

# Chapter 1

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## Overview

### 1.0 INTRODUCTION

The shipboard electrical system design process consists of concept design, preliminary design, detail design, design development, design verification, installation, and commissioning. Shipboard power-system design and development is an engineering art that requires many years of engineering experience, specifically, designing electrical systems with experienced engineers. Shipboard electrical system design and development has become very challenging due to complex electrical power generation and distribution requirements including higher voltage, high power, and adjustable speed propulsion drives. The ship propulsion system has changed from direct mechanical drive to an electric motor with an adjustable speed drive. The across the line starters for auxiliary systems are being replaced with adjustable frequency/speed drive. Solid-state power electronics are being programmed to perform necessary ASD functions. However, solid-state devices and functionality also have some drawbacks, such as electrical noise. Most of the power electronic application-related hardware for shipboard application is migrated from well-established, shore-based industrial applications. There are subtle differences where industrial-based equipment is not suitable for shipboard applications. The shipboard power-system design process needs to be validated by methodical analysis with pros and cons. Sometimes the design process must go through a physics-based simulation process including hardware in the loop simulation to ensure that the design is optimized. The modeling and simulation of a shipboard electrical system provides many design options so that optimal design can be adapted for a custom shipboard design application. This book describes the following design and development process:

- a. Basic design process, verification, and validation
- b. Modeling and simulation-based design and verification
- c. Smart ship system design (S3D)

Shipboard electrical power generation and distribution requirements are guided by rules, regulations, standards, and established recommendations by authorities

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having jurisdiction in the design and development field. Power-system design engineers are to follow these guidelines to design required systems and get the design approved by the authority having approval jurisdiction. The shipboard low-voltage power system includes 1000 V, 690 V, 480 V, 230 V, and 120 V at 60 Hz and DC power at the voltage range from 12 V to 48 V, etc. The medium-voltage system includes all voltages from 1000 V to 35 kV AC as applicable for specific application. This book covers up to 15 kV maximum (11 kV or 13.8 kV nominal per MIL-STD-1399-300 and MIL-STD-680).

The shipboard power system consists of ship service power, emergency power, and propulsion power.

Shipboard power demand has evolved from a few megawatts to hundreds of megawatts. The voltage level has also been upgraded to 690 V, 2400 V, 4160 V, 6600 V, and beyond. Variable frequency drive or adjustable speed drive technology has become a dominant feature to mitigate propulsion-related higher voltage and high-power demand. The transition of proven VFD or ASD applications from industrial application to ship application has created many challenges.

The transition from low-voltage to medium-voltage generation and distribution may not have fathomed the requirements of grounded and ungrounded systems. The current practice of designing shipboard power generation and distribution systems may reflect a combination of both industrial and maritime applications.

Design engineers must understand the difference between industrial and ship applications of high voltage and high power. Design engineers must address these problems as uniform across all applications including shipbuilding; however, they should not arbitrarily consider the same solutions, as shipboard power generation and distribution fundamentals are different. For example, the harmonic noise problem can be addressed in general for all applications, but harmonic problem solution criteria for ships are different from those of other applications.

This handbook provides detail design and development of shipboard power generation and distribution based on low-voltage power generation and distribution, which has been well defined, as well as the medium-voltage system.

Model-based design has been presented to establish design variations and then the selection process starting from the concept design:

- Optimize the performance of the shipboard power system
- Optimize the functionality of the shipboard electrical network
- Define the requirements of electrical power equipment
- Define and coordinate the protective devices
- Reduce power losses
- Quantify harmonics contents and then systematically apply a harmonic management program to achieve an acceptable level
- Arc flash analysis and the establishment of a Hazard Risk Category (HRC)

## 1.1 SHIPBOARD POWER SYSTEM DESIGN FUNDAMENTALS

In general, a shipboard power system is ungrounded with delta distribution. The ground detection system is provided to detect ground in the system so that the ground is lifted as soon as possible. Single-phase ground is detectable, but will let the system continue to operate on the other two healthy phases. However, second ground fault, phase to phase will create arcing, which must be monitored and lifted as soon as possible. Three-system fault, which is also called bolted fault, must be detected as fast as possible and then the protective system must isolate the bolted fault to avoid any kind of explosion.

Power generation and distribution as well as solid-state devices operate with some ground reference. The basic requirements of a shipboard ungrounded system may be violated. The resistance grounding system using a wye-delta transformer with wye neutral connected to a ground with resistor also establishes a ground reference point in the ungrounded power system. The resistance grounded system and ungrounded low-voltage distribution system create a ground loop in the entire power system. The ungrounded power system ground plane in ideal conditions is a zero-voltage reference point. However, the combination of all ground paths in a shipboard power system may create the zero ground point other than zero plane to an unacceptable level.

The use of the delta-delta transformer has been changed over to ungrounded delta-wye or grounded delta-wye. The delta-wye configuration is not acceptable for shipboard installation as it can propagate electric noise with the wye distribution. The delta-delta is recommended as both primary and secondary will help to circulate electric noise within the winding. The delta-wye will circulate noise all over the distribution system due to the wye configuration. Again, it is very difficult to maintain zero ground reference in a wye distribution system. The grounded wye distribution system creates a ground plane coupled with an ungrounded zero reference point.

There are some special cases where a grounded wye distribution system is allowed due to operator safety reasons, such as an electrical workshop where the operator may use handheld electrical tools.

## 1.2 SHIP DESIGN REQUIREMENTS

Ship design USCG regulations, ABS rules, IEEE recommendations and IEC standards are used as appropriate. However, there are fundamental differences that must be taken under consideration. For example, the electrical grounding is “earthing” in the IEC standard. The three “A, B, C” phases are identified as “U, V, W,” or “R, S, T,” etc. These are very confusing, but the design and development expert must be

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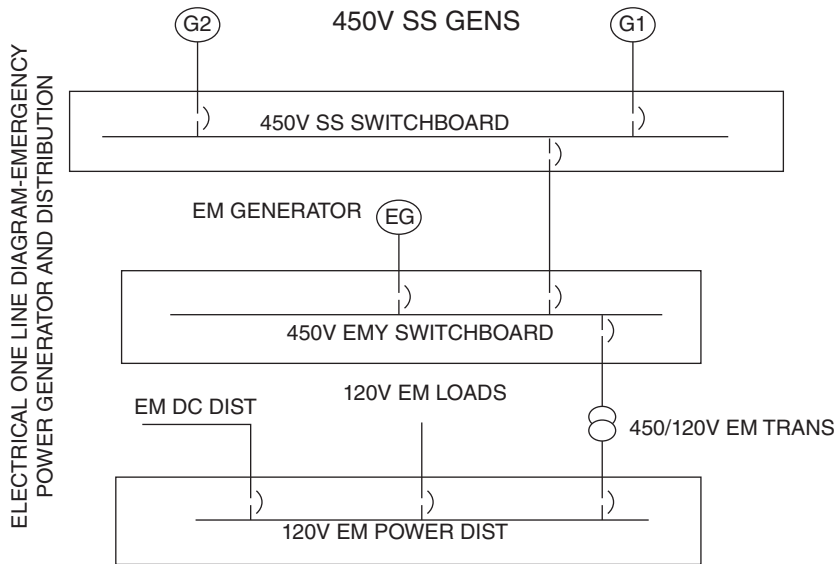
familiar with them simply because IEC standards are equally recognized by US rules and regulations.

**1.3 ETO CERTIFICATION: MEECE**

The shipboard engine room watch-keeping Electro-Technical Officer (ETO) is required to go through training as evidence of competency. One of the competency training courses, “Management of Electrical and Electronic Control Equipment” (MEECE), is outlined in Chapter 13.

Each candidate for endorsement as an Electro-Technical Officer (ETO) on ships powered by main propulsion machinery of 750 kW/1,000 HP or more must provide evidence of having achieved the standard of competence specified in Table A-III/6 of the STCW Code (USCG 46 CFR 11.335(a)(2)). The table in this enclosure is adopted from Table A-III/6 of the STCW Code (found in Enclosure (4)) to assist the candidate and the assessor in the demonstration of competency.

**1.4 LEGACY SYSTEM DESIGN DEVELOPMENT AND VERIFICATION**



**Figure 1.1** Typical EOL with Ship Service and Emergency Generator.

1.5 Shipboard Electrical System Design Verification and Validation (V&V) 5

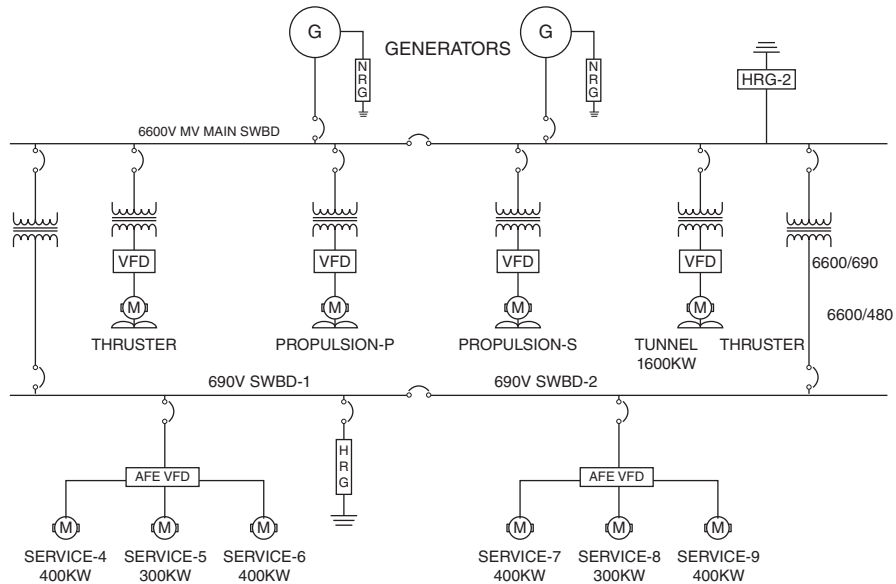


Figure 1.2 Typical EOL with Electric Propulsion and other VFD Services.

