

IEEE Recommended Practice for 1 kV to 35 kV Medium-Voltage DC Power Systems on Ships

IEEE Industry Applications Society

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Petroleum & Chemical Industry Committee

and the

IEEE Power Electronics Society

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Abstract: Guidelines to specify, procure, design, manufacture and develop manuals, safety procedures, practices and procedures for effective maintenance of medium-voltage direct current (MVDC) electrical power systems are discussed in this recommended practice. Recommendations are made for analytical methods, preferred interconnection interfaces and performance characteristics for reliable integration of MVDC electrical components into the ship MVDC electrical power systems.

Keywords: IEEE 1709™, integrated power systems, marine electrical-power systems, medium-voltage direct current, MVDC, PEBB, power electronic building blocks, power electronics

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Introduction

This introduction is not part of IEEE Std 1709-2018, IEEE Recommended Practice for 1 kV to 35 kV Medium-Voltage DC Power Systems on Ships.

The purpose of this recommended practice is to provide recommendations that can be used by medium-voltage dc (MVDC) Power systems stakeholders and designers for applying contemporary technologies to generate, convert, and distribute shipboard MVDC electrical power with desired reliability, survivability, and power quality.

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IEEE Recommended Practice for 1 kV to 35 kV Medium-Voltage DC Power Systems on Ships

1. Overview

This recommended practice addresses specific aspects of shipboard medium-voltage dc (MVDC) power systems and defines recommended practice for applying contemporary technologies to convert and distribute shipboard electrical power with adequate reliability, survivability, and power quality. It is not intended in any way to impede development of new or improved techniques.

Target users for this recommended practice are evaluators and designers of electrical power systems for commercial marine and military applications, commercial and military ship end-users, shipbuilders, port operators, classification societies, machinery and equipment manufacturers, research institutes, and universities.

1.1 Scope

This recommended practice provides analytical methods, preferred interconnection interfaces, performance characteristics and testing for applying 1 kV to 35 kV MVDC power distribution and dc power-delivery systems on ships.

1.2 Purpose

The purpose of this recommended practice is to define requirements on proper interfaces, sizing, life cycle cost, efficiency and risk reduction of MVDC power systems implementation. It complements the family of IEEE 45 standards (IEEE Recommended Practice for Electric Installations on Shipboard).

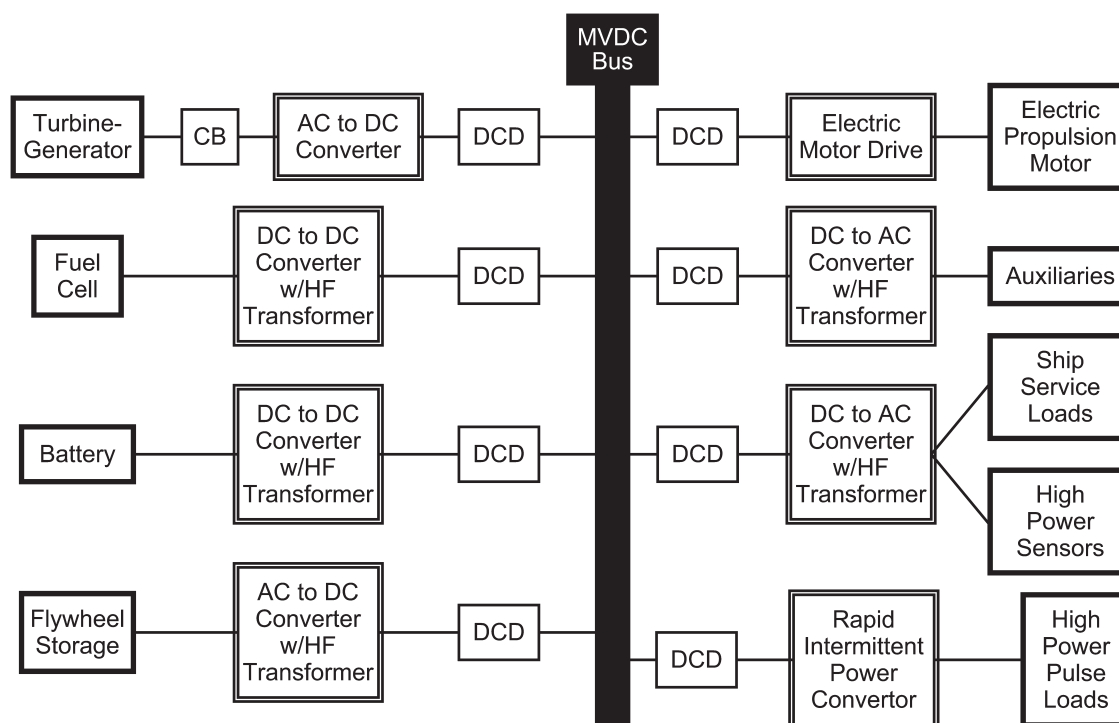
1.3 Power electronics in MVDC power systems

Recent successes in the development of fast switching medium-voltage power semiconductors made it possible to realize the following:

- Simplifying connection and disconnection of different types and ratings of power generation and electrical energy storage devices.
- Limiting and managing fault currents and enabling reconfiguration.
- Eliminating reactive voltage drop.

