, Chapter 4 of the Guidelines.

1.1.4 A complete short-circuit current calculation is to be capable of providing the details of the current at the short-circuit point and the short-circuit current supplied by each short-circuit source varying with time, when a short circuit occurs at a typical location in the system, without considering the operation of protective devices. The modelling and simulation method is generally adopted for the integrated DC power system. The system modelling is to construct a simulation model of the integrated DC power system according to the system topological structure and the equipment put into operation under different operating conditions, and select mature and commercially available power electronic and power system electromagnetic transient simulation software to perform short-circuit calculations.

1.1.5 For power systems with fuses as the primary protective devices, the electromagnetic transient process of the short-circuit fault within 10 ms after the occurrence of the short circuit is to be accurately calculated, and the simulation calculation step size is preferably not to exceed 0.5 μ s; for power systems with circuit breakers as the primary protective devices, the electromagnetic transient process of the short-circuit fault within 200 ms after the occurrence of the short circuit is to be accurately calculated, and the simulation calculation step size is preferably not to exceed 50 μ s.

1.1.6 The various characteristic parameters of electrical equipment, cables, etc., required for the calculations are to be provided by the product manufacturer with sufficient accuracy. The resistance and inductance of the short-circuit loop may also be determined by measurement on the actual system. When calculating the short-circuit current, the load current may not be considered.

1.1.7 For the initially installed system, test verification is to be carried out according to 4.4.4, Chapter 4 of the Guidelines; the model is to be modified based on the test results, and the corrected data is to be used in subsequently installed systems.

1.1.8 The short-circuit current of the system under the maximum and minimum operating modes is to be calculated:

(1) Short-circuit current under the maximum operating mode of the system is used for checking the dynamic stability, thermal stability and breaking capacity of electrical equipment;

(2) Short-circuit current under the minimum operating mode of the system is used for checking the protection setting values and sensitivity of protective devices.

1.1.9 When calculating the short-circuit current under the maximum operating mode of the system, the following operating and running conditions are to be considered:

(1) Conductor resistance is the value at 20 °C;

(2) The impedances of bus-bars, voltage transformers and the contact resistance at connection points between conductors are to be neglected;

(3) The power battery pack is at the rated capacity corresponding to the fully charged state (SoC of 100%);

(4) The current-limiting effect of fuses and other protective converters (such as choppers and inverters) is to be taken into account.

1.1.10 When calculating the short-circuit current under the minimum operating mode of the system, the following operating and running conditions are to be considered:

(1) Conductor resistance is the value at the maximum operating temperature (the conductor temperature at the end of the short circuit; due to the rapid operation of fuse protection, the conductor resistance at 20 °C may be used if no measured value is available);

(2) The contact resistance of bus-bars connected by bolts is to be considered;

(3) The power battery pack is at the capacity corresponding to the final discharge voltage;

(4) The current-limiting effect of fuses and other converters (such as choppers and inverters) is to be taken into account.

Section 2 SHORT-CIRCUIT CALCULATIONS AND PROTECTION

CHECK METHODS FOR DC DISTRIBUTION SYSTEM

2.1 Calculating conditions and assumptions

2.1.1 The short-circuit calculations and protection check in this Section apply to the condition of a short circuit between the positive and negative poles in a two-wire insulated system.

2.1.2 When calculating the short-circuit current of the integrated DC power system, the following equipment is to be considered as short-circuit sources^①:

(1) Generator + rectifier;

(2) Power battery pack (or super capacitor), fuel cell and their connected DC/DC converter;

(3) Frequency converter + propulsion motor (if it can feed short-circuit current to the DC bus-bar during a short circuit in the DC distribution system);

① 1. When a short circuit occurs in the converter module on the AC side of an asynchronous motor, the main current is reactive current, which may be considered to have no effect on the DC bus-bar.

2. For branches with an energy storage device (storage battery or super capacitor) and fuel cell plus a converter, when a short circuit occurs at the output terminal of the energy storage device or fuel cell, protection can be provided by its own short-circuit protective device, and the converter triggers instantaneous protection at the same time, which may be considered to have no effect on the DC bus-bar.

3. For branches with an energy storage device (storage battery or super capacitor) and fuel cell plus a converter, when a short circuit occurs at the rear end of the converter, the possibility that the energy storage device or fuel cell feeds short-circuit current to the DC bus-bar through the anti-parallel diodes of the converter switching devices when the DC bus-bar voltage drops below the output voltage of the energy storage device or fuel cell is to be considered.

(4) Other converters connected to the DC bus-bar^①.

2.1.3 All possible short-circuit points are to be selected according to the system characteristics, which generally include:

(1) Inter-pole short-circuit fault at the output terminal of the power supply unit (including converter);

(2) Inter-pole short-circuit fault of the DC bus-bar and bus-bar connecting cables;

(3) Short-circuit fault between the positive and negative poles at the input terminal of the load device (including converter), etc.

2.1.4 The short-circuit calculations in this Section adopt the following assumptions:

(1) The short-circuit arc impedance and all capacitances to earth in the DC distribution system are neglected;

(2) The transmission path of the short-circuit current remains unchanged during the short circuit;

(3) The short circuit occurs simultaneously between the positive and negative poles.

2.2 Modelling and calculation methods for primary electrical equipment

2.2.1 Modelling of power plants and connecting converters

(1) Three-phase AC synchronous generator + three-phase controlled rectifier:

This model applies to the DC distribution system supplied by a three-phase AC synchronous generating set via a three-phase PWM rectifier. When a short circuit occurs between the positive and negative poles of the DC distribution system, the PWM rectifier will immediately block the pulses. The PWM rectifier may be equivalent to a three-phase uncontrolled rectifier, as shown in Figure 2.2.1-1. The short-circuit current I_{fg} at the short-circuit point consists of two parts: 1) the discharge current I_{cg} supplied by the DC-side support capacitor C_g to the short-circuit point immediately after the occurrence of the short circuit; 2) when the capacitor voltage U_{cg} drops below the peak line voltage of the AC generator, the three-phase uncontrolled rectifier conducts, and the generator discharges through the uncontrolled rectifier and supplies the short-circuit current I_{dcg} .