**1.5 SHIPBOARD ELECTRICAL SYSTEM DESIGN VERIFICATION AND VALIDATION (V&V)**

**1.5.1 Verification and Validation (V&V) Overview**

Shipboard electrical system design and development should have appropriate verification methods associated with them. Design verification must be traceable to a point that qualitative failure analysis (QFA) and design verification test procedure (DVTP) could be tied to each system as a deliverable.

The design verification and validation process must be traceable to operational scenarios so they are consistent with the Concept of Operations (CONOPS) of the ship.

**1.5.2 Verification**

Verification may be at the equipment level, system level, or system-of-system level.

The design verification method should include the following:

- i. Longhand calculation for preliminary design
- ii. Modeling and simulation
- iii. System-level engineering analysis

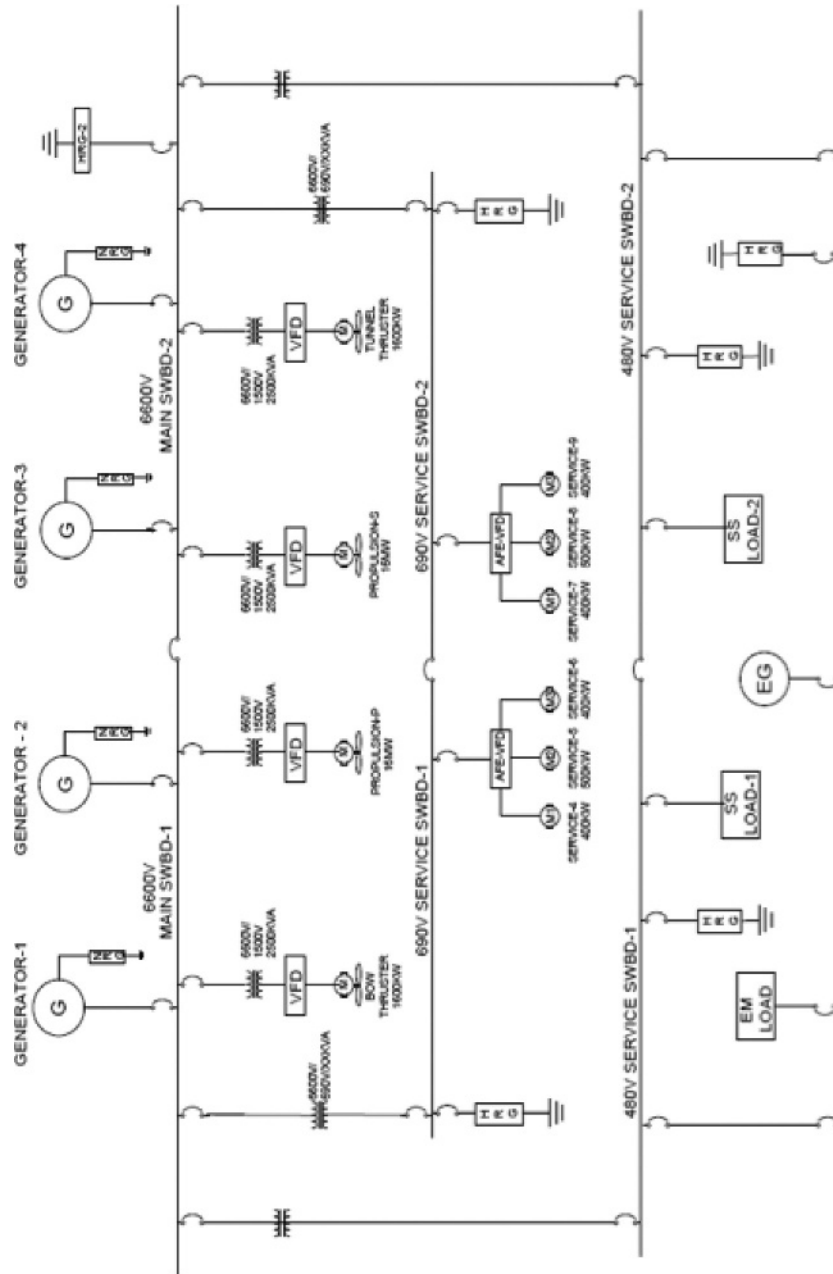


Figure 1.3 Typical EOL with All Electric Services and Emergency Generator.

1.5 Shipboard Electrical System Design Verification and Validation (V&V) 7

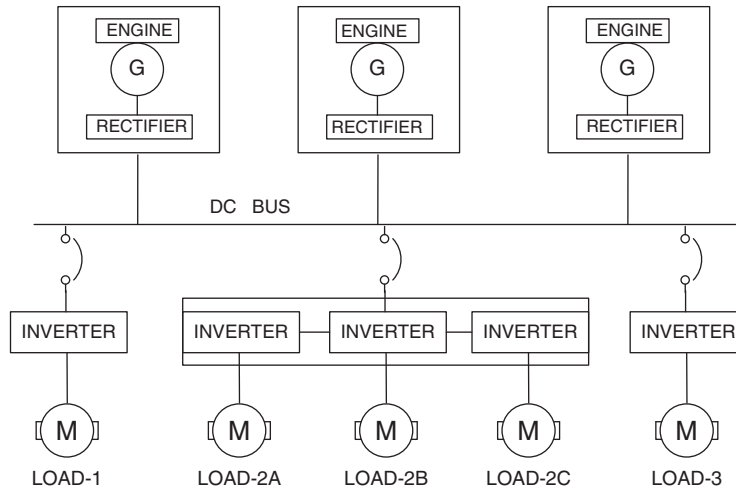


Figure 1.4 Typical EOL with All Electric Services.



Figure 1.5 Typical Ship Variations for Commercial, USCG, Navy, and Offshore.

- iv. Complete system review
- v. Concept of operation development
- vi. Fundamentals QFA & DVTP
- vii. Compliance certification

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### 1.5.2a Acceptance of Verification

Verification of the Support System involves verifying that each of the Support System Constituent Capabilities satisfy its relevant specification and that the Support System overall satisfies the requirements defined in the Support System Functional Baseline.

### 1.5.3 Validation

Validation of design should be conducted using scenarios that are consistent with the concept of operation. Because of the complexity of the systems that are being addressed and the significant time and effort required to conduct a comprehensive V&V program, the likelihood of completing a V&V program without the need for rework is low.

It is important that all test environments and equipment used during the V&V phases are controlled and validated to confirm that they will meet their objectives. If however the design development is verifiable as to the fact that the system has developed with a proven history of performance then it can be used, as prototype use may not require additional design verification.

### 1.5.4 Differences Between Verification and Validation: Shipboard Electrical System Design and Development Process

It is possible that an electrical design will pass the verification process but will fail when validated. It can happen that the design and development is in accordance with the specification, but the specification's shortcomings will lead to an overall non-functional ship or nonfunctional system. Therefore, as the design fundamentals are reviewed, proper verification and validation should be done to capture shortcomings and see appropriate corrective measures are taken.

The fundamentals of successful design are:

- regulatory body approval for the overall design
- individual equipment selection also with proven successful operation in the shipboard environment. Sometimes the equipment of a system works fine in the land-based installation but fails in the shipboard installation. Therefore it is mandatory to select marine duty equipment for shipboard installation.

The proliferation of VFD application has introduced many drawbacks and created many mishaps. Those drawbacks will be discussed for better understanding as to the overall design requirements and responsibilities.