- Reducing power system weight by using high speed generators because there is no need for all generators to output a synchronous ac voltage.
- Enabling higher power ratings for a given cable size due to reduced skin effect losses.
- Improving control of power flows, especially in transient and emergency conditions.
- Improving efficiency when energy storage and power conversion from batteries, fuel cells, and emergency generators is required.
- Eliminating the need for phase angle synchronization of multiple sources and loads.

Figure 1 illustrates a concept of the MVDC distribution power system in which every electrical power source and every electrical load are connected to the MVDC bus via power electronics.



NOTE—CB = circuit breaker, DCD = DC disconnect, HF = high frequency

Figure 1—Concept of MVDC distribution power system

The system shown in Figure 1 maybe expanded with redundant generators of large and small size, redundant storage systems of different kinds, two variable speed propulsion drives, etc., or there may be two redundant MVDC systems.¹ All loads requiring an independent ground should be connected to the MVDC bus via a means such as compact high frequency transformers. Converters will accommodate reactive power required for loads.

Furthermore, with the capability of power electronics to control and interrupt current, most load-side circuit breakers may be replaced by simple switches such as dc disconnect switches. In case of a fault in the converter between generator and MVDC bus, or failure of converters to limit fault current, there should be a backup short circuit protection device between each generator and its protection scheme.

¹Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this recommended practice.

All power sources should actively limit fault currents. Such an approach allows relative ease of connection of different size generators, storage devices and loads. Commercial ships may not require storage except for satisfying the requirements for safety of personnel, for computers, controls, and communications, and for international regulations. In case of large pulse-type loads, short-time power demand may significantly exceed the power rating of all the installed generators.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 60092-101, Electrical Installations in Ships—Part 101: Definitions and General Requirements.²

IEC 60092-202, Electrical Installations in Ships—Part 202: System Design—Protection.

IEC 60092-350, Electrical Installations in Ships—Part 350: General Construction and Test Methods of Power, Control and Instrumentation Cables for Shipboard and Offshore Applications.

IEC 60092-502, Electrical Installations in Ships—Part 502: Tankers—Special Features.

IEC 60092-503, Electrical Installations in Ships—Part 503: Special Features—AC Supply Systems with Voltages in the Range of Above 1 kV up to and Including 15 kV.

IEC 60146, Semiconductor Convertors.

IEC 60533, Electrical and Electronic Installations in Ships—Electromagnetic Compatibility.

IEC 61010-1, Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use—Part 1: General Requirements.

IEEE Std 45.1TM, IEEE Recommended Practice for Electric Installations on Shipboard—Design.^{3,4}

IEEE Std 45.2TM, IEEE Recommended Practice for Electric Installations on Shipboard—Controls and Automation.

IEEE Std 45.3TM, IEEE Recommended Practice for Electric Installations on Shipboard—Systems Engineering.

IEEE Std 142TM, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.

IEEE Std 1547TM, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

IEEE Std 1100TM, IEEE Recommended Practice for Powering and Grounding Electronic Equipment.

IEEE Std 1584TM, IEEE Guide for Performing Arc-Flash Hazard Calculations.

²IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch/>). IEC publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org>).

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⁴IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

IEEE Std 1662™, IEEE Recommended Practice for the Design and Application of Power Electronics in Electrical Power Systems.

IEEE Std 1676™, IEEE Guide for Control Architecture for High Power Electronics (1 MW and Greater) Used in Electric Power Transmission and Distribution Systems.

IEEE Std 1899™, IEEE Guide for Establishing Basic Requirements for High-Voltage Direct-Current Transmission Protection and Control Equipment.

IEEE Std 3007.3™, IEEE Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems.

IEEE Std C37.100™, IEEE Standard Definitions for Power Switchgear.

ISO/IEC/IEEE 80005-1, Utility Connections in Port—Part 1: High Voltage Shore Connection (HVSC) Systems—General Requirements.

UL 840 Standard for Safety for insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment.⁵

Requirements of international, federal, state, country, provincial, or local regulations should be observed. If any conflict exists between this recommended practice and the rules established by the owner of the MVDC system, the owner should determine and confirm which rules should take precedence.