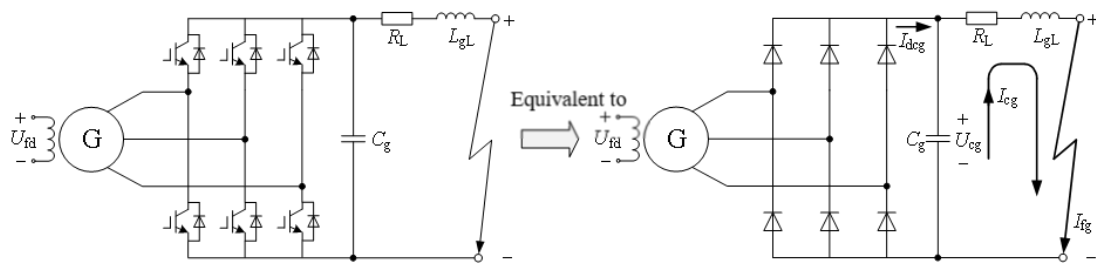


Figure 2.2.1-1 Schematic Diagram and Equivalent Circuit Diagram of Three-Phase AC Synchronous Generator + Three-Phase Controlled Rectifier

In Figure 2.2.1-1, R_L is the conductor resistance of the rectifier output cable; $L_{gL}=L_L+L_g$, L_L is the conductor inductance of the rectifier output cable, and L_g is the current-limiting inductance (if any) connected in series at the rectifier output.

The equivalent circuit model of the three-phase AC synchronous generator + three-phase controlled

^① For converters in the DC bus-bar system, if capacitors are installed internally, their contribution to the short-circuit current is to be considered in the system protection design. If an isolating switch is installed on the converter branch, the isolating switch installed between the converter and the DC bus-bar is to remain in the connected state at all times, unless a branch is in a fault condition, or documentary evidence can be submitted to demonstrate that the isolating switch to be disconnected will not affect the selective protection of the system.

rectifier shown in Figure 2.2.1-1 may be built using the simulation models of the three-phase AC synchronous generator, diode, etc., that come with the commercial simulation software, such as the Synchronous Machine model and the Power electronic switch model in PSCAD/EMTDC software.

(2) Twelve-phase AC rectifier generator:

This model applies to the DC distribution system directly supplied by a twelve-phase AC rectifier generating set. The twelve-phase AC rectifier generator integrates a twelve-phase AC synchronous generator and a twelve-phase uncontrolled rectifier into one unit. When a short circuit occurs between the positive and negative poles of the DC distribution system, the twelve-phase AC generator immediately supplies short-circuit current to the short-circuit point via the twelve-phase uncontrolled rectifier. At this time, the four sets of three-phase stator windings of the twelve-phase AC generator may be considered to be completely symmetrical, and it may be equivalent to a circuit of four three-phase AC synchronous generators with the same parameters respectively connected in series with phase-shifting transformers, as shown in Figure 2.2.1-2. The quantitative relationship between the electrical parameters of the three-phase generator and the twelve-phase generator is as follows:

① Relationship of stator circuit parameters: The actual values and reference values of the stator voltage and current of each three-phase generator are respectively equal to the actual values and reference values of the corresponding parameters of a single three-phase winding of the twelve-phase generator stator. That is, the per-unit values of the stator circuit parameters of each three-phase generator are equal to the per-unit values of the stator circuit parameters of a single three-phase winding of the twelve-phase generator.

② Relationship of rotor circuit parameters: The actual value of the excitation voltage and the actual values of the rotor winding (including excitation winding, D-axis and Q-axis damper winding, Q-axis stabilizing winding) currents of each three-phase generator are respectively equal to the actual value of the excitation voltage and the actual values of the corresponding rotor winding currents of the twelve-phase generator; the reference value of the excitation voltage of each three-phase generator is equal to the reference value of the excitation voltage of the twelve-phase generator; the reference values of the rotor winding (including excitation winding, D-axis and Q-axis damper winding, Q-axis stabilizing winding) currents of each three-phase generator are 4 times the reference values of the corresponding rotor winding currents of the twelve-phase generator. That is, the per-unit value of the excitation voltage of each three-phase generator is equal to the per-unit value of the excitation voltage of the twelve-phase generator; the per-unit values of the rotor winding (including excitation winding, D-axis and Q-axis damper winding, Q-axis stabilizing winding) currents of each three-phase generator are 1/4 of the per-unit values of the corresponding rotor winding currents of the twelve-phase generator; the per-unit values of the rotor winding (including excitation winding, D-axis and Q-axis damper winding, Q-axis stabilizing winding) resistance and reactance of each three-phase generator are 4 times the per-unit values of the corresponding rotor winding resistance and reactance of the twelve-phase generator.

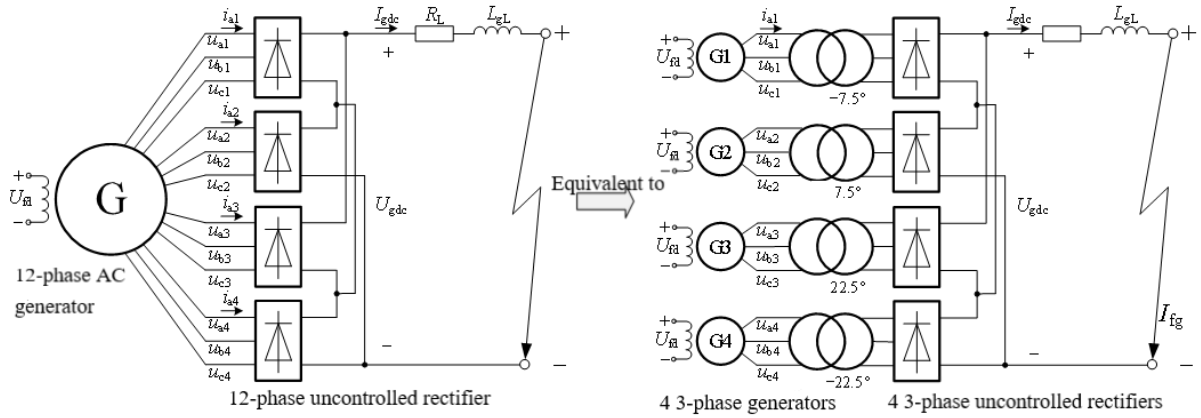


Figure 2.2.1-2 Schematic Diagram and Equivalent Circuit Diagram of Twelve-Phase AC Rectifier Generator

In Figure 2.2.1-2, R_L is the conductor resistance of the twelve-phase AC rectifier generator output cable; $L_{gL}=L_L+L_g$, L_L is the conductor inductance of the twelve-phase AC rectifier generator output cable, and L_g is the current-limiting inductance (if any) connected in series at the output of the twelve-phase AC rectifier generator.

The equivalent circuit model of the twelve-phase AC rectifier generator shown in Figure 2.2.1-2 may be built using the simulation models of the three-phase AC synchronous generator, diode, etc., that come with the commercial simulation software, such as the Synchronous Machine model and the Power electronic switch model in PSCAD/EMTDC software.

(3) Three-phase AC asynchronous generator + converter:

Same as 2.2.3 "Modelling of frequency converters and motors".

