Electric Ship Knowledge Elements

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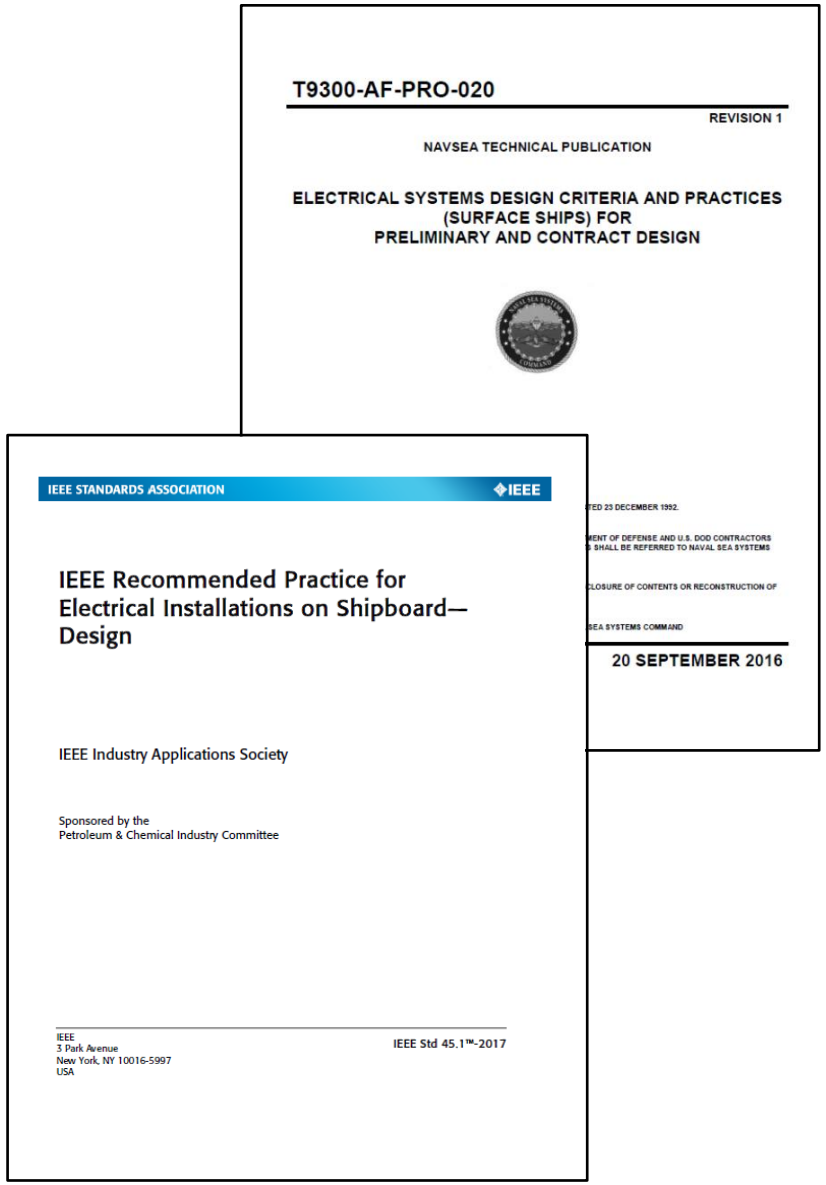
Background

- Design requirements exist for the electrical and propulsion systems on a ship
  - IEEE 45 series
  - T9300-AF-PRO-020
- Design workforce is small and generally inexperienced
  - New designs occur infrequently
  - Typical college courses do not cover many of the knowledge elements needed to design a ship
- Electrical Power and Propulsion System Preliminary and Contract Design Process – Activity Modeling tasking
  - Ongoing effort since FY20
  - Identified 27 design activities
  - Each design activity documented in a Model Description Document (MDD)
  - http://doerry.org/norbert/papers/20210604%20IEEE%20ESTS%20Tutorial%20-%20activity%20modeling-1.pdf
- Knowledge elements derived from the MDDs
  - Mapped to existing Consortium of Universities for Sustainable Power (CUSP) courses where possible
  - Remaining knowledge elements organized into eight knowledge groups and presented here