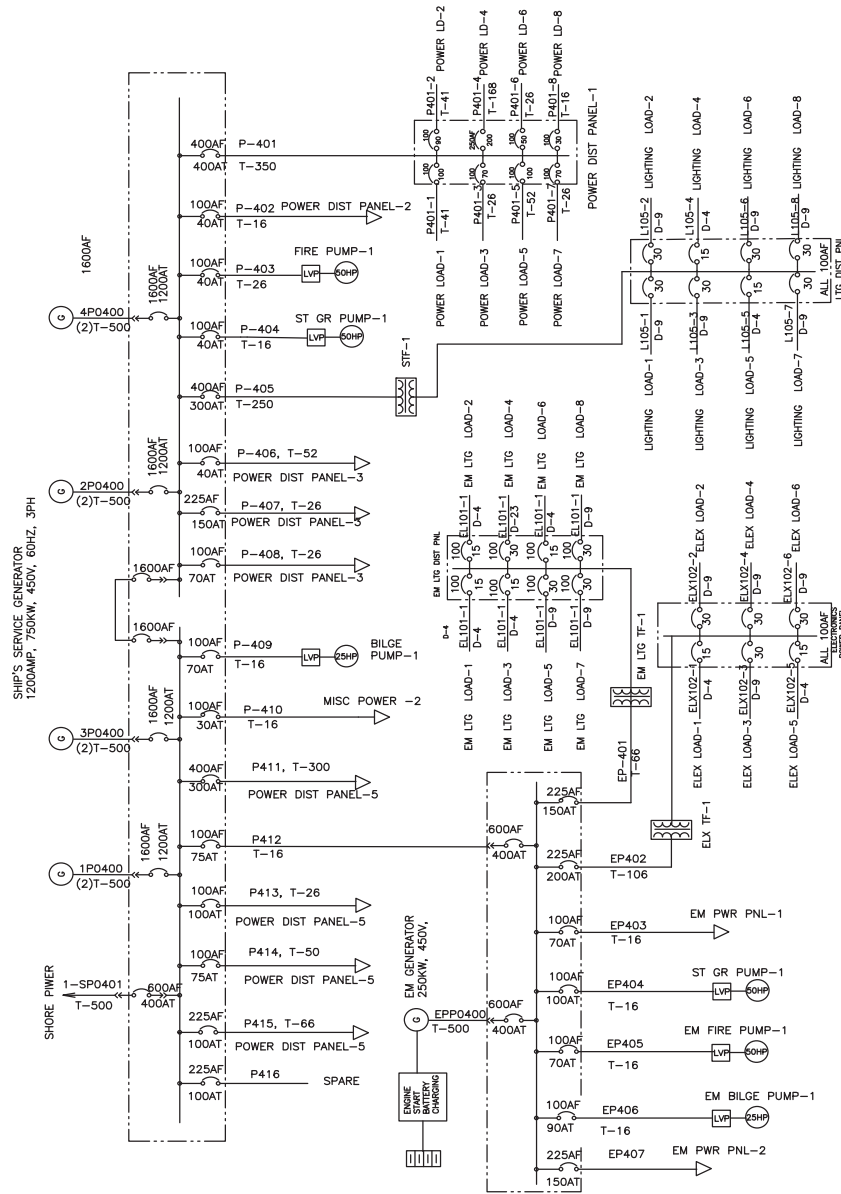


Figure 1.6 Typical EOL with Detail Distribution System.

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**Table 1.1** Typical Verification and Validation Table

Criteria	Verification	Validation
<i>Definition</i>	The process of evaluating electrical system design and development work deliverable products (not the actual final product procurement) of a development phase to determine whether they meet the specified requirements for the phase of development. The phases may be concept design, preliminary design or detail design.	The process of evaluating electrical system design development deliverables during or at the end of the development process to determine whether they satisfy the specified overall shipbuilding requirements.
<i>Objective</i>	To ensure that the design and development product is being developed (built) according to the requirements and design specifications. In other words, to ensure that work products meet their specified requirements.	To ensure that the product actually meets the customer’s needs, and that the specifications were correct in the first place. In other words, to demonstrate that the product fulfills its intended use when placed in its intended environment.
<i>Question</i>	Are we designing and developing right for a functional ship?	Are we building the right ship?
<i>Evaluation Items</i>	Plans, Requirement Specs, Design Specs, Code, Test Cases	The actual functional ship.
<i>Example-1</i>	The requirement is to provide electric propulsion with 6-pulse drive. The drive selection verifies that the 6-pulse propulsion drive has been purchased and the system design has been developed accordingly.	The validation process has proved that though the procurement has met the customer requirement, it will not function as intended or will produce objectionable electrical noise which will contaminate the entire electrical system leading to a nonfunctional ship.
<i>Example-2</i>	Plans, Requirement Specs, Design Specs, Code, Test Cases	

**1.6 IEEE 45 DOT STANDARDS: RECOMMENDED PRACTICE FOR SHIPBOARD ELECTRICAL INSTALLATION**

The IEEE 45 standard development working group decided to further subgroup the standard with IEEE 45 DOT standards. This is to accommodate additional features of electrical installations on ships.

Therefore the IEEE 45 DOT standard subgroupings are:

IEEE 45 – Recommended Practice for Electrical Installations on Shipboard: Base Document (under development)

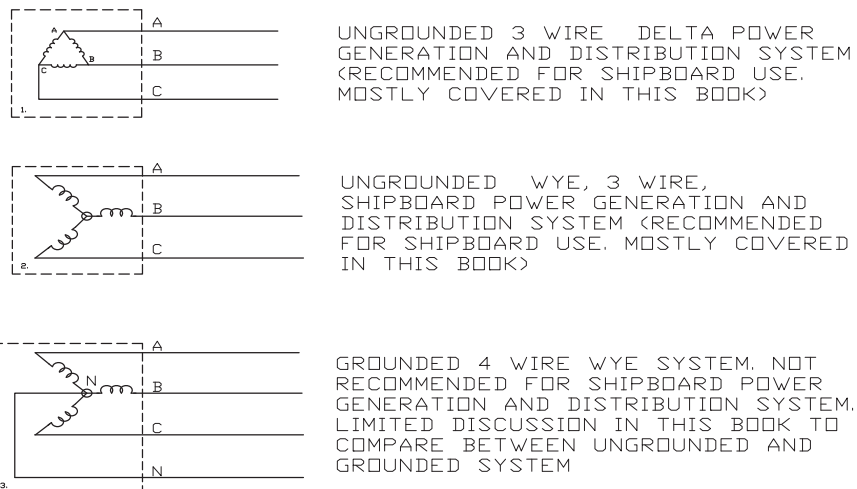
1.8 Shipboard Ungrounded Power System **11**

- IEEE 45.1 – Shipboard Design and Development
- IEEE 45.2 – Shipboard Controls and Automation
- IEEE 45.3 – Shipboard System Engineering
- IEEE 45.4 – Marine Sectors and Functions
- IEEE 45.5 – Shipboard Electrical Safety Considerations
- IEEE 45.6 – Shipboard Electrical Testing
- IEEE 45.7 – Shipboard AC Switchboards
- IEEE 45.8 – Shipboard Cable Installations

**1.7 OTHER RULES AND REGULATIONS, AND STANDARDS IN SUPPORT OF IEEE 45 DOT STANDARDS**

- NEC – National Electrical Code
- NFPA 70-E
- IEEE 1662
- IEEE 1580 – Standard for Shipboard Cable Construction
- IEEE 1580.1 – Standard for Shipboard Bus-Pipe Installations
- IEEE/IEC/ISO 80005.1 – Standard for MV Ship-to-Shore Power System

**1.8 SHIPBOARD UNGROUNDED POWER SYSTEM**



**Figure 1.7** Typical 3-4 Wire Distribution System.

## 1.9 SHIPBOARD ELECTRICAL DESIGN BASICS

This book covers electrical power system detailed design and development for commercial ships such as cruise ships, cargo ships, tankers, related support vessels, offshore industry-related floating platforms, and all other support vessels. Some military vessel ship designs are also included to establish basic design fundamental differences as to redundancy requirements and zonal distributions. These design requirements and fundamentals are with the understanding of the following:

- Regulatory requirements
- Operational requirements
- Redundancy requirements
- Understanding of emergency requirements as to power generation as well as emergency load distribution
- Understanding the causes of a blackout (dead ship) situation. The blackout situation for all electric ship-related power generation and distribution is more complex than for the ship with nonelectric propulsion.
- Electric propulsion-related power generation and distribution requirements have been taken to adapt medium voltage power generation, due to the fact that ample power is available to change a hydraulic system or mechanical system to an electric system with variable drive operation
- The grounding requirements are different than the traditional low-voltage distribution though both systems are three-wire ungrounded systems
- A vital auxiliary must be properly classified as one design may be different than the other due to operational requirements
- There are regulatory requirements of vital auxiliary-related redundant services and operational requirements that directly contribute to the design and development

In general, a shipboard electrical system is ungrounded with few exceptions. The ungrounded system is only there is no dedicated neutral line in the distribution system. However, there always exists a capacitive ground path. This phenomenon needs to be explained with grounding and bonding. For better understanding, grounding and bonding will be called “G.” Otherwise, the neutral line will be called “N.” Nonlinear solid-state power applications usually create rapid changes to voltage and current while transferring energy to the load. These changes cause high-frequency current to flow to the ground. This is considered electrical noise.

There are many good features of electric drive-related applications onboard ships and platforms. However, many features may contribute electric noise, such as harmonics, transients, and grounding at the equipment level and system level. The design engineer must understand those issues so that causes and effects are properly analyzed during concept design and detail design. Recent VFD-related failure reports warrant better understanding, better design, and then overall design management.

## 1.9 Shipboard Electrical Design Basics 13

Electrical propulsion and auxiliary service requirements for the use of variable frequency drive have contributed to recent operational challenges due to critical operational issues.

Regulatory bodies are in the process of addressing some of those issues and are considering additional regulations. The International Maritime Organization (IMO), under the Safety of Life at Sea (SOLAS), is considering additional redundancy considerations for critical propulsion-related auxiliary redundancy and further consideration of emergency power management. The requirements of these new initiatives are beyond the scope of this book; however, some will be addressed as a specific design is presented. These additional requirements will be addressed along with the proven requirements for better understanding of the origins of those requirements, and then added to the design.

There are many sample designs presented in this book, to show that each and every operational requirement is unique, leading to a customized design. The designs are presented with drawings and diagrams, so fundamental steps are discussed and then compared with the service requirements. This includes ship service power requirements, power requirements, and emergency power requirements. The design developments are presented strictly in compliance with regulatory body requirements.