(4) Fuel cell power installation:

Taking the commonly available proton exchange membrane fuel cell power installation stack on the current market as an example, it may be represented by the equivalent circuit model shown in Figure 2.2.1-3. In the figure, E is the internal potential of the fuel cell stack; U_{fc} and I_{fc} are the output voltage and current of the fuel cell power installation. The internal potential E of the stack is a function of the output current I_{fc} , and its correspondence may be obtained by looking up the fuel cell V-I characteristic curve (i.e., the internal potential of the stack corresponding to different output currents) provided by the manufacturer; R_i is the ohmic resistance of the stack, R_d is the activation equivalent resistance of the stack, R_w is the concentration loss equivalent impedance (it is generally considered that the operating condition range provided by the manufacturer has avoided concentration polarization), and C_{dl} is the double-layer charge effect equivalent capacitance. These parameters may be provided by the manufacturer or obtained by testing the actual fuel cell power installation.

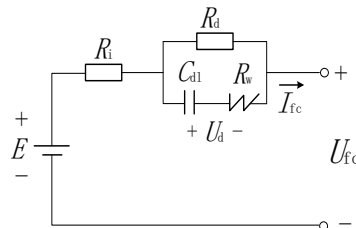


Figure 2.2.1-3 Equivalent Circuit Model of Fuel Cell Stack

2.2.2 Modelling of energy storage devices and connecting converters

(1) Power battery energy storage device:

Power battery energy storage devices usually achieve high voltage and high power output through a large number of series and parallel connections of small-capacity battery cells. Under the assumption of good consistency of battery cells, the battery pack may be represented by the Thevenin equivalent circuit model shown in Figure 2.2.2-1. In the figure, U_{OC} is the open-circuit voltage of the power battery pack, $U_{OC} = N_{sb} \times U_{OCV}$, where N_{sb} is the number of cells connected in series, U_{OCV} is the open-circuit voltage of a single cell. U_{OCV} varies with the battery SoC and may be obtained by looking up the OCV-SoC characteristic curve (i.e., the battery open-circuit voltage corresponding to different SoC) provided by the manufacturer according to the current SoC value of the battery pack; R_0 is the ohmic resistance, R_s is the polarization resistance, and C_s is the polarization capacitance. These parameters may be provided by the manufacturer or obtained by testing the actual power battery energy storage device.

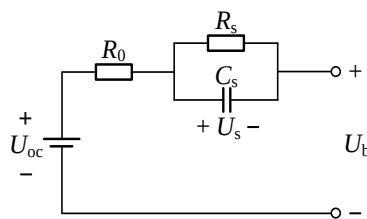


Figure 2.2.2-1 Equivalent Circuit Model of Power Battery Energy Storage Device

(2) Super capacitor energy storage device:

Super capacitor energy storage devices usually achieve high voltage and high power output through a large number of series and parallel connections of small-capacity super capacitor cells. Its equivalent circuit model is a structure where the equivalent capacitance C_{sc} is connected in series with the equivalent internal resistance R_{sc} , and then connected in parallel with the equivalent self-discharge resistance R_{sd} , as shown in Figure 2.2.2-2. This model is a first-order approximation of the charging and discharging process of the super capacitor. In the figure, the equivalent capacitance $C_{sc} = N_{pc} \times C_c / N_{sc}$ where N_{pc} is the number of super capacitor cells connected in parallel, N_{sc} is the number of super capacitor cells connected in series, and C_c is the capacitance of a super capacitor cell; the equivalent internal resistance R_{sc} and equivalent self-discharge resistance R_{sd} may be provided by the manufacturer or obtained by testing the actual super capacitor energy storage device.

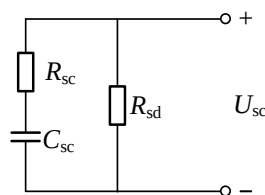


Figure 2.2.2-2 Equivalent Circuit Model of Super Capacitor Energy Storage Device

(3) DC/DC converter for energy storage devices:

Lithium battery or super capacitor energy storage devices may be connected to the DC distribution system via a DC/DC converter. DC/DC converters can be divided into isolated and non-isolated types, among which non-isolated DC/DC converters can be further subdivided into boost type, buck type and buck-boost composite type. The models in this Section apply to DC distribution systems where energy storage devices

are connected via DC/DC converters. When a short circuit occurs between the positive and negative poles of the DC distribution system, the equivalent circuit models of these four types of DC/DC converters are shown in Figure 2.2.2-3. In the figure, U_{in} is the input voltage of the DC/DC converter (e.g., the output voltage of an energy storage device or other DC power generation device), R_L is the conductor resistance of the DC/DC converter output cable, and L_L is the conductor inductance of the DC/DC converter output cable.

① Non-isolated boost type DC/DC converter: When a short circuit occurs between the positive and negative poles of the DC distribution system, this converter immediately blocks the pulse T_b . The short-circuit current I_{fb} at the short-circuit point consists of the superposition of two parts: 1) the DC-side filter capacitor C_b supplies discharge current I_{cb} to the short-circuit point immediately after the short circuit occurs; 2) when the capacitor voltage U_{cb} drops below the input voltage U_{in} , the diode D_b conducts, and the input side (energy storage device) supplies short-circuit current I_{Lb} to the short-circuit point via the diode D_b .

② Non-isolated buck type DC/DC converter: When a short circuit occurs between the positive and negative poles of the DC distribution system, this converter immediately blocks the pulse T_b . The input side (energy storage device) will not supply short-circuit current to the short-circuit point. The short-circuit current I_{fb} at the short-circuit point is mainly the discharge current I_{cb} supplied by the DC-side filter capacitor C_b to the short-circuit point.

③ Non-isolated buck-boost composite type DC/DC converter: When a short circuit occurs between the positive and negative poles of the DC distribution system, this converter may operate in constant current mode. The short-circuit current I_{fb} at the short-circuit point consists of the superposition of two parts: 1) the DC-side filter capacitor C_{b2} supplies discharge current I_{cb} to the short-circuit point immediately after the short circuit occurs; 2) the converter outputs a constant current according to the set current command value I_{Lim} . This constant current value I_{Lim} may be set according to the actual operation requirements of the DC distribution system, but is to be within the safe operation range of the converter power devices and filtering elements.

④ Isolated DC/DC converter: Same as the above-mentioned type ③ DC/DC converter. When a short circuit occurs between the positive and negative poles of the DC distribution system, this converter may operate in constant current mode. The short-circuit current I_{fb} at the short-circuit point consists of the superposition of two parts: 1) the DC-side filter capacitor C_{b2} supplies discharge current I_{cb} to the short-circuit point immediately after the short circuit occurs; 2) the converter outputs a constant current according to the set current command value I_{Lim} . This constant current value I_{Lim} may be set according to the actual operation requirements of the DC distribution system, but is to be within the safe operation range of the converter power devices and filtering elements.