Other International, Regulatory, and Industrial specific standards referenced in this recommended practice are listed in [Annex A](#). These references are considered informative.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁶ IEEE Std 1662, IEEE Std C37.100, and IEEE Std 1313.1 should be referenced for terms not defined in this clause.

auctioneering diodes: A configuration of diodes that connects multiple dc sources to a load, but prevents current from one source feeding another source in the reverse direction.

crash back: Maneuvering from full propulsor speed ahead to full propulsor speed astern with the ship initially making full way ahead.

emergency condition test: Evaluates power system performance under sudden interruptions of power, rapid re-application of power after an interruption and emergency condition voltage tolerances.

medium-voltage dc (MVDC): Direct current (dc) voltages above 1 kV and up to and including 35 kV.⁵

quality of power: In reference to medium-voltage dc (MVDC) systems this means compliance with specified voltage tolerances and voltage ripple.

quality of service (QoS): The metric of how reliably the power system provides power to the loads.

voltage class: Categorizes the voltage capability of power system components. For a chosen rated voltage, only equipment categorized for a voltage class equal to or greater than the rated voltage should be used.

⁵UL standards are available from Global Engineering Documents (<http://www.global.ihs.com/>).

⁶*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>.

3.2 Acronyms and abbreviations

AVM	average value model
EMALS	electromagnetic aircraft launch system
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EPLA	electric plant load analysis
ES-CONOPS	electrical system concept of operations
HVDC	high-voltage dc
IC	initial condition
LRU	last-recently used
LVAC	low-voltage ac
LVDC	low-voltage dc
MVDC	medium-voltage dc
MTBSI	mean time between service interruptions
PEBB	power electronic building block
PM	permanent magnet
PWM	pulse-width modulation
QoS	quality of service
UPS	uninterrupted power supply

4. MVDC power systems fundamentals

Throughout this document the reader may encounter similarities with ac power systems. However, readers should avoid using ac practices directly. For example, the fault level in MVDC distribution systems can have vessel embedding fault clearance within power electronic converters or using dedicated solid state or hybrid switchgear, which bring their own challenges such as increased power losses and more complex converter topology. It is important to remember that this document addresses all issues from a MVDC point of view.

4.1 MVDC functional diagram

This subclause defines the boundaries of the MVDC system and the scope of this recommended practice. The MVDC power system must generate, store, and deliver electrical power of the proper quality and continuity to the served loads with minimal risks.

A notional functional diagram of a MVDC power system for ships is shown in [Figure 2](#). The functional blocks are defined as follows:

- *Shore Power Interface* is primarily a power source that adapts electric energy from the utility system on shore to MVDC (e.g., interface transformer + rectifier). This may or may not be capable of bi-directional energy flow.
- *Power Generation* is primarily a power source that converts prime energy from fuel into MVDC (e.g., gas turbine + generator + rectifier).

- *Energy Storage* is a standalone power source (discharging) or is load (charging) whose purpose to provide power to the system when needed but also to draw power from the system to recharge (e.g., battery or a capacitor bank with a bi-directional dc/dc converter).
- *Pulsed Load* is a stand-alone load center that primarily draws intermittent pulses of power from the system [e.g., electromagnetic aircraft launch system (EMALS)].
- *Propulsion* is a load center that primarily draws power from the system for vessel propulsion (e.g., a motor drive inverter + propulsion motor). It may also generate power during certain maneuvers such as crash back whereas the energy must either be dissipated or converted for use on the ship's distribution bus.
- *Ship Service* is a load center that primarily draws power from the system to power ship services within zones [e.g., dc/dc converter for in-zone distribution of low-voltage dc (LVDC), dc/ac inverter for in-zone distribution of low-voltage ac (LVAC)]. Note that "ship service" modules may take power from either the MVDC bus or from in-zonal energy storage systems.
- *Dedicated High-Power Load* is a stand-alone load center that draws 1 MW or more of power in steady-state operation (e.g., 3 MW radar sensor array). A dedicated high-power load could also be a pulse load.
- *MVDC Bus* is a functional block that allows interrupting and isolating sections of the MVDC system (e.g., mechanical disconnect, solid-state dc breaker). In addition, each functional block in the system can connect, disconnect, and isolate itself from the system through its own means (e.g., a "power generation" module should have at least a disconnect switch at its dc output).

Note that interruption, isolation, and configuration are actually independent functions. One device may fulfill one or more of these functions. Examples include the following:

- *Circuit Breaker*: interruption, isolation, and configuration
- *Fuse*: interruption and isolation (a fuse cannot turn on and hence cannot configure)
- *Load Switch*: isolation and configuration
- *Power Electronics on Output of Generator*: interruption and configuration

This functional breakdown allows the design of any kind of MVDC ship power system. The number of blocks and modules is not limited to the number of blocks depicted in [Figure 2](#).