The design includes:

- (1) Shipboard electrical low-voltage and medium-voltage power generation, electrical propulsion, and power distribution systems. The fundamental shipboard electrical design requirements, design details, verification of the design prior to equipment installation, and then verification of the test results to establish a design base for the ship.
- (2) Offshore floating platforms and offshore support vessels as applicable.

The variable frequency drive application has become an integral part of the electrical propulsion system, thruster applications, and other ship service auxiliary loads. High power requirements such as a propulsion system require high voltage and power. The power conversion of fundamental AC power to DC and then to AC conversion comes with many different technologies and challenges. Some of those challenges are at the electrical-system level and some are at the VFD-equipment level. These technical issues and challenges are presented for a basic understanding of the fundamentals as well as design guidelines so that design engineers can use this book as a reference. Details of practical design examples are also presented so that engineering students can learn the fundamentals of electrical power system design and development.

The shipboard electrical power system is usually ungrounded, with some exceptions. All design and development will be analyzed for ungrounded systems only. Different system-level groundings are presented with examples and recommendations so that design engineers understand the complexity of the grounding issues and then decide on a specific type of grounding as applicable and best suited for the installation.

Due to high power requirements for many applications such as propulsion-related services, medium-voltage generation and distribution is a requirement. This leads to

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many new technologies such as VFD, power filtering, EMC filters, dynamic braking systems, etc.

Due to the use of national and international standards for design and equipment selection, design engineers are challenged with many issues where compromises must be made. There are cases where compromise may not be in the best interest of the overall system design as well as the selection of equipment. It has been decided to identify the issues related to the process of harmonization of different standards with limited understanding of the consequences. Those issues are identified as much as possible so that the decision process can be better informed.

All examples are presented in this book mostly in view of practical experience and installation in compliance with rules and regulations for the intended operation, and required protection for the safety of the equipment, system, and operators.

### 1.10 ELECTRICAL DESIGN PLAN SUBMITTAL REQUIREMENTS

#### USCG Code of Federal Regulations CFR 46 Part 110

##### *Subpart 110.25—Plan Submittal*

**§110.25-1 Plans and information required for new construction.** The following plans, if applicable to the particular vessel, must be submitted for Coast Guard review in accordance with §110.25-3:

- (a) Elementary one-line wiring diagram of the power system, supported by cable lists, panel board summaries, and other information including—
  - (1) Type and size of generators and prime movers;
  - (2) Type and size of generator cables, bus-tie cables, feeders, and branch circuit cables;
  - (3) Power, lighting, and interior communication panel boards with number of circuits and rating of energy consuming devices;
  - (4) Type and capacity of storage batteries;
  - (5) Rating of circuit breakers and switches, interrupting capacity of circuit breakers, and rating or setting of overcurrent devices;
  - (6) Computations of short circuit currents in accordance with Subpart 111.52; and
  - (7) Overcurrent protective device coordination analysis for each generator distribution system of 1500 kilowatts or more that includes selectivity and shows that each overcurrent device has an interrupting capacity sufficient to interrupt the maximum asymmetrical short-circuit current available at the point of application.
- (b) Electrical plant load analysis including connected loads and computed operating loads for each condition of operation.
- (c) Elementary and isometric or deck wiring plans, including the location of each cable splice, a list of symbols, and the manufacturer's name and identification of each item of electrical equipment, for each—

1.11 ABS Rules for Building and Classing Steel Vessels **15**

- (1) Steering gear circuit and steering motor controller;
  - (2) General emergency alarm system;
  - (3) Sound-powered telephone or other fixed communication system;
  - (4) Power-operated boat winch;
  - (5) Fire detecting and alarm system;
  - (6) Smoke detecting system;
  - (7) Electric watertight door system;
  - (8) Fire door holding systems;
  - (9) Public address system;
  - (10) Manual alarm system; and
  - (11) Supervised patrol system.
- (d) Deck wiring or schematic plans of power systems and lighting systems, including symbol lists, with manufacturer's name and identification of each item of electric equipment, and showing:
- (1) Locations of cables;
  - (2) Cable sizes and types;
  - (3) Locations of each item of electric equipment;
  - (4) Locations of cable splices.
- (e) Switchboard wiring diagram.
- (f) Switchboard material and nameplate list.
- (g) Elementary wiring diagram of metering and automatic switchgear.
- (h) Description of operation of propulsion control and bus transfer switchgear.

**1.11 ABS RULES FOR BUILDING AND CLASSING STEEL VESSELS**

ABS-SVR: Part 4, Chapter 8, Section 1

V Electrical Systems: General Provisions 4-8-1

ABS5 Plans and Data to Be Submitted

One-Line Diagram:

One-line diagram of main and emergency power distribution systems to show:

- A.** Generators: kW rating, voltage, rated current, frequency, number of phases, power factor.
- B.** Motors: kW or HP rating, voltage, and current rating.
- C.** Motor controllers: type (direct-on-line, star-delta, etc.), disconnect devices, overload and undervoltage protections, and remote stops, as applicable.
- D.** Transformers: kVA rating, rated voltage and current, winding connection.
- E.** Circuits: designations, types and sizes of cables, trip setting and rating of circuit protective devices, rated load of each branch circuit, emergency tripping and preferential tripping features.

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F. Batteries: type, voltage, rated capacity, conductor protection, charging and discharging boards.

### ABS 5.1.2 Schematic Diagrams

Schematic diagrams for the following systems are to be submitted. Each circuit in the diagrams is to indicate type and size of cable, trip setting and rating of circuit protective device, and rated capacity of the connected load.

General lighting, normal and emergency

Navigation lights

Interior communications

General emergency alarm

Intrinsically safe systems

Emergency generator starting

Steering gear system

Fire detection and alarm system

### ABS 5.1.3 Short-Circuit Data

Maximum calculated short-circuit current values, both symmetrical and asymmetrical values, available at the main and emergency switchboards and the down stream distribution boards.

Rated breaking and making capacities of the protective devices. Reference may be made to IEC Publication 61363-1 Electrical Installations of Ships and Mobile and Fixed Offshore Units – Part 1: Procedures for Calculating Short-Circuit Currents in Three-Phase A.C.

### ABS 5.1.4 Protective Device Coordination Study

This is to be an organized time-current study of all protective devices, taken in series, from the utilization equipment to the source, under various conditions of short circuit. The time-current study is to indicate the settings of long-time delay tripping, short-time delay tripping, and instantaneous tripping, as applicable. Where an overcurrent relay is provided in series and adjacent to the circuit protective devices, the operating and time-current characteristics of the relay are to be considered for coordination. Typical thermal withstanding capacity curves of the generators are to be included, as appropriate.

### ABS 5.1.5 Load Analysis

An electric-plant (including high-voltage ship service transformers or converters, where applicable per 4-8-2/3.7) load analysis is to cover all operating conditions of the vessel, such as conditions in normal seagoing, cargo handling, harbor maneuver, and emergency operations.

### ABS 5.1.6 Other Information

– Description of the power management system, including equipment fitted with preferential trips.

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- Schedule of sequential start of motors, etc., as applicable.
- Voltage-drop for the longest run of cable of each size.
- Maintenance schedule of batteries for essential and emergency services.
- Plans showing details and arrangements of oil mist detection/monitoring and alarm arrangements.
- Information on alarms and safeguards for emergency diesel engines.

## 1.12 SHIPBOARD ELECTRICAL SAFETY CONSIDERATIONS

In general, shipboard electrical safety considerations recommendations are as in IEEE 45.5, NFPA 70E and other applicable standards. The safety considerations are outlined as:

*“All electrical facilities shall be installed and maintained in a safe manner. All work involving electrical energy must be performed in a safe manner. The primary safe work practice is to establish an electrically safe work condition. The policy of this shipboard electrical design, development and operation is to implement the requirements found in NFPA 70E, Standard for Electrical Safety in the Workplace.”*

A basic rule that should be derived from the policy statement is that work on or near any exposed energized electrical conductors or circuit parts should be prohibited, except under justified, controlled, and approved circumstances, knowing that exceptions to this policy may become necessary. For example, measuring voltage or current are common and necessary tasks that involve exposure to energized conductors. Guidelines for such justification are provided in NFPA 70E, Section 130.2: *“Energized electrical conductors and circuit parts to which an employee might be exposed shall be put into an electrically safe work condition before an employee performs work.”* NFPA Section 130.2(A) goes on to provide the acceptable exceptions to this rule.

Under blackout situations there are specific requirements to restore power. Some requirements are with specific time ranges. This is an attempt to identify these requirements and analyze those requirements. The requirements are given as follow to better indicate how to comply with those requirements.

- Starting and connection to the main switchboard of the standby generator are to be preferably within 30 seconds, but in any case not more than 45 seconds, after loss of power.
- Where electrical power is necessary to restore propulsion, the capacity shall be sufficient to restore propulsion to the ship in conjunction with other machinery, as appropriate, from a dead ship condition within 30 minutes after blackout.
- The emergency generator and other means needed to restore propulsion are to have a capacity such that the necessary propulsion-starting energy is available within 30 minutes of the blackout/dead ship condition as previously defined.

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Emergency generator stored starting energy is not to be directly used for starting the propulsion plant, the main source of electrical power and/or other essential auxiliaries (emergency generator excluded).