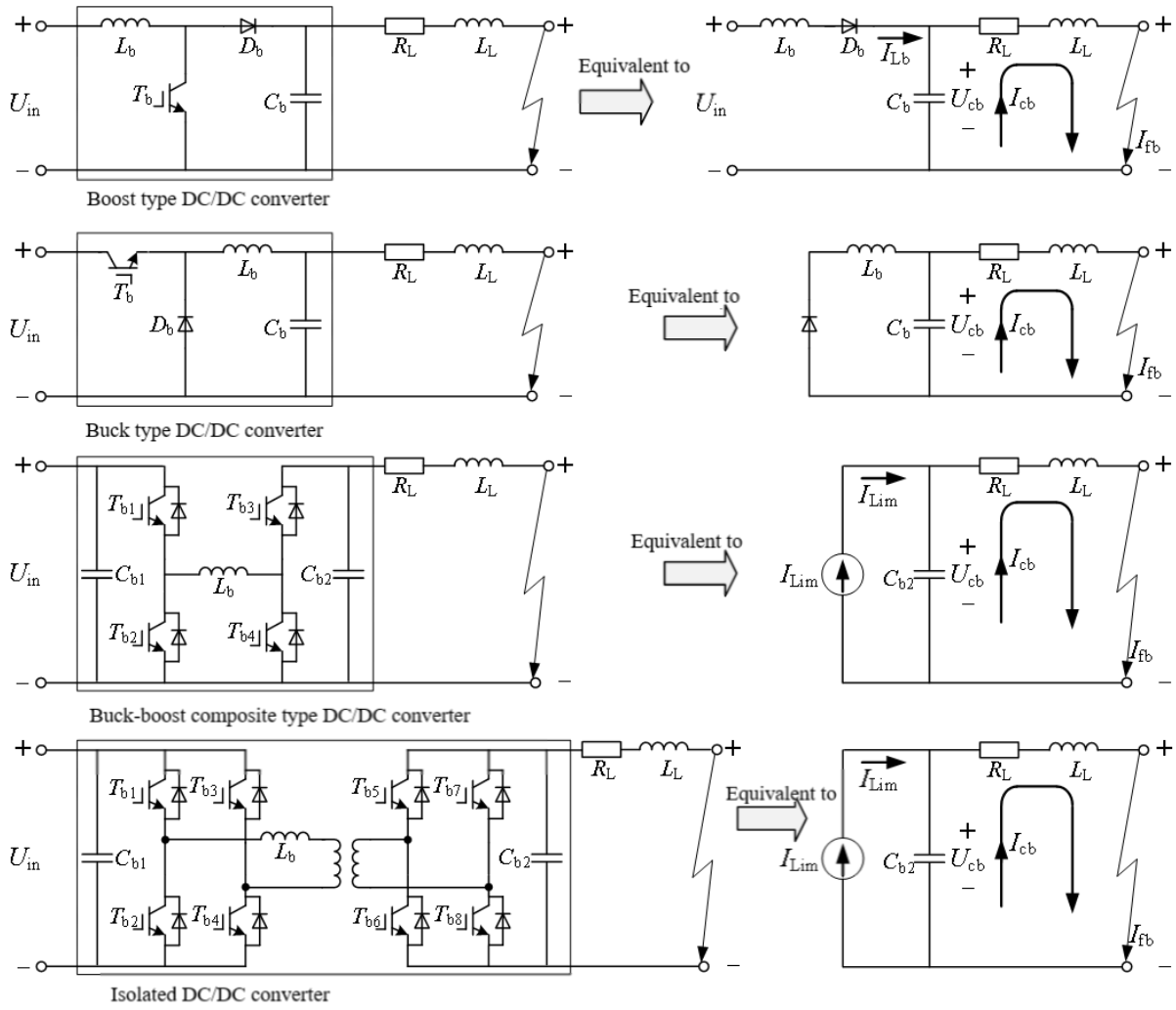


Figure 2.2.2-3 Equivalent Circuit Models of Four Types of DC/DC Converters

The above four types of DC/DC converters are the most basic forms. If an actual system combines multiple basic converters with the same structure to form a multi-phase, multiplex structure DC/DC converter, similar methods in this Section may also be used for modelling.

The equivalent circuit models of various types of DC/DC converters shown in Figure 2.2.2-3 may be built using the simulation models of resistor, capacitor, inductor, diode, constant current source, etc., that come with the commercial simulation software, such as the Resistor model, Inductor model, Capacitor model, Power electronic switch model, and Current Source model in PSCAD/EMTDC software.

2.2.3 Modelling of frequency converters and motors

This model applies to propulsion motors driven by frequency converters directly supplied by the DC bus-bar in the DC distribution system, and other operational motors (if any) driven by frequency converters, where no anti-reverse diode is configured on the DC side of the frequency converter.

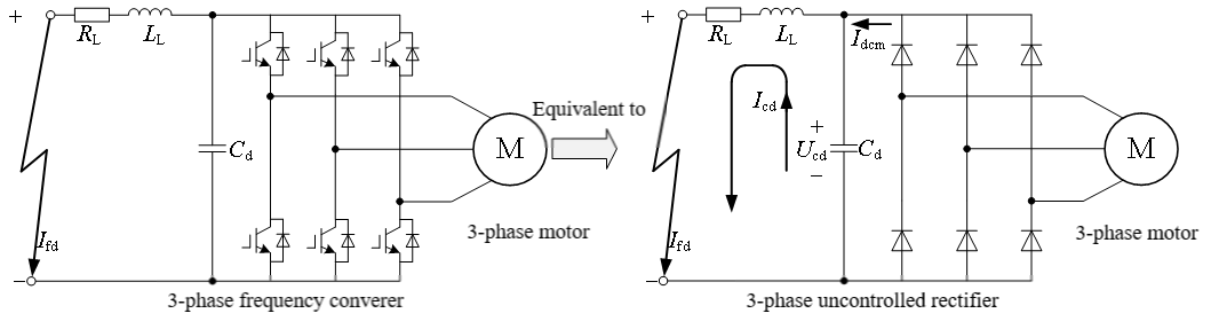


Figure 2.2.3-1 Schematic Diagram and Equivalent Circuit Diagram of Three-Phase Frequency Converter + Three-Phase Motor

When a short circuit occurs between the positive and negative poles of the DC distribution system, the frequency converter will immediately block the pulses. The frequency converter may be equivalent to a three-phase uncontrolled rectifier, as shown in Figure 2.2.3-1. In the figure, R_L is the conductor resistance of the frequency converter DC input cable, and L_L is the conductor inductance of the frequency converter DC input cable. The short-circuit current I_{fd} supplied by the frequency converter and motor to the short-circuit point consists of the superposition of two parts: 1) the DC-side support capacitor C_d of the frequency converter supplies discharge current I_{cd} to the short-circuit point immediately after the short circuit occurs; 2) when the capacitor voltage U_{cd} drops below the peak back EMF of the motor, the three-phase uncontrolled rectifier conducts, and the three-phase motor supplies short-circuit current I_{dcm} to the short-circuit point via the uncontrolled rectifier.