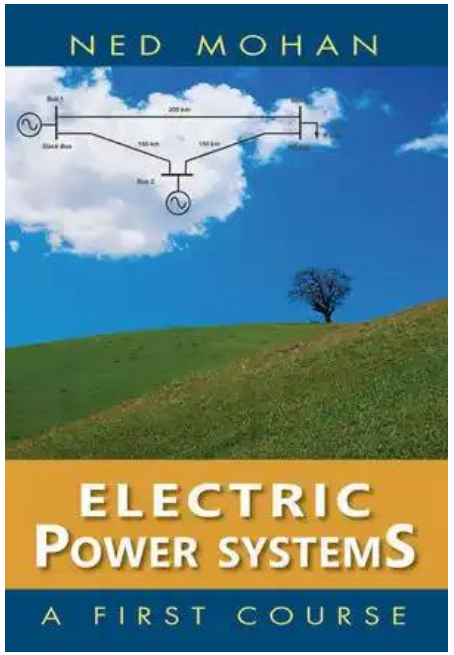


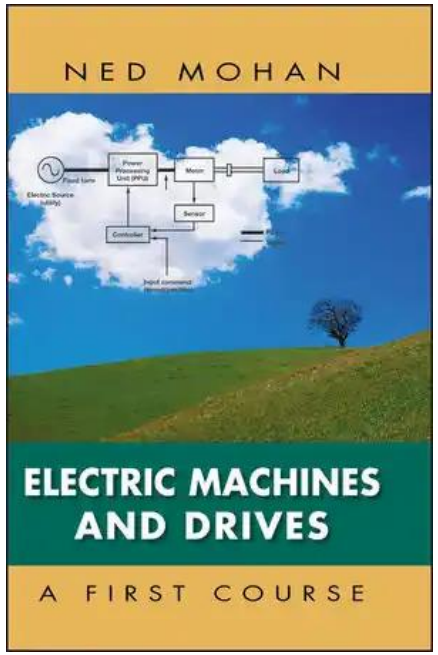
Knowledge Groups

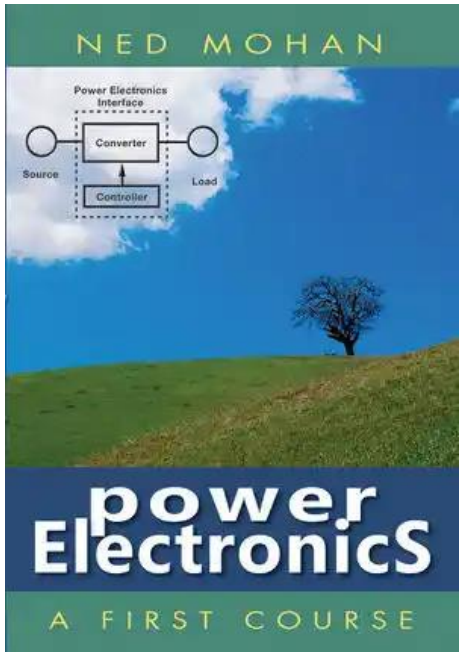
- Shipboard Power System Fundamental
- Shipboard Electric Power Load Analysis (EPLA)
- Shipboard Electrical Distribution System Design
- Shipboard Electrical Power Dynamic Analysis
- Electric Ship Mobility
- Shipboard Power Generation, Power Conversion, and Energy Storage
- Shipboard Electric Power System Design and Integration 1
- Shipboard Electric Power System Design and Integration 2

Existing CUSP courses provide a foundation

- Electric Power Systems: A First Course
- Electric Machines & Drives
- Introduction to Power Electronics







https://cusp.umn.edu/

Shipboard Power System Fundamentals

- 3 phase Alternating Current (AC) Review
- Shipboard Power Systems characteristics
- Shipboard Power Systems as a microgrid
- Differences between Shipboard Power Systems and terrestrial power systems.
- Ship Requirements
- Shipboard Power System Architectures
- Architecture Choice considerations
- Operating Conditions and Mission Profiles
- Power Generation Overview
- Power Conversion Overview
- Power Distribution Overview
- Propulsion Motor Overview
- Energy Storage Overview (dedicated, limited access, shipwide)
- Electric Load Overview
- Power and Propulsion Control Overview
- System Voltage Regulation
- System Frequency Regulation
- Power System Grounding overview
- Real and Reactive Power Sharing
- Power Management
- Load Management (load shedding)
- Control Interaction with mission systems
- Cybersecurity
- Electrical Power System Concept of Operation
- Propulsion System Concept of Operation
- Standards, specifications, regulatory requirements, classification societies

Shipboard Electric Power Load Analysis (EPLA)

- Load Lists
- Composite Loads
- Margin and Service Life
- Ship Operating Profiles and Mission Profiles
- Ambient Condition Profiles
- One Line Diagrams
- Electrical Power system Concept of Operations
- Propulsion System Concept of Operations
- Generator capacity sizing
- Power electronics capacity sizing
- Transformer capacity sizing including primary and alternate feeds
- Switchgear capacity sizing
- Cable / bus duct capacity sizing
- Load Factor Analysis
- Zonal Load Factor Analysis
- Modeling and Simulation Load Analysis
- Stochastic Load Analysis (develop probability density functions)
- Demand Factor Analysis
- Connected load
- 24-Hour Average Load
- Load Flow and Limiting Load Flow
- Validation of EPLA
- Energy Storage Capacity (Power and Energy) Analysis
- In-rush current analysis (sufficiency of Power Electronics ability to supply capacitive and inductive in-rush current), soft start
- Pulsed load analysis (sufficiency of sources to support maximum pulse and current ramp rate)
- Quality of Service Analysis
- Endurance Fuel Calculations
- Annual energy usage and annual energy cost calculations