- Emergency generators should be capable of carrying a full rated load within 45 seconds after the loss of the normal power source.
- Take home power requirements:

All examples are presented in this book mostly in view of practical experience and installation in compliance with rules and regulations for the intended operation, and the required protection for the safety of equipment, system and operators.

The ship steering gear and maneuvering system is considered one of the most critical systems on board ship.

- In case of main power loss to the steering gear, power must be totally restored within 45 seconds. This can be accomplished by the automatic bus transfer feature of the emergency switchboard. In case of a blackout of ship service power, there must be an automatic start-up of the emergency generator and transfer to emergency power.
- The alternate power must be capable of continuously operating for half an hour for steering the ship from 15 degree to 45 degree roll to either side in not more than 60 seconds, at maximum design draft loading, and half of the maximum design speed or 7 knots, whichever is greater.

### **1.13 HIGH-RESISTANCE GROUNDING REQUIREMENTS FOR SHIPBOARD UNGROUNDED SYSTEMS (SEE CHAPTER 9 FOR DETAILS)**

#### **(a) Background of High-Resistance Grounding (HRG) with Maximum Fault Current 5 Amp RMS**

In 1935, a 40 ohm neutral to ground resistor was installed as a “safety resistor” on a 2300 V (L-N) minning shovel feed transformer to limit ground fault current to 55 Amp, a value sensed by protective relays of the era. This resistor, along with a guaranteed Ground Grid resistance of 2 ohms, limited line-ground fault voltage on the frame to a maximum 110 V potential, considered a “safe” level. It was also duly noted that single line-fault damage to cable, motors, and other electrical equipment was greatly reduced. Resistance grounded distribution systems found widespread use in the 1940s and 1950 s for industrial application with continuous process where a first line-ground fault could not be tolerated or would result in a more hazardous situation than automatic circuit breaker trip-off. A common problem was the lack of a fault location technology to quickly find the fault that would appear decades later. For comparison, modern low-voltage high-resistance grounding systems usually have a maximum fault current of 2 to 5 Amps.

## 1.14 SHIPBOARD ELECTRICAL SAFETY CONSIDERATIONS

### 1.14.1 Arc Flash Basics (See Section 12 for Details)

An arc flash is a dangerous condition associated with the release of energy caused by an electric arc, as per *IEEE 1584 Guide for Performing Arc Flash Hazard Calculations*.

Over the past two decades the electrical industry has begun to recognize arc flash as a serious safety hazard for anyone working near exposed, energized conductors and equipment.

*NFPA 70E: Standard for Electrical Safety in the Workplace*, requires that equipment be clearly labeled with safety information to minimize risk of injury to personnel. The National Electrical Code (NEC) article 110-16 requires arc flash hazard warning labels.

In addition, OSHA 29 CFR-1910 Subpart S regulates and states in part that safety practices shall be employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts.

Electrical equipment, such as switchboards, panel boards, industrial control panels, meter socket enclosures, and motor control centers, that are in other than dwelling units, and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc flash hazards. See Figure 1 for an example of arc flash study results.

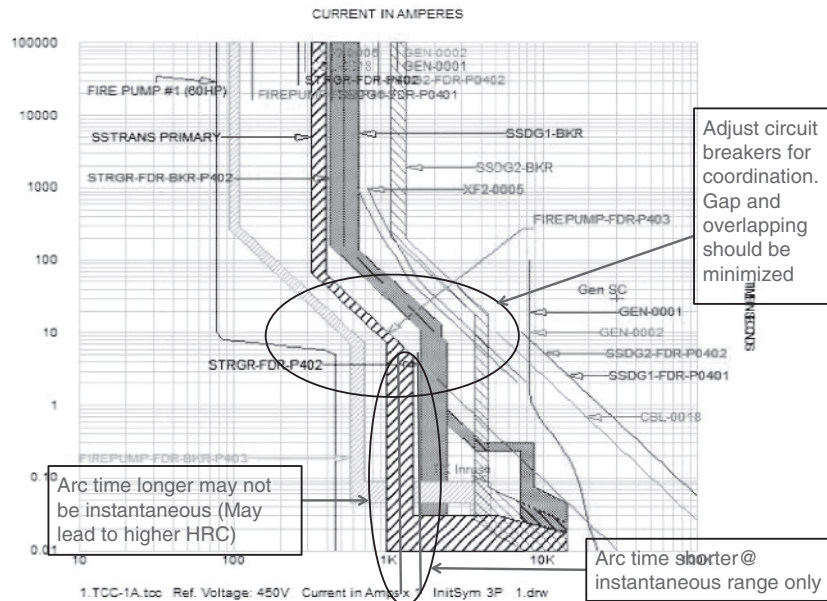


Figure 1.8 Typical Shipboard Power System Coordination Curves.

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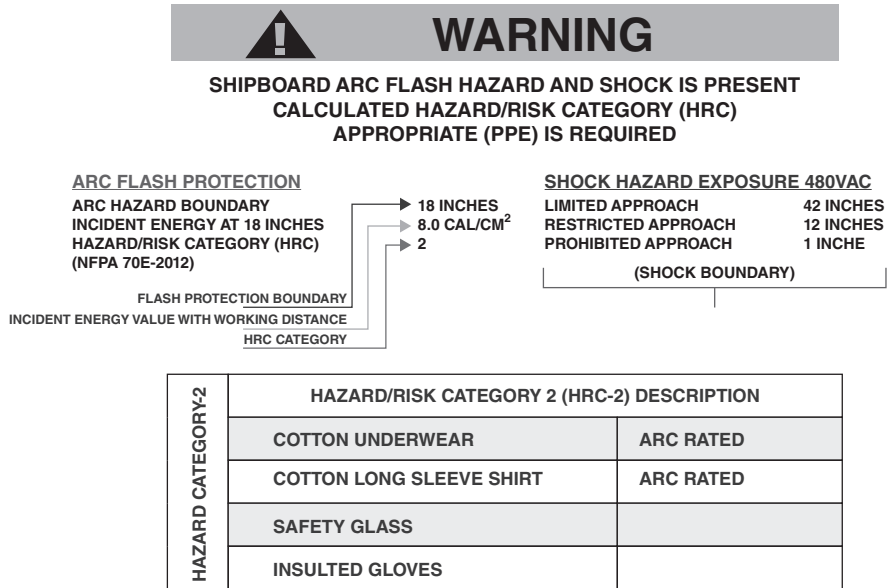


Figure 1.9 Typical Shipboard Power System ARC Flash Label.

At the completion of the study, 4" x 6" vinyl labels meeting the requirements of ANSI Z535 are furnished. The labels indicate the information required per NFPA 70E including the arc flash hazard boundary and the PPE (Personal Protective Equipment) levels. The labels are white vinyl, suitable for indoor or outdoor use, and printed on a thermal imaging printer. An example of an arc flash label is indicated in Figure 1.9.

**1.14.2 Arc Flash Hazard Analysis Procedures**

To conduct an arch flash hazard analysis, we go through the following steps per IEEE 1584:

1. Collect system and installation data
2. Determine the system modes of operation
3. Determine the bolted fault currents
4. Determine the arc fault currents
5. Find the protective device characteristics and the duration of the arcs
6. Document the system voltages and classes of equipment
7. Select the working distance

**1.15 Propulsion Power Requirements (IEEE Std 45-2002, Clause 7.4.2) 21**

8. Determine the incident energy for all equipment
9. Determine the flash protection boundary for all equipment

**1.14.3 Warning Label Placement**

Labels shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

The following equipment is included in an arc flash study and will be furnished with warning labels:

- 15 kV metal clad switchgear
- 5 kV metal clad switchgear
- 5 kV motor controllers
- 480 V low-voltage drawout switchgear
- 480 V motor control centers
- 480 V panelboards
- 480 V disconnect switches
- 208 V equipment served from a transformer greater than 125 kVA

**1.15 PROPULSION POWER REQUIREMENTS (IEEE STD 45-2002, CLAUSE 7.4.2)**

In determining the number and capacities of generating sets to be provided for a vessel, careful consideration should be given to the normal and maximum load demands (i.e., load analysis) as well as the safe and efficient operation of the vessel when at sea and in port. The vessel must have at least two generating sources. For ships, the number and ratings of the main generating sets should be sufficient to provide one spare generating set (one set not in operation) at all times to service the essential and habitable loads.

For MODUs, with the largest generator offline, the combined capacity of the remaining generators must be sufficient to provide normal (non-drilling) load demands.

For vessels propelled by electric power and having two or more constant-voltage, constant-frequency, main power generators, the ship service electric power may be derived from this source and additional ship service generators need not be installed, provided that with one main power generator out of service, a speed of 7 knots or one-half of the design speed (whichever is the lesser) can be maintained. The combined normal capacity of the operating generating sets should be at least equal to the maximum peak load at sea. If the peak load and its duration are within the limits of the specified overload capacity of the generating sets, it is not necessary to have the combined normal capacity equal to the maximum peak load.

## 1.16 IMO-SOLAS ELECTRIC PROPULSION POWER REDUNDANCY REQUIREMENTS

### (a) Electrical Propulsion and Blackout

#### ELECTRIC PROPULSION REQUIREMENT: IMO REQUIREMENTS

##### Main Source of Electrical Power

(IMO-SOLAS Regulation II-1/41.5)

Interpretation of the clause “will be maintained or immediately restored” as detailed in Reg. II-1/41.5.1.1 amending SOLAS Reg. II-1/41 - Main Source of electrical power and lighting systems.