The equivalent circuit model of the frequency converter and motor shown in Figure 2.2.3-1 may be built using the simulation models of diode, three-phase motor, etc., that come with the commercial simulation software, such as the Power electronic switch model, Induction Machine model or Permanent Magnet Machine model in PSCAD/EMTDC software.

If an anti-reverse diode is configured in front of the support capacitor on the DC side of the frequency converter in the actual system, the frequency converter and motor will not feed short-circuit current to the short-circuit point when a short circuit occurs between the positive and negative poles of the DC distribution system, and the short-circuit modelling of this type of frequency converter and motor may not be considered.

2.2.4 Modelling of DC conductor loops

The resistance and inductance values may be obtained by multiplying the resistance R' and inductance L' per unit length of the conductor loop by the length of the single-run conductor, respectively.

$$R_n = R'x$$

$$L_n = L'x$$

where, R_n is the total cable resistance, L_n is the total cable inductance, and x is the cable length.

2.3 Short-circuit calculations and protection check methods for DC distribution systems with fuses as the primary protective devices

2.3.1 Build simplified simulation models of the main equipment of the system. The protection speed of fuses is fast; fast-acting fuses can generally operate within the range of hundred μs to ms. Therefore, during the period from the occurrence of a short circuit between the positive and negative poles of the DC distribution system to the blowing of the corresponding fuse in the fault branch, the system short-circuit

current is mainly the discharge current of the DC-side support capacitors of various converters and frequency converters, as well as the short-circuit current provided by AC rectifier generators (if any), power batteries or super capacitors (if any), etc., which directly supply power to the DC bus-bar (without passing through additional converters). Specifically, the models of the electrical equipment described in Section 2.2 may be appropriately simplified as follows:

- (1) Three-phase AC synchronous generator + three-phase controlled rectifier: Only the discharge current I_{cg} supplied by the DC-side support capacitor C_g to the short-circuit point may be considered;
- (2) Twelve-phase AC rectifier generator: Maintain the model of 2.2.1(2) unchanged;
- (3) Fuel cell power installation (or power battery energy storage device, super capacitor energy storage device) + DC/DC converter: Only the discharge current I_{cb} supplied by the DC-side support capacitor C_b of the converter to the short-circuit point may be considered;
- (4) Power battery energy storage device, super capacitor energy storage device (when directly supplying power to the DC bus-bar): Maintain the models of 2.2.2(1) and 2.2.2(2) unchanged;
- (5) Frequency converter and motor (if there is no anti-reverse diode on the DC side of the frequency converter): Only the discharge current I_{cd} supplied by the DC-side support capacitor C_d of the frequency converter to the short-circuit point may be considered;
- (6) DC conductor loop: Maintain the model of Section 2.2.4 unchanged;
- (7) Modelling of fast-acting fuse: The model of a fast-acting fuse is a variable resistor. When the I^2t integral value of the loop where the fast-acting fuse is located reaches the pre-arcing I^2t of the fuse, the fuse element begins to melt, the resistance increases, and the fuse blows when the I^2t integral value of the loop reaches the total I^2t of the fuse. Generally, the equivalent short-circuit resistance value should be several times the steady-state DC resistance value before arcing, and even larger after arcing. The equivalent short-circuit resistance of the fuse provided by the manufacturer is generally to be used. If it cannot be determined and when necessary, the equivalent resistance model is to be determined by a special short-circuit test of the fuse.

2.3.2 Based on the equipment operation states and the connection relationships among the various equipment, build the equivalent simulation models under the maximum and minimum operating modes of the system. For the short-circuit points selected in 2.1.3, set inter-pole short-circuit faults in sequence, and carry out the calculation of DC bus-bar voltage and instantaneous short-circuit current.

2.3.3 Based on the calculation results of the instantaneous short-circuit current, obtain the maximum peak short-circuit current of each loop and its total I^2t value, and check the selection of the fast-acting fuse according to the provisions of 4.4.2.6, Chapter 4 of the Guidelines.

2.3.4 Based on the simulation results of the fuse under various short-circuit conditions and the DC bus-bar voltage drop, check the reasonability of the protection design of the DC distribution system according to the provisions of 4.4.3.1, Chapter 4 of the Guidelines.

2.4 Short-circuit calculations and protection check methods for DC distribution systems with circuit breakers as the primary protective devices

2.4.1 Using the equipment models given in Section 2.2, based on the equipment operation states and the connection relationships among the various equipment, according to the system simulation models under the maximum and minimum operating modes respectively, set inter-pole short-circuit faults in sequence for the short-circuit points selected in 2.1.3, and carry out the calculation of DC bus-bar voltage and

instantaneous short-circuit current.

2.4.2 Based on the calculation results of the instantaneous short-circuit current, obtain the maximum peak short-circuit current of each loop, and check the selection of the DC circuit breaker according to the provisions of 4.4.2.7, Chapter 4 of the Guidelines.

2.4.3 Based on the simulation results of the circuit breaker under various short-circuit conditions and the DC bus-bar voltage drop, check the reasonability of the protection design of the DC distribution system according to the provisions of 4.4.3.1, Chapter 4 of the Guidelines.

Section 3 SHORT-CIRCUIT CALCULATIONS AND PROTECTION

CHECK METHODS FOR DAILY AC DISTRIBUTION SYSTEM

3.1 Calculating conditions and assumptions

3.1.1 The short-circuit calculations and protection check in this Section apply to the condition of an inter-phase short circuit occurring in an AC three-wire insulated system supplied by an inverter and/or AC generating set.

3.1.2 When calculating the short-circuit current of the daily AC distribution system, the following equipment is to be considered as short-circuit sources:

- (1) Daily inverter (together with transformer, if any);
- (2) AC generating set (if any);
- (3) Direct-on-line started three-phase motor loads;
- (4) Three-phase AC shore power grid.

3.1.3 All possible short-circuit points are to be selected according to the system characteristics, which generally include:

- (1) Inter-phase short-circuit fault at the output terminal of the inverter (together with transformer, if any) and AC power generation equipment (if any);
- (2) Inter-phase short-circuit fault of the AC bus-bar (e.g., 380 V bus-bar) and bus-bar connecting cables;
- (3) Inter-phase short-circuit fault at the input side of the AC load (e.g., 380 V AC load);
- (4) Inter-phase short-circuit fault of the power/lighting distribution box bus-bar (e.g., 230 V bus-bar).

