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Design Criteria and Practices for the Electric Warship

ABSTRACT

NAVSEA T9300-AF-PRO-020 is the U.S. Navy's design practices and criteria manual for design of surface ship electrical systems. During FY2016 revision 1 of this document was issued to replace the original version issued in 1992. Revision 1 was created to reflect the significant changes in electrical power system technology that have occurred since 1992. This paper highlights the extensive format and technical changes made to the document as well as the reasons for the changes. In particular, revision 1 focuses on Preliminary and Contract Design and clearly discriminates between criteria (requirements) and practices (recommendations). It also incorporates criteria and practices for new technologies such as integrated power systems, medium-voltage (high-voltage) distribution systems, energy storage, advanced controls, and power electronics. The new revision provides updated references to industry and military specifications, standards, and other technical documents. The paper concludes with topics that were not included in revision 1, but are planned for the next revision. These topics include medium-voltage and low-voltage d.c. systems and support for pulse-power loads.

INTRODUCTION

Design Practices and Criteria (DPC) Manuals provide engineers associated with the design, conversion and modernization of naval ships with design criteria and accepted design practices. NAVSEA T9300-AF-PRO-020 is the DPC manual that applies to electrical system design of non-nuclear surface ships. The original document was issued in December 1992. A project to update the document started about a decade later, but did not result in an approved update. By 2012, the original document was clearly dated. Work to create an update commenced with the goal of addressing the following:

- Since the Naval Combatant Design Specification (NCDS) and ABS rules apply to detail design and construction, target the DPC to preliminary and contract design. This does require a harmonization of the NCDS and the DPC.
- To avoid confusion as to what is required and what is recommended, clearly separate design criteria from design practices
- Update references
- Update the format to the latest guidance for DPC manuals
- Reflect insight gained in revising IEEE 45.
- Update criteria and practices for applying zonal and radial distribution architectures
- Include criteria and practices for zonal and compartment survivability
- Include criteria and practices for incorporating Quality of Service
- Include criteria and practices for incorporating energy storage
- Include criteria and practices for high voltage systems (1000 volts and higher -- also called medium voltage)
- Clarify differences between margins and service life allowances
- Delete content copied from other DPCs
- Define standard d.c. voltages

- Update grounding criteria and practices, including ground fault detection
- Update required analyses
- Provide criteria and practices for electric propulsion, hybrid electric drive, and propulsion derived ship service power.
- Update criteria and practices for 400 Hz. power.
- Provide guidance for cybersecurity
- Harmonize with the Ship Design Manager (SDM) and System Integration Manager (SIM) Manual
- Incorporate many lessons learned by subject matter experts.

This update would be a major revision; while many of the concepts of the base document would be preserved, little of the original text would remain in the revision.

The following sections highlight many of the changes incorporated into the new DPC.

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STRUCTURE AND FORMATTING

The original DPC document structure was based on topics. One of the drawbacks to this structure is the difficulty in differentiating between criteria, which are required, and practices, which are not required but recommended.

The new DPC has three chapters:

Chapter 1: Introduction

Chapter 2: Design Criteria

Chapter 3: Design Practices

The sections of chapter 2 and chapter 3 complement each other; for a given topic, chapter 2 contains only requirements and chapter 3 contains only recommendations. This ensures a clean distinction between criteria and practices.

In general, the new DPC references existing handbooks, DPCs, standards and specifications. Replicating information in other technical standards has been minimized. As a result, some information detailed in the original DPC has been deleted and replaced with references to other approved technical documents. For example, the original DPC contained considerable detail on load analysis which is currently well described in T9070-A3-DPC-010/310-1. The new DPC references T9070-A3-DPC-010/310-1 instead of incorporating its content.

Not all applicable electrical specifications are referenced. If an electrical specification is a sub-tier specification to another specification, it may not be referenced in the new DPC.

HIGH VOLTAGE AND ELECTRIC PROPULSION

The original DPC only addressed power systems covered by MIL-STD-1399-300. These power systems are characterized by 440 V a.c. three phase 60 Hz. and 400 Hz. power distribution.

Ship service electric loads on naval ships have grown significantly since 1992, mostly due to more power demand from combat systems and the transition from steam to all-electric auxiliaries.

The growth in electric load has resulted in the adoption of high voltage (1000 volts and higher) a.c. distribution systems. Note that the Navy's definition of high voltage corresponds to the term medium voltage by IEEE and other organizations. *U.S.S. Makin Island* (LHD 8), *U.S.S. America* (LHA 6), *Zumwalt* (DDG 1000), and DDG 51 Flight III all employ high voltage a.c. distribution systems. The new DPC incorporates criteria and guidance for high voltage a.c. distribution that reflect the lessons learned from these ship acquisition programs.

DC SYSTEMS

Zumwalt re-introduces d.c. power to naval surface combatants. As part of the Integrated Fight Through Power (IFTP) system, *Zumwalt* employs a 1000 V d.c. distribution system. Additionally, *Zumwalt* incorporates 375 V d.c. and 650 V d.c load interfaces. The new DPC establishes these nominal voltages as d.c. standards as well as recognizing existing standard voltages (28 V d.c. and 270 V d.c. as specified in MIL-STD-704 and 155 V d.c. as specified in MIL-STD-1399-390)

In anticipation of higher voltage d.c. distribution systems in future ships, the new DPC recognizes standard high voltages of nominally 6 kV, 12 kV and 18 kV d.c. These values are recommended in IEEE 1709-2010.