1. Reg. II-1/41.5.1.1 - Where the main source of electrical power is necessary for propulsion and steering of the ship, the system shall be so arranged that the electrical supply to equipment necessary for propulsion and steering and to ensure safety of the ship will be maintained or immediately restored in case of loss of any one of the generators in service.
2. To fulfill the above the following measures are required:
  - 2.1 Where the electrical power is normally supplied by more than one generator set simultaneously in parallel operation, provision of protection, including automatic disconnection of sufficient non-essential services and if necessary secondary essential services and those provided for habitability, should be made to ensure that, in case of loss of any of these generating sets, the remaining ones are kept in operation to permit propulsion and steering and to ensure safety.
  - 2.2 Where the electrical power is normally supplied by one generator, provision shall be made, upon loss of power, for automatic starting and connecting to the main switchboard of stand-by generator(s) of sufficient capacity with automatic restarting of the essential auxiliaries, in sequential operation if required. Starting and connection to the main switchboard of the stand-by generator is to be preferably within 30 seconds, but in any case not more than 45 seconds, after loss of power.

Where prime movers with longer starting time are used, this starting and connection time may be exceeded upon approval from the society.
  - 2.3 Load shedding or other equivalent arrangements should be provided to protect the generators required by this regulation against sustained overload.
    - 2.3.1 The load shedding should be automatic.
    - 2.3.2 The non-essential services, service for habitable conditions may be shed and where necessary, additionally the secondary essential services, sufficient to ensure the connected generator set(s) is/are not overloaded.

1.17 Regulatory Requirements for Emergency Generator **23**

**(b) IMO-SOLAS Emergency Requirements**

IMO-SOLAS Emergency Source of Power in Passenger and Cargo Ships

IMO-SOLAS Reg. II-1/42.3.4 and II-1/43.3.4

SOLAS Regulations II-1/42 and II-1/43 address emergency sources of electrical power in passenger ships and cargo ships respectively. Regulations II-1/42.3.4 and II-1/43.3.4 read as follows:

For ships constructed on or after 1 July 1998, where electrical power is necessary to restore propulsion, the capacity shall be sufficient to restore propulsion to the ship in conjunction with other machinery, as appropriate, from a dead ship condition within 30 minutes after blackout.

Interpretation:

“Blackout” as used in Regulation II-1/42.3.4 and II-1/43.3.4 is to be understood to mean a “dead ship” condition.

“Dead ship” condition, for the purpose of Regulation II-1/42.3.4 and II-1/43.3.4, is to be understood to mean a condition under which the main propulsion plant, boilers, and auxiliaries are not in operation and in restoring the propulsion, no stored energy for starting the propulsion plant, the main source of electrical power and other essential auxiliaries is to be assumed available. It is assumed that means are available to start the emergency generator at all times.

The emergency generator and other means needed to restore the propulsion are to have a capacity such that the necessary propulsion starting energy is available within 30 minutes of blackout/dead ship condition as defined above. Emergency generator stored starting energy is not to be directly used for starting the propulsion plant, the main source of electrical power and/or other essential auxiliaries (emergency generator excluded).

**1.17 REGULATORY REQUIREMENTS FOR EMERGENCY GENERATOR**

There are strict requirements as to the size selection, space selection and dead ship starting requirements for the safety of life at sea. For detailed requirements refer to IMO-SOLAS regulations, USCG regulations, ABS rules and IEEE-45 recommendations. Special consideration for the use of an emergency generator:

ABS-SVR-4-8-2-5.17 Use of Emergency Generator in Port (2002)

Unless instructed otherwise by the Flag Administration, the emergency generator may be used during lay time in port for supplying power to the vessel, provided the following requirements are complied with. Arrangements for the Prime Mover

- (a) Fuel oil tank. The fuel oil tank for the prime mover is to be appropriately sized and provided with a level alarm, which is to be set to alarm at a level where

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there is still sufficient fuel oil capacity for the emergency services for the period of time required by ABS-SVR 4-8-2/5.5.

- (b) Rating. The prime mover is to be rated for continuous service.
- (c) Filters. The prime mover is to be fitted with fuel oil and lubricating oil filters in accordance with ABS-SVR 4-6-5/3.5.4 and 4-6-5/5.5.2, respectively.
- (d) Monitoring. The prime mover is to be fitted with alarms, displays and automatic shutdown arrangements as required in 4-9-4/Table 8, except that for fuel oil tank low-level alarm, ABS-SVR 4-8-2/5.17.1(a) above is to apply instead. The displays and alarms are to be provided in the centralized control station. Monitoring at the engineers' quarters is to be provided as in ABS-SVR 4-9-4/19.

United States Coast Guard regulations make no mention of the use of an emergency generator in port as outlined in the ABS requirements. Due to a deepwater horizon incident, the USCG issued directives for DP vessels in 2012 as a draft, which is in full effect. Therefore, USCG regulations must be complied with for all new building.

## **1.18 USCG DYNAMIC POSITIONING (DP) GUIDELINES**

### **(a) Background**

Over the past several decades, the expansion of offshore exploration, development and production into deeper water has transformed an industry once characterized by relatively simple, domestic shallow water fixed platforms and small logistical vessels into an industry with complex, international floating vessels supplied and serviced by other large, international multipurpose vessels. This has given rise to the use of DP as a practical means for keeping these vessels within precise geographic limits. Failure of a DP system on a vessel conducting critical operations such as oil exploration and production could have severe consequences including loss of life, pollution, and property damage. This is particularly true for Mobile Offshore Drilling Units (MODUs), where a loss of position could result in a subsea spill and potentially catastrophic environmental consequences. The Deepwater Horizon incident demonstrated the serious challenges associated with subsea spill response. In a preliminary effort to better understand critical systems, training, and emergency procedures put in place to prevent or mitigate a loss of position on a dynamically positioned MODU and inform any related future rulemaking, the Coast Guard published a notice in the Federal Register (76 FR81957) requesting public comment on a draft policy. We received comments both as submissions to the docket and at a public meeting held on February 9, 2012. The Coast Guard was encouraged to publish a rule for areas where no standard has been set and to consider industry standards and guidance when developing the rule. The Coast Guard agrees and intends to initiate a rulemaking that addresses DP incident reporting requirements and minimum DP system design and operating standards

**(b) USCG Interim Voluntary DP System Guidance**

On July 7th, 2010, in response to a request from the Coast Guard, NOSAC issued the report “Recommendations for Dynamic Positioning System Design and Engineering, Operational and Training Standards.” The report contained draft guidelines from the Marine Technology Society (MTS) Dynamic Positioning Committee, which the MTS has since completed. The Coast Guard has reviewed the guidance, referred to it when responding to known DP incidents and found it to be comprehensive and highly useful. Until the Coast Guard publishes a DP Rule, the Coast Guard recommends owners and operators of dynamically positioned MODUs (not leaseholders who contract MODUs) operating on the U.S. Outer Continental Shelf (OCS) voluntarily follow guidance provided in the “DP Operations Guidance Prepared through the Dynamic Positioning Committee of the Marine Technology Society to aid in the safe and effective management of DP Operations,” March 2012 Part 2 Appendix. It is particularly important they identify the DP System’s Critical Activity Mode of Operation (CAMO) and ensure Well Specific Operating Guidelines (WSOGs) are developed for operations at every well and location. A MODU attached to the seafloor of the U.S. OCS should be operated in accordance with the appropriate WSOG.

**(c) DP Operating Engineering Guidelines (Same for All Electric Ships)**

Marine Technology Society Dynamic Positioning Committee (MTS-DPC) Guidelines  
Sept. 2012

**MTS DP Part 1**

- 4.16.2** Engineers – There should be sufficient licensed engineers on board for all expected operations.
- 4.16.3** At least one licensed engineer should be available at all times, should be on watch during critical activities and should have at least 6 months experience on similar equipment and operations.
- 4.16.4** The engineer should be fully cognizant of DP operations, familiar with the vessel’s DP FMEA document and the effects of failures of equipment relating to the position keeping of the vessel.
- 4.16.5** In DP 2 or 3 operations, the engineer should be familiar with the general philosophy of redundancy as it relates to split mechanical, electrical and ancillary systems.
- 4.16.6** Electrician/Electrical Engineer – If required on board, an electrician should have appropriate high voltage training/certification, if applicable to the vessel. As

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with vessel engineers, the electrician/electrical engineer should have at least 6 months experience on similar equipment and operations.

- 4.16.7** The electrician should likewise be fully cognizant of DP operations, familiar with the vessel's DP FMEA document and the effects of failures of equipment relating to the position keeping of the vessel. Note: Where the minimum experience requirements cannot be met a risk based approach should be taken to determine the suitability of personnel and any additional support requirements for intended operations.