3.1.4 The short-circuit calculations in this Section adopt the following assumptions:

- (1) The short-circuit arc impedance and the distributed capacitance to earth of AC equipment and cables are neglected;
- (2) The transmission path of the short-circuit current remains unchanged during the short circuit;
- (3) The short circuit occurs simultaneously in all three phases.

3.2 Modelling and calculation methods for primary electrical equipment

3.2.1 Modelling of daily inverters:

This model applies to the daily AC distribution system supplied by an inverter directly or via a transformer. When a three-phase short circuit occurs in the daily AC distribution system, if the inverter was operating in constant voltage mode before the short circuit, it is to immediately switch to the constant current output mode after the short circuit according to the requirements of 2.3.2.2, Chapter 2 of the Guidelines. The inverter may adopt the equivalent circuit model shown in Figure 3.2.1, and the short-circuit current at the short-circuit point is the constant current output current of the inverter.

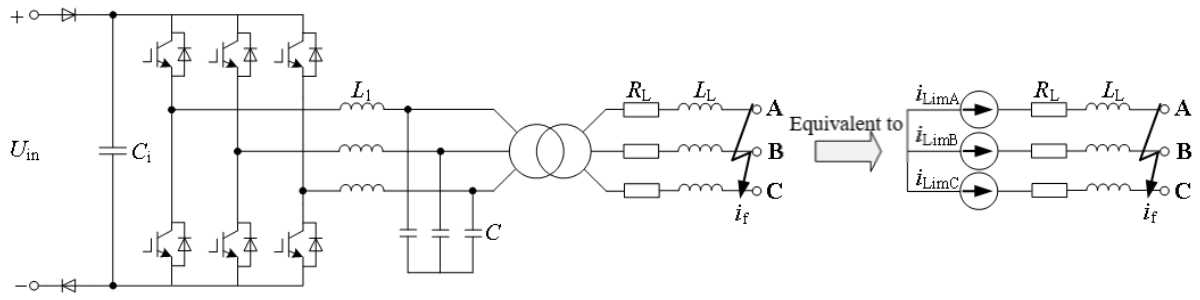


Figure 3.2.1 Schematic Diagram and Equivalent Circuit Diagram of Daily Inverter

The equivalent circuit model of the inverter during a short circuit in the AC distribution system shown in Figure 3.2.1 may be built using the simulation models of controlled current source, etc., that come with the commercial simulation software, such as the Current Source model in PSCAD/EMTDC software.

3.2.2 Modelling of three-phase AC generators, AC conductor loops, resistive-inductive loads and motor loads:

The simulation models of these equipment may be built using the simulation models of three-phase AC synchronous generator, resistor, inductor, three-phase asynchronous motor, etc., that come with the commercial simulation software, such as the Synchronous Machine model, Resistor model, Inductor model, and Induction Machine model in PSCAD/EMTDC software.

3.2.3 Modelling of three-phase AC shore power grid:

The three-phase AC shore power grid may adopt the Thevenin equivalent circuit of a three-phase ideal voltage source connected in series with a resistor and inductor. The amplitude of the three-phase ideal voltage source may be obtained by actual no-load measurement according to the connected shore power condition, and the resistor and inductor may be estimated based on the short-circuit capacity of the shore power system.

3.3 Short-circuit calculations and protection check methods for daily AC distribution system

3.3.1 Using the equipment models given in Section 3.2, based on the equipment operation states and the connection relationships among the various equipment, according to the system simulation models under the maximum and minimum operating modes respectively, set three-phase short-circuit faults in sequence for the short-circuit points selected in 3.1.3, and carry out the calculation of instantaneous short-circuit current.

3.3.2 Based on the calculation results of the instantaneous peak short-circuit current and the time to reach the instantaneous peak, check the protection design of the daily AC distribution system and the selection of protective devices according to 4.4.3.3, Chapter 4 of the Guidelines.

ANNEX 2 RISK ANALYSIS OF ELECTROMAGNETIC COMPATIBILITY AND DESIGN REPORT TEMPLATES

Section 1 POWER SYSTEM DESCRIPTION

1.1 Overview of system composition

Briefly describe the system functions and primary equipment. For example:

The ship's integrated power system obtains electric power from generators, storage batteries, etc., outputs 1000 V DC via power converters to supply frequency converters, and the frequency converters drive propulsion motors to provide power for the ship.

1.2 System composition block diagram

Provide the system composition block diagram. For example:

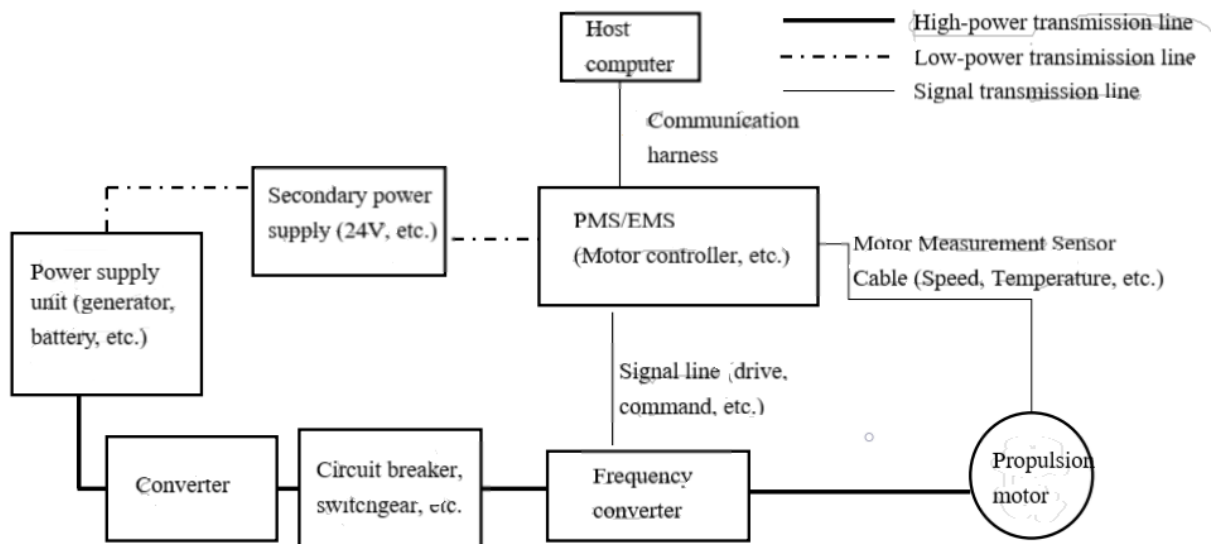


Figure 1.2 Block diagram of the integrated DC power system composition

Section 2 ANALYSIS OF ELECTROMAGNETIC ENVIRONMENT

2.1 Electromagnetic environment within the system

Briefly describe the installation locations of the system components and the relevant electromagnetic environment within the system. This section may be used to guide the application of electromagnetic compatibility standards for equipment selection. For example:

The integrated power system can be divided into power supply units, distribution system, propulsion system and PMS/EMS according to functions. The installation locations of each unit and system and the relevant electromagnetic environment are as follows:

Power supply units: including generators and storage batteries; located in the bottom engine room and battery compartment, with the main interference source coming from the rectifier generator;

Distribution system: including DC switchboard and converters, etc.; located in the bottom engine room, with the main interference source coming from converters;

Propulsion system: including frequency converters and propulsion motors; located in the aft engine room, with the main interference source coming from frequency converters;

PMS/EMS: including controllers and host computers; located in the navigation bridge; it is not a main interference source but a sensitive device, facing interference mainly from heavy-current equipment to sensors.