Governing power quality standards have not yet been developed for d.c. voltages above 270 V. Instead, designers are directed to contact the technical warrant holder.

POWER SYSTEM ARCHITECTURES

While the original DPC discussed zonal distribution systems in a single paragraph, much of the document focused on radial distribution systems. Based on experience in recent designs (for example: DDG 51 Flight IIA, *U.S.S. San Antonio* (LPD 17), *Makin Island*, *Zumwalt*) the new DPC covers both radial and zonal distribution systems in detail. The new DPC also includes coverage of mixed high voltage and low voltage distribution systems to support electric propulsion and high power mission systems.

Since the number of 400 Hz. loads has decreased with time, the new DPC recommends that point of use power conversion (such as an Integrated Power Node Center (IPNC)) be considered in lieu of a 400 Hz. distribution system.

MARGIN AND SERVICE LIFE ALLOWANCE

Margins and service life allowances (SLA) are often confused. Both are factors applied to the calculated electric load, but their purposes are different. Margins account for uncertainty during the design and construction of a ship. Margins reduce the risk that the ship delivered to the Navy has a higher operating load than for which the power system was designed. SLA accounts for growth in electrical load due to modernization and due to equipment degradation during the ship's service life. SLA helps ensure a ship has sufficient electrical generation capacity to enable upgrades during the ship's design service life to keep the ship operationally relevant. Insufficient SLA can result in a ship being decommissioned prior to its design service life.

The new DPC clearly distinguishes between margin and service life allowance. The criteria have also been adjusted and reworded to account for lessons learned.

QUALITY OF SERVICE

The original DPC did not directly address reliability of the power system under normal operations. The new DPC incorporates Quality of Service (QOS) as defined in IEEE 45.3.

One of the key aspects of QOS is classifying loads by the duration of a power interruption they can withstand. The three QOS categories are un-interruptible loads, short-term interrupt loads, and long-term interrupt loads. Previously, un-interruptible loads would be required to provide their own un-interruptible power supply (UPS). This has resulted in a proliferation of UPSs onboard ship; maintaining these many UPSs has proven expensive and manpower intensive. The new DPC provides criteria and guidance for sizing energy storage as part of the shipboard power system.

For new combatant ship designs, the new DPC requires a two tiered load shed strategy. Initially, loads are shed based on QOS. If sufficient generation capacity cannot be restored within a specified time, then loads are shed based on mission priority; some loads retained under QOS based load shedding may be shed to restore other loads with a higher mission priority. The purpose of this two tiered approach is to improve the overall operational availability of the ship.

SIZING GENERATOR SETS AND ENERGY STORAGE

The original DPC requirements for sizing generators was based on traditional ship service distribution systems without electric propulsion. The original DPC did not provide any guidance or direction for sizing energy storage because it required loads to provide their own energy storage if they needed it.

The new DPC provides a more comprehensive policy for sizing generator sets and energy storage for both integrated power systems (providing power to both propulsion and ship service loads) and traditional ship service power systems.

SURVIVABILITY

The new DPC provides updated direction and guidance for designing survivable power systems. The objective of the updated direction and guidance is to support the survivability approach described in OPNAVINST 9070.1A.

For zonal distribution systems, vulnerability is addressed through shock hardening and zonal survivability. For zonal distribution systems, recoverability is addressed through compartment survivability. Casualty power is described as one method for providing compartment survivability.

ANALYSES

Based on guidance provided by IEEE 45.3, requirements for the following analyses are included in the new DPC:

- Electric Power Load Analysis
- Load Flow Analysis
- Transient Analysis
- Fault Current Analysis and Protective Device Coordination Study
- Harmonic and Non-Fundamental Frequency Analysis
- Stability Analysis
- Electromagnetic Interference (EMI) Analysis
- Reliability Analysis
- QOS Analysis
- Vulnerability and Recoverability Analysis
- Arc Flash Analysis

Additionally, the new DPC directs the creation and maintenance of an "Electrical Power System Concept of Operations" in accordance with IEEE 45.3 to serve as a reference for how the electrical power system was intended to be operated. This document is intended to guide ship's force as well as support the analyses listed above.

FUTURE WORK

Twenty years between revisions is too long for most technical standards. In a highly evolving technical discipline, such as shipboard power systems, standards should be reviewed and updated frequently to reflect evolving technologies and lessons learned. For T9300-AF-PRO-020, the next update cycle should start immediately (with the goal of issuing revision 2 within 2 to 3 years) to address the following:

- More guidance on high voltage d.c. systems

- More guidance on high voltage power system protection, including arc fault detection
- More guidance on high voltage cables
- Improved criteria for high voltage shore power connectors
- Criteria for high voltage casualty power systems.
- Improved criteria for podded propulsion
- Guidance on harmonic filters and active power filters and conditioners
- Guidance on braking resistors
- Criteria for fuel cells
- Improved guidance for the health monitoring system
- Improved guidance for essential lighting to reflect emerging technologies
- More guidance on how to conduct analyses
- More guidance on support for pulse power mission systems
- Update references.
- Updated guidance on margin and service life allowance.

The development of the new DPC has illuminated the need to create other new technical documents and to update a number of existing documents. These recommendations are detailed in Appendix A of the Naval Power and Energy Systems Technology Development Roadmap (NAVSEA 2015).

CONCLUSION

NAVSEA T9300-AF-PRO-020 revision 1 provides designers of US naval ships with the guidance needed to design modern electric power systems. While it reflects the significant advances in technology and practice since the original version was published in 1992, additional revision is needed to meet the ship designer needs of the future.

REFERENCES

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