## DNV Part 4, Chapter 8

### ELECTRICAL INSTALLATIONS

#### DNV REQUIREMENTS:

##### **DNV-Section-2-103 System earthing (grounding)**

- (a) System earthing (grounding) shall be effected by means independent of any earthing (grounding) arrangements of the non-current carrying parts.
- (b) Any earthing (grounding) impedances shall be connected to the hull. The connection to the hull shall be so arranged that any circulating current in the earth connections do not interfere with radio, radar, communication and control equipment circuits. (IACS UR E11 2.1.4)
- (c) If the system neutral is connected to earth, suitable disconnecting links or terminals shall be fitted so that the system earthing (grounding) may be disconnected for maintenance or insulation resistance measurement. Such means shall be for manual operation only.
- (d) If the system neutral is connected to earth at several points, equalizing currents in the neutral earthing (grounding) exceeding 20% of the rated current of connected generators or transformers is not acceptable. Transformer neutrals and generator neutrals shall not be simultaneously earthed in the same distribution system at same voltage level. On distribution transformers with star connected primary side, the neutral point shall not be earthed.
- (e) In any four wire distribution system the system neutral shall be connected to earth at all times without the use of contactors.
- (f) Combined PE (protective earth) and N (system earth) is allowed between transformer/generator and N bus bar in first switchboard where the transformer secondary side/generator is terminated i.e. TN-C-S system. There shall be no connection between the N- and PE-conductor after the PEN-conductor is separated.
- (g) In case of earth fault in high voltage systems with earthed neutral, the current shall not be greater than full load current of the largest generator on the

## 1.18 USCG Dynamic Positioning (DP) Guidelines 27

switchboard or relevant switchboard section and not less than three times the minimum current required to operate any device against earth fault. Electrical equipment in directly earthed neutral or other neutral earthed systems shall withstand the current due to single phase fault against earth for the time necessary to trip the protection device. It shall be assured that at least one source neutral to ground connection is available whenever the system is in the energized mode. For divided systems, connection of the neutral to the earth shall be provided for each section. (IACS UR E11 2.1.5 and 2.1.2)

**DNV-Section 6-207 Harmonic distortion**

- (a) Equipment producing transient voltage, frequency and current variations shall not cause malfunction of other equipment on board, neither by conduction, induction or radiation.
- (b) In distribution systems the acceptance limits for voltage harmonic distortion shall correspond to IEC 61000-2-4 Class 2. (IEC 61000-2-4 Class 2 implies that the total voltage harmonic distortion shall not exceed 8%.) In addition, no single order harmonic shall exceed 5%.
- (c) The total harmonic distortion may exceed the values given in b) under the condition that all consumers and distribution equipment subjected to the increased distortion level have been designed to withstand the actual levels. The system and components ability to withstand the actual levels shall be documented.
- (d) When filters are used for limitation of harmonic distortion, special precautions shall be taken so that load shedding or tripping of consumers, or phase back of converters, do not cause transient voltages in the system in excess of the requirements in 204. The generators shall operate within their design limits also with capacitive loading. The distribution system shall operate within its design limits, also when parts of the filters are tripped, or when the configuration of the system changes.

**DNV-Section 6-204 Transformer Parallel operation**

Transformers for parallel operation shall have compatible coupling groups and voltage regulation, so that the actual current of each transformer will not differ from its proportionate share of the total load by more than 10% of its full load current.

Remark: "USCG regulation for DP system's Critical Activity Mode of Operation (CAMO) and ensure Well Specific Operating Guideline (WSOGs) are developed for operations at every well and location."

This is also the application for ships, as ships are custom-designed for specific operational requirements. Therefore the preceding requirement can be interpreted as "all vessel's critical systems Critical Mode of Operation (CAMO) must be well defined which is extension to the normal operation to ensure ship specific operating guideline." For example, electrical propulsion-related variable frequency drive

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operation at a critical mode of operation. This CAMO should be a part of the ship-board electrical system operational FMEA.

**1.19 IEC/ISO/IEEE 80005-1-2012: UTILITY CONNECTIONS IN PORT—HIGH VOLTAGE SHORE CONNECTION (HVSC) SYSTEMS—GENERAL REQUIREMENTS**

General requirements for high-voltage shore connection systems outline the connection details for RORO cargo ships, RORO passenger ships, cruise ships, container ships, LNG ships, and tankers. This standard is for the design, installation and testing of high-voltage shore connection systems for tankers and cruise ships detailing the following:

- High-voltage shore distribution system
- Shore-to-ship connection and interface equipment
- Transformer and reactors
- Semiconductor/rotating converters
- Ship distribution system
- Control, monitoring, interlocking, and power management systems

Chapter 10 provides further details of high-voltage shore power connection and low-voltage shore power connection in view of shipboard detail design and operation.

**1.20 MIL STANDARD 1399 MEDIUM VOLTAGE POWER SYSTEM CHARACTERISTICS**

**Table 1.2** MIL-STD-1399—680: Power System Characteristics

Characteristics	5 kV Class	8.7 kV Class	15 kV Class
1. Nominal frequency	60 Hz	60 Hz	60 Hz
2. Frequency tolerances	±3%	±3%	±3%
3. Frequency modulation	$\frac{1}{2}\%$	$\frac{1}{2}\%$	$\frac{1}{2}\%$
4. Frequency transient	±4%	±4%	±4%
5. The worst-case frequency excursion from nominal frequency resulting from item 2, item 3, and item 4 combined, except under emergency conditions	±5.5%	±5.5%	±5.5%
6. Recovery time from items 4 or 5	2 sec	2 sec	2 sec
7. Nominal user voltage	4.16 kV rms	6.6 kV rms	11 kVrms, 13.8 kV rms
8. Line voltage unbalance	3%	3%	3%

1.21 Shipboard Power Quality and Harmonics (See Chapter 7 for Detail Requirements) **29**

**Table 1.2** (Cont.)

Characteristics	5 kV Class	8.7 kV Class	15 kV Class
9a. Average of the three line-to-line voltages	±5%	±5%	±5%
9b. Any one line-to-line voltage, including items 8 and 9a	±7%	±7%	±7%
10. Voltage modulation	2%	2%	2%
11. The maximum departure voltage resulting from item 8, 9a, 9b, and 10 combined, except under transient or emergency conditions	±6%	±6%	±6%
12. Voltage transient tolerance	±16%	±16%	±16%
13. Worst-case voltage excursion from nominal user voltage resulting from items item 8, 9a, 9b, 10, and 12 combined, except under transient or emergency conditions	±20%	±20%	±20%
14. Recovery time from items 12 or 13	2 sec	2 sec	2 sec
15. Voltage spike	60 kV peak	75 kV peak	90 kV peak
16. Maximum total harmonic distortion	5%	5%	5%
17. Maximum single harmonic	3%	3%	3%
18. Maximum deviation factor	5%	5%	5%

**Table 1.3** MIL-STD-1399—680: High-Voltage Class, and Hi-Pot Test Voltage and BIL

Class	System Voltage Maximum	System Voltage Nominal	HI-Pot Test Voltage (2 X Nominal + 1000 V)	Basic Impulse Test (BIL)
I	5.0 kV rms	4.16 kV rms	9.32 kV	30.0 kV
II	8.7 kV rms	6.6 kV rms	14.2 kV	60.0 kV
III	15.0 kV rms	11.0 kV rms 13.8 kV rms	28.6 kV	90.0 kV

**1.21 SHIPBOARD POWER QUALITY AND HARMONICS (SEE CHAPTER 7 FOR DETAIL REQUIREMENTS)**

**1.21.1 IEEE Std 45-2002, Clause 4.6, Power Quality and Harmonics**

Solid state devices such as motor controllers, computers, copiers, printers, and video display terminals produce harmonic currents. These harmonic currents may cause additional heating in motors, transformers, and cables. The sizing of protective devices

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should consider the harmonic current component. Harmonic currents in nonsensically current waveforms may also cause EMI and RFI. EMI and RFI may result in interference with sensitive electronics equipment throughout the vessel.

Isolation, both physical and electrical, should be provided between electronic systems and power systems that supply large numbers of solid state devices, or significantly sized solid state motor controllers. Active or passive filters and shielded input isolation transformers should be used to minimize interference. Special care should be given to the application of isolation transformers or filtering as the percentage of power consumed by solid state power devices compared with the system power available increases. Small units connected to large power systems exhibit less interference on the power source than do larger units connected to the same source. Solid state power devices of vastly different sizes should not share a common power circuit. Where kilowatt ratings differ by more than 5 to 1, the circuits should be isolated by a shielded distribution system transformer. Surge suppressers or filters should only be connected to power circuits on the secondary side of the equipment power input isolation transformers.

## Notes:

1. To preclude radiated EMI, main power switchboards rated in excess of 1 kV and propulsion motor drives should not be installed in the same shipboard compartment as ship service switchboards or control consoles. (This is per IEEE 45-1998 Clause 4.6.)
2. To reduce the effect of radiated EMI, special considerations on filtering and shielding should be exercised when main power switchboards and propulsion motor drives are installed in the same shipboard compartment as ship service switchboards or control consoles.
3. IEEE Std 519<sup>TM</sup>-1992 provides additional recommendations regarding power quality. IEEE Std 519-2014 is the latest edition, which is widely different from the 1992 version. Reference to both standards will be necessary to establish the state of the requirement and apply as recommended.

**1.21.2 Power Conversion Equipment-Related Power Quality****1.21.2a IEEE Std 45-2002, Clause 31.8, Propulsion Power Conversion Equipment (Power Quality)**

The following quote is an extract referring only to the power quality portion of this clause.