2.2 Electromagnetic environment outside the system (optional)

If necessary, briefly describe the positional relationship and electrical connection between other systems on board and the integrated DC power system. This section is used to analyze the impact of the integrated power system on the external environment. For example:

The ship's external communication system is located in a separate compartment above the hull and has no direct connection with the integrated power system, so the integrated power system has no impact on it.

Section 3 ELECTROMAGNETIC COMPATIBILITY

CHARACTERISTICS OF PRIMARY EQUIPMENT (SYSTEMS)

This section classifies and analyzes the electromagnetic compatibility of relevant equipment based on their electromagnetic compatibility data and electromagnetic environment analysis: it describes the electromagnetic compatibility situation among various equipment (systems) within the integrated DC power system, including electromagnetic interference characteristics and electromagnetic immunity characteristics. The content of this section may be tailored according to the actual system characteristics, but it is recommended to follow the methods in Annex B4 of IEC 60533 Electrical and Electronic Installations in Ships – Electromagnetic Compatibility (EMC) – Ships with a Metal Hull to obtain the equipment classification table (example as Table 3.1), interference frequency distribution diagram (example as Figure 3.4-1), interference amplitude distribution diagram (example as Figure 3.4-2), and finally obtain the equipment interference matrix (example as Table 3.4).

3.1 Equipment classification

For example, the primary equipment of this system can be qualitatively classified according to interference characteristics and susceptibility characteristics as shown in Table 3.1.

Table 3.1 Primary Equipment Classification

Equipment Classification		Equipment	Equipment Type	Equipment Code
A	Power Plant and Converter	Rectifier generator	Interference source, non-sensitive	A1
		Motor exciter	Interference source, sensitive	A2
		Power converter	Interference source, non-sensitive	A3
B	Switchgear and Controlgear	Circuit-breaker/contactors	Interference source, non-sensitive	B1
		Relay	Sensitive	B2
		Electronic protection device	Sensitive	B3
C	Communication and Signal Processing Equipment	Network switch	Sensitive	C1
		Motor controller	Sensitive	C2
		Sensor	Sensitive	C3
		Host computer	Sensitive	C4

D	Energy Storage Device	Storage battery	Non-sensitive	D1
E	Propulsion System	Propulsion frequency converter	Interference source, non-sensitive	E1
		Propulsion motor	Non-sensitive	E2

3.2 Equipment electromagnetic interference characteristics

Summarize the electromagnetic interference characteristics of primary equipment, giving priority to data from equipment electromagnetic interference test reports; if there is no test data, it can also be estimated based on the equipment working principle. For example:

The main interference sources in this integrated power system come from common-mode interference and differential-mode interference of high-power power electronic equipment, as well as transient interference of high-power circuit breakers; the harmonic interference frequency distribution of high-power power electronic equipment extends from 150 Hz in the power frequency range to the MHz range; the amplitude ranges from the 10 V level (140 dB μ V) in the low-frequency range to the mV level (60 dB μ V) in the high-frequency range; the frequency distribution of circuit breaker transient interference is from 100 kHz to 50 MHz, with the amplitude fluctuating between 0.1 V and 5 V (i.e., 100~134 dB μ V).

3.3 Equipment electromagnetic susceptibility characteristics

Summarize the electromagnetic susceptibility characteristics of primary equipment, giving priority to data from equipment electromagnetic interference test reports; if there is no test data, it can also be estimated based on the equipment working principle. For example:

The main sensitive equipment in this integrated power system is Class B and Class C equipment, with a sensitive frequency range of 1 M~30 MHz and a sensitive threshold of 1~10 V (i.e., 120~140 dB μ V).

3.4 Electromagnetic compatibility risk analysis

Based on the summary of the interference characteristics of the system equipment described above, the interference frequency distribution diagram (as shown in Figure 3.4-1) and interference amplitude distribution diagram (as shown in Figure 3.4-2) of the integrated power system can be obtained. The frequencies here include equipment operating frequencies, generated harmonic frequencies, interference frequencies, etc. Based on the analysis results of equipment electromagnetic interference characteristics, an equipment electromagnetic interference matrix (example as Table 3.4) is generated. The equipment interference matrix table is to make a rough estimate of the interference possibility between the disturbed equipment and the emission source. Where interference is impossible, mark "-" at the matrix intersection; where interference may occur, mark "+"; for those where analysis and calculation are performed, if the analysis shows no interference, use the symbol " $\oplus$ " in the matrix; if it shows interference, use the symbol "#".

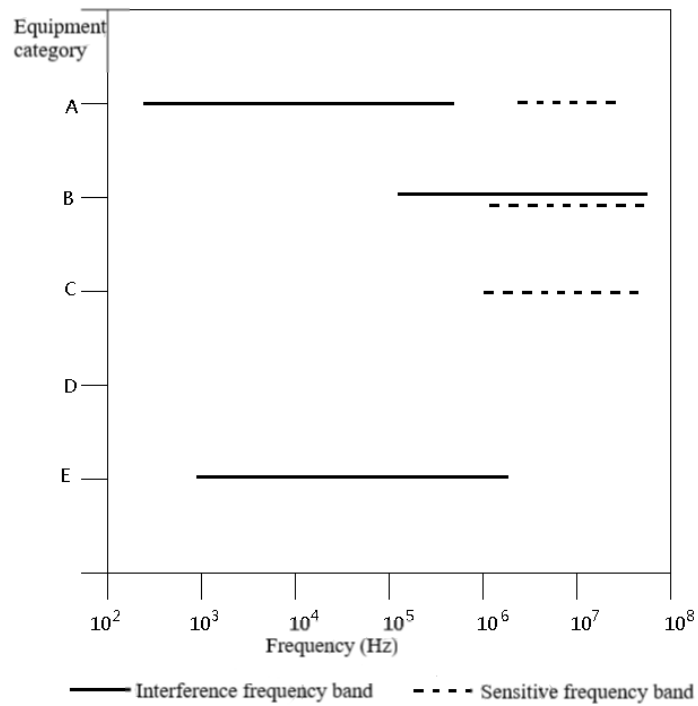


Figure 3.4-1 Equipment Interference Frequency Distribution Diagram (solid line: equipment emission frequency, dashed line: equipment sensitive frequency)

