



**Smart Transformer for Enhanced Efficiency and
Sustainability in Maritime Transportation**

Deliverable 6.3– Report on AC compatibility in DC grid

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Abstract

Deliverable abstract	
This task defines electromagnetic compatibility (EMC) requirements for the STEESMAT onboard DC grid by assessing voltage ripple, high-frequency disturbances, and electromagnetic emissions generated by power electronic equipment. It establishes acceptable AC voltage components on the DC bus to limit stress on capacitors and energy storage systems, while addressing EMC challenges specific to shipboard IT networks, including common-mode disturbances and leakage currents. The work also identifies EMC-critical components and defines mitigation measures to support the reliable integration and operation of the STEESMAT DC microgrid.	

Task T6.6 (M4–M15) Objective: Determination of the maximum permissible AC voltage component in the STEESMAT onboard grid (e.g., caused by switching frequencies) as well as evaluation of conducted/radiated electromagnetic interference; identification of critical DC components with regard to EMC.

1 Electromagnetic Compatibility (EMC) in Maritime DC Grids

1.1 Normative System Classification: Land vs. Marine

For EMC design of DC grids, the transition from land-based to maritime applications represents a fundamental change in the normative framework. While the IEC 61000 series forms the basis in terrestrial industrial environments, IEC 60533 defines the applicable requirements in the maritime sector.

IEC 60533 specifically addresses the environmental conditions on ships, where generation, distribution, and highly sensitive loads (such as communication and navigation systems) operate in close proximity, and where operational safety is directly linked to overall system availability.

1.2 System-wide EMC Challenges in Maritime DC Grids

The extensive use of power electronics — such as solid-state transformers (SST), DC/DC converters, variable frequency drives, and active semiconductor-based protection devices — fundamentally alters the EMC behavior of the entire onboard grid. Key aspects include:

1.2.1 Isolated System (IT System) and Common-Mode Disturbances

Shipboard power systems are typically operated as ungrounded IT systems in order to increase fault tolerance.

- **The issue:** High-frequency switching power semiconductors in DC/DC converters and SSTs generate steep voltage edges (du/dt). These excite parasitic capacitances between conductors and the ship hull.
- **Consequence:** Significant common-mode currents are generated, which flow through the steel hull. As no defined low-impedance return path exists — as in grounded land-based systems — these disturbances propagate uncontrollably throughout the DC grid and couple into adjacent signal structures.

1.2.2 Harmonics and Ripple Voltages on the DC Bus

In contrast to conventional AC shipboard systems with harmonic distortion (THD), voltage quality in DC grids is dominated by high-frequency components, commonly referred to as voltage ripple.

- **The issue:** The parallel and often asynchronous switching of multiple DC/DC converters and SSTs leads to superposition of switching frequencies on the main DC bus.
- **Consequence:** Without coordinated filtering or interleaved switching strategies, this voltage ripple causes thermal stress in DC-link capacitors, accelerates aging of battery and storage systems, and interferes with precise sensing for grid monitoring.

1.2.3 Spatial Constraints and Coupling Mechanisms

Electrical power cables of the DC grid and sensitive signal lines often cannot be sufficiently separated spatially due to the limited space available on board.

- **The issue:** Extremely fast switching events during fault conditions, such as semiconductor-based protection actions or sudden load rejection, generate transient magnetic fields in the near field of cable trays.
- **Consequence:** This leads to significant inductive and capacitive coupling (cross-talk) into parallel cable bundles, which can trigger false signals in the ship's automation system.

1.2.4 System Engineering Measures according to IEC 60533

Integrated design approaches are essential to meet the requirements of IEC 60533 at the system level:

- **Symmetrization of the DC topology:** A strictly symmetrical conductor layout (+ / – / reference potential) minimizes the generation of common-mode disturbances at the converters.
- **Coordinated filtering concept:** Use of centralized and decentralized EMC filters (common-mode and differential-mode chokes), which must be specifically matched to the input capacitors of DC/DC converters and SSTs in order to avoid resonance effects within the overall system.
- **Shielding and zoning (EMC zoning concept):** Consistent use of the steel hull as shielding by dividing the vessel into defined EMC zones. High-power electronic components (such as SSTs) must be strictly separated, from a signal perspective, from bridge and communication systems.

2 Specific EMC Phenomena in Maritime DC Grids

- **Static magnetic fields and compass interference:** The high DC currents on ships — particularly in main propulsion systems and central DC buses — generate strong, constant static magnetic fields. The static disturbance field from the cables adds vectorially to the Earth's magnetic field. For the compass sensor, these two static fields are physically indistinguishable. Since the disturbance field cannot be removed from the sensor data afterwards, its generation in the external environment must be prevented by design.
- **Hull currents (structural DC currents):** DC currents flowing uncontrollably through the metallic ship structure represent a critical risk to the mechanical integrity of the vessel. Due to insulation faults, unbalanced loads, or improper grounding in the IT system, continuous DC currents may be injected into the steel hull. DC hull currents cause electrochemical reactions at exit points (e.g. shafts, propellers, or seawater valves). These lead to electrolytic corrosion, which can irreparably damage the ship structure within a very short time.
- **High-frequency leakage currents (HF leakage currents):** The fast switching of power semiconductors in DC/DC converters, SSTs, and inverters shifts the EMC problem into the high-frequency domain. The use of HF filters (e.g. common-mode chokes) directly at the converter outputs is therefore mandatory.

3 Equipment Groups According to IEC 60533

IEC 60533 classifies onboard equipment into EMC-relevant groups, each with its own limits for conducted and radiated emissions and immunity requirements:

- **Group A:** Radio and navigation equipment (additional base EMC standard: IEC 60945)
- **Group B:** Power generation and power conversion equipment. This category includes the STEESMAT components SSTs and DC/DC converters.
- **Other Groups (C–G):** Including automation and integrated systems, among others, depending on installation location and function.

Important literature note: The limit values differ significantly depending on the installation zone. Equipment installed in bridge and deck areas is subject to substantially stricter limits (approximately 20 dB lower) than equipment located in general onboard power system areas, because it operates in close proximity to navigation and radio communication equipment.

4 Candidate List of EMC-Critical STEESMAT Components

Based on the architecture already described in the main report, the following list of candidate EMC-critical components can be derived as an engineering assessment rather than a direct citation from the literature. The list should be reviewed and confirmed together with the ship integration team:

- Solid-State Transformers (SSTs) – high-frequency switching operation; considered the primary source of electromagnetic emissions
- DC/DC Converters connected to energy storage systems and consumer loads
- Main Propulsion Converters
- SSCB Protection Devices (rapid switching events during fault conditions)

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