Whenever power converters for propulsion are applied to integrated electric plants, the drive system should be designed to maintain and operate with the power quality of the electric plant. The effects of disturbances, both to the integrated power system and to

1.22 USCG Plan Submittal Requirements **31**

other motor drive converters, should be regarded in the design. Attention should be paid to the power quality impact of the following:

- (a) Multiple drives connected to the same main power system.
- (b) Commutation reactance, which, if insufficient, may result in voltage distortion adversely affecting other power consumers on the distribution system. Unsuitable matching of the relation between the power generation system's sub-transient reactance and the propulsion drive commutation impedance may result in production of harmonic values beyond the power quality limits.
- (c) Harmonic distortion can cause overheating of other elements of the distribution system and improper operation of other ship service power consumers.
- (d) Adverse effects of voltage and frequency variations in regenerating mode.
- (e) Conducted and radiated electromagnetic interference and the introduction of high-frequency noise to adjacent sensitive circuits and control devices. Special consideration should be given for the installation, filtering, and cabling to prevent electromagnetic interference . . . .

**1.22 USCG PLAN SUBMITTAL REQUIREMENTS**

CFR 46-PART-10-1.15. ELECTRICAL PLAN SUBMITTAL REQUIREMENTS:

1.15.1 USCG REGULATION: (Partial Listing)

USCG CODE OF FEDERAL REGULATIONS CFR 46 PART 110

Subpart 110.25—Plan Submittal

§110.25-1 Plans and information required for new construction.

The following plans, if applicable to the particular vessel, must be submitted for Coast Guard review in accordance with §110.25-3:

- (a) Elementary one-line wiring diagram of the power system, supported, by cable lists, panelboard summaries, and other information including—
  - (1) Type and size of generators and prime movers;
  - (2) Type and size of generator cables, bus-tie cables, feeders, and branch circuit cables;
  - (3) Power, lighting, and interior communication panelboards with number of circuits and rating of energy consuming devices;
  - (4) Type and capacity of storage batteries;
  - (5) Rating of circuit breakers and switches, interrupting capacity of circuit breakers, and rating or setting of overcurrent devices;
  - (6) Computations of short circuit currents in accordance with Subpart 111.52; and

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- (7) Overcurrent protective device coordination analysis for each generator distribution system of 1500 kilowatts or above that includes selectivity and shows that each overcurrent device has an interrupting capacity sufficient to interrupt the maximum asymmetrical short-circuit current available at the point of application.
- (b) Electrical plant load analysis including connected loads and computed operating loads for each condition of operation.
- (c) Elementary and isometric or deck wiring plans, including the location of each cable splice, a list of symbols, and the manufacturer's name and identification of each item of electrical equipment, of each—
  - (1) Steering gear circuit and steering motor controller;
  - (2) General emergency alarm system;
  - (3) Sound-powered telephone or other fixed communication system;
  - (4) Power-operated boat winch;
  - (5) Fire detecting and alarm system;
  - (6) Smoke detecting system;
  - (7) Electric watertight door system;
  - (8) Fire door holding systems;
  - (9) Public address system and
  - (10) Manual alarm system
- (d) Deck wiring or schematic plans of power systems and lighting systems, including symbol lists, with manufacturer's name and identification of each item of electric equipment, and showing:
  - (1) Locations of cables;
  - (2) Cable sizes and types;
  - (3) Locations of each item of electric equipment;
  - (4) Locations of cable splices.
- (e) Switchboard wiring diagram.
- (f) Switchboard material and nameplate list.
- (g) Elementary wiring diagram of metering and automatic switchgear.
- (h) Description of operation of propulsion control and bus transfer switchgear.

**1.23 ABS RULES FOR BUILDING AND CLASSING STEEL VESSELS (PARTIAL LISTING)**

ABS-SVR - Part 4, Chapter 8, Section 1

Vessel Systems and Machinery Electrical Systems General Provisions 4-8-1

5 Plans and Data to be Submitted

5.1 System Plans

5.1.1 One-Line Diagram

5.1.2 Schematic diagrams

1.24 Design Verification and Validation 33

Schematic Diagrams Schematic diagrams for the following systems are to be submitted. Each circuit in the diagrams is to indicate type and size of cable, trip setting and rating of circuit protective device, and rated capacity of the connected load.

General lighting, normal and emergency

Navigation lights

Interior communications

General emergency alarm

Intrinsically safe systems

Emergency generator starting

Steering gear system

Fire detection and alarm system

Short-Circuit Data

Maximum calculated short-circuit current values, both symmetrical and asymmetrical values, available at the main and emergency switchboards and the down stream distribution boards.

Rated breaking and making capacities of the protective devices. Reference may be made to IEC Publication 61363-1 Electrical Installations of Ships and Mobile and Fixed Offshore Units – Part 1: Procedures for Calculating Short-Circuit Currents in Three-Phase A.C.

Protective Device Coordination Study:

This is to be an organized time-current study of all protective devices, taken in series, from the utilization equipment to the source, under various conditions of short circuit. The time-current study is to indicate settings of long-time delay tripping, short-time delay tripping, and instantaneous tripping, as applicable. Where an overcurrent relay is provided in series and adjacent to the circuit protective devices, the operating and time-current characteristics of the relay are to be considered for coordination. Typical thermal withstanding capacity curves of the generators are to be included, as appropriate.

**1.24 DESIGN VERIFICATION AND VALIDATION**

**1.24.1 Design Verification Test Procedure (DVTP)**

**Table 1.4** Design Verification Test Procedure (DVTP)

Propulsion Transformer							
Step	Equipment	Action	Result	Alt Action	Alarm	Verified	Verify
Prop transformer	Winding temp	Monitoring temp	C-degree	Meter	Hi point	Local/ remote alarm	Verified- Degrade overall operation

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**Table 1.4** Alternating Current (AC) LV System Power Characteristics Per Mil-STD-1399

Characteristics	Limits
Frequency	
(a) Nominal frequency	50/60 Hz
(b) Frequency tolerances	± 3%
(c) Frequency modulation	$\frac{1}{2}\%$
(d) Frequency transient:	
(1) Tolerance	± 4%
(2) Recovery time	2 sec
(e) The worst-case frequency excursion from nominal frequency resulting from item (b), item (c), and item (d) (1) combined, except under emergency conditions.	± 5 $\frac{1}{2}\%$
Voltage	
(a) User voltage tolerance:	
(1) Average of the three line-to-line voltages	±5%
(2) Any one line-to-line voltage, including item (a) (1) and line voltage unbalances item (b)	±7%
(b) Line voltage unbalance	3%
(c) Voltage modulation	5%
(d) Voltage transient:	
(1) Voltage transient tolerances	±16%
(2) Voltage transient recovery time	2 s
(e) Voltage spike (peak value includes fundamental)	±2500 V (380–600 V system; 1000 V (120–240 V) system)
(f) The maximum departure voltage resulting from item (a) (1) and item (d) combined, except under transient or emergency conditions.	±6%
(g) The worst case voltage excursion from nominal user voltage resulting from item (a) (1), item (a) (2), and item (d) (1) combined, except under emergency conditions.	±20%
Waveform voltage distortion	
(a) Maximum total harmonic distortion	5%
(b) Maximum single harmonic	3%
(c) Maximum deviation factor	5%

MIL-STD—1399-680: Table-II Electrical Power System Characteristics At The Interface (High Voltage For Shipboard Application) (Partial Extract)

**Table 1.5** Qualitative Failure Analysis (QFA) Sample Table

Propulsion Power—Qualitative Failure Analysis (QFA)		Propulsion Generation				
ITEM No	Failure description	3	4	5	6	7
1	Overvoltage	Systems effect due to the failure	Failure detection and indication Alarm	Effect on overall ship performance due to failure Probably yes	Corrective action	Failure evaluation
Propulsion Generation	Actual value failure				Reduce load if possible	Verify the cause of the failure. If possible correct the failure on changeover to standby generator

### **1.24.2 Qualitative Failure Analysis (QFA)**

### **1.24.3 IEEE 519 Harmonic Standard**

IEEE 519-1992 has been superseded by IEEE 519-2014. IEEE 519-2014 has major changes to the voltage THD requirements. Many technical details of IEEE 519-1992 have been removed. It will be necessary to refer to both versions for a better understanding of shipboard harmonic issues. For additional details refer to Chapter 7 Shipboard power system quality of power management and verification.

## **1.25 REMARKS FOR VFD APPLICATIONS ONBOARD SHIP**

For all shipboard ungrounded power generation and distribution systems, if VFD is used, where there is a possibility of a system-level ground path, such as HRG, EMC filter, and harmonic filters where transient power-system noise is prevalent, local manual close-and-open operation of the circuit breaker with a remote manual operator and remote automatic operator is encouraged due to the fact that there may be an arcing path through that point, which may cause an explosion. Therefore, it is strongly recommended that the circuit breaker must have the capability of remote operation to avoid manual operation on a live bus. The remote operations shall be supported by mimic display. FMEA must be done for the remote circuit breaker control to establish that all required safety interlocks and functions are properly maintained. The remote circuit breaker operational capability shall be in addition to system coordination and protection features.

System-level capacitance monitoring and management is recommended.

If there are HRGs used in an ungrounded system, the total probable current path shall be monitored and managed to establish and maintain a safe level.

All high-frequency harmonics and low-frequency harmonics must be calculated and managed to establish safe harmonic levels. This recommendation may require harmonic calculation beyond the 49<sup>th</sup> harmonic of IEEE 519 requirements.