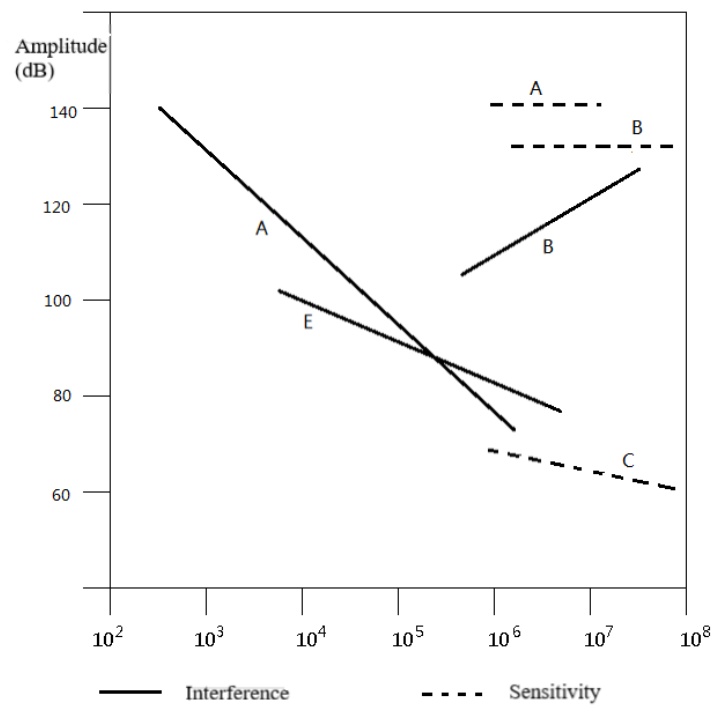


Figure 3.4-2 Equipment Interference Amplitude Distribution Diagram (solid line: equipment emission amplitude, dashed line: equipment sensitive amplitude)

Table 3.4 Equipment Interference Matrix

Sensitive Equipment	Source of interference												
	A1	A2	A3	B1	B2	B3	C1	C2	C3	C4	D1	E1	E2
A1	-	-	-	-	-	-	-	-	-	-	-	-	-
A2	⊕	-					-	-	-	-	-		
A3	-	-	-	-	-	-	-	-	-	-	-	-	-
B1	-	-	-	-	-	-	-	-	-	-	-	-	-
B2	⊕	-	#	#	-		-	-	-	-	-	#	-
B3	⊕	-	#	#	-	-	-	-	-	-	-	#	-
C1	⊕	⊕	#	⊕	-	-	-	-	-	-	-	#	⊕
C2	⊕	-	#	⊕	-	-	-	-	-	-	-	#	⊕
C3	#	#	#	⊕	-	-	-	-	-	-	-	#	⊕
C4	⊕	-	#	⊕	-	-	-	-	-	-	-	#	⊕
D1	-	-	-	-	-	-	-	-	-	-	-	-	-
E1	-	-	-	-	-	-	-	-	-	-	-	-	-
E2	-	-	-	-	-	-	-	-	-	-	-	-	-

Section 4 MAJOR ELECTROMAGNETIC COMPATIBILITY DESIGN MEASURES AND EXPECTED EFFECTS

4.1 System-level electromagnetic compatibility design measures

This section describes the electromagnetic compatibility design measures and effects taken from the system design, such as spectrum allocation and equipment layout. For example:

According to Table 3.1 and Table 3.4, the main interference sources in this integrated power system are Class A, B, and E equipment, while the sensitive equipment are Class B and C equipment; therefore, in the system design, the layout of strong and weak current equipment is separated, and in the absence of shielding, it is necessary to ensure that Class C equipment and its transmission signal cables are more than 1 m away from the cables of Class A and E equipment.

4.2 Equipment-level electromagnetic compatibility optimization measures

Describe the corresponding measures taken for equipment electromagnetic compatibility issues, such as filtering and shielding. For example:

According to Table 3.4, the main situation where electromagnetic interference may occur is the interference generated by A3 and E1 equipment to Class C equipment; for this reason, EMI filters are added at the grid side of A3 and E1 equipment, and twisted-pair cables and shielded twisted-pair cables are respectively adopted for the transmission signal lines of Class C equipment.

Section 5 ILLUSTRATION BLOCK DIAGRAM OF SYSTEM LAYOUT, WIRING, FILTERING AND EARTHING

Provide illustrative explanations for the design measures in Section 4 of this Annex. For example:

5.1 EMI filter arrangement for A3 and E1 equipment

Filter location:

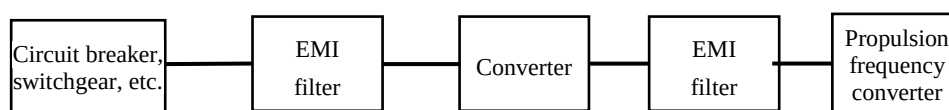


Figure 5.1-1 Schematic Diagram of EMI Filter Location

Filter configuration:

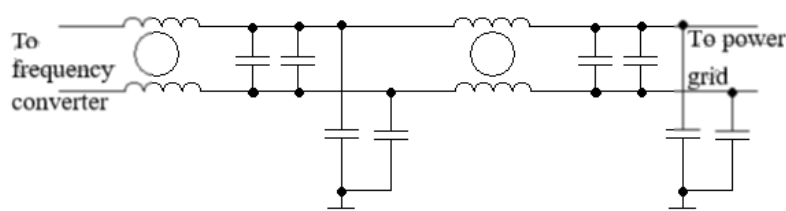


Figure 5.1-2 Schematic Diagram of EMI Filter Structure

5.2 Transmission signal lines for Class C equipment

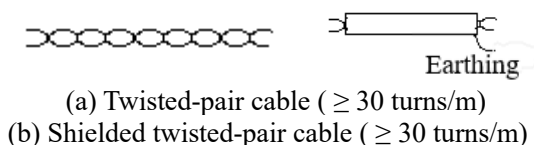


Figure 5.2 Schematic Diagram of Transmission Signal Lines

Note: This example takes a simple integrated power system as an example to illustrate the template of the electromagnetic compatibility risk analysis and design report, mainly used to explain the content framework that should be included in each part of the risk analysis and design report. In practical application, the content of the report needs to be tailored or supplemented according to the specific situation of the system. For example, only the conducted interference characteristics of equipment are given in this example, while radiation interference characteristics may also need to be given in actual systems.