Shipboard Electrical Distribution System Design

- Architectures (Ring, Radial, Zonal)
- Electrical Distribution voltage type (Medium (MV) or Low Voltage (LV), Alternating Current (AC) or Direct Current (DC) and power quality.
- Grounding methods and practices. Ground detection systems.
- Insulation monitoring systems (installed, periodic, trend analysis)
- Electromagnetic Interference and Electromagnetic Compatibility
- Common mode system modeling
- Common mode voltage and current control
- AC Fault Detection, Localization, and Isolation (Circuit Breaker Coordination – Fault Protection Relaying – Impact of power electronics on coordination – fault current interruption limitations – impact on transformer design for MV systems)
- DC Fault Detection, Localization, and Isolation (Different approaches, Solid State Circuit Breakers, Disconnects, Differential and Directional Protection, role of Energy Storage, minimum system inductance, fuses for Low Voltage Direct Current (LVDC)
- Design for Quality of Service (Electric Power Reliability)
- Voltage Drop Calculations
- Cable selection, cable installation practices, shielding (including cable termination considerations for different voltage levels), cable repair
- Bus Duct and Insulated Bus Pipe
- Switchboards, Load Centers, and Power Panels
- Maintenance considerations
- Cooling considerations
- Shore Power
- Types of controllers (Low Voltage Release (LVR), Low Voltage Protection (LVP) …)
- Motor controllers
- Variable Speed Drive integration
- Low Voltage Alternating Current (LVAC) Distribution Transformers
- Phase shifting transformers
- Automatic Bus Transfers, Manual Bus Transfers, Controllable Bus Transfers (discuss impact of out of phase bus transfers on inductive loads / transformers, time delays necessary)
- Primary and Alternate Power Feeds
- Emergency Power; installed and temporary
- Electrical Lighting system design
- Navigational Lighting system design
- Lightning Protection
- Point of Use Power Conversion
- Uninterruptible Power Supplies and strategies for consolidating

Shipboard Electrical Power Dynamic Analyses

- Transient Analysis
- Stability Analysis
- Dynamic Response Analysis
- Common mode current analysis
- Fault Current Analysis and Protective Device Coordination Study
- Harmonic and Non-fundamental frequency analysis
- Harmonic mitigations (active front ends, phase shifting transformers)
- Thermal analysis

Electric Ship Mobility

- Mobility requirements
- Shipboard / vehicle environment
- Efficiencies
- Ship / vehicle resistance (calm water, in a seaway, appendage drag, stern flaps, bulbous bows, wind drag)
- Propellers (propeller curves, propeller law, thrust deduction, wake fraction, contra-rotating, cavitation)
- Waterjets
- Rudders and steering systems
- Directional stability and maneuverability (turning diameter, advance, transfer, etc.)
- Bearings
- Shafting
- Reduction Gears
- Propulsion and Power System Architectures
- Propulsion Motors (Induction, Synchronous, Permanent Magnet, Superconducting)
- Motor Drives (Load Commutated Inverters (LCI), Cycloconverter, Pulse Width Modulated (PWM), Neutral Point Clamped Converter (NPC), Modular Multilevel Converter (MMC), other variations)
- Power, speed, torque control modes for electric propulsion
- Rectifiers (Passive, Controlled, Active)
- Transformers
- Dynamic Braking resistors and crashback
- Thrusters (side thrusters, azimuthing, fixed, auxiliary and primary)
- Controls
- Dynamic Positioning
- Design issues (margin, harmonics, insulation, common mode, thermal, etc.)
- Dynamic Simulation
- Machinery Arrangements
- Specifications, standards, class rules

Shipboard Power Generation, Power Conversion, and Energy Storage

- Synchronous Generators
- Prime Movers – Gas Turbines and Diesel Engines
- Prime mover auxiliary systems (including starting systems)
- Intakes and Exhaust systems
- Fuel Cells
- Emergency Generators
- Energy Storage Systems
- Rectifiers for DC Distribution Systems
- Soft start for electronic converters (DC link capacitance)
- DC to DC converters
- DC to AC inverters
- AC to AC frequency changers (i.e., 400 Hz)
- Medium Voltage Alternating Current (MVAC) to LVAC Transformers (including pre-magnetizing circuits to limit inrush)
- Phase shifting transformers (extended delta, zig zag)
- Efficiency Calculations
- Voltage Regulation
- Frequency Regulation
- Power Quality
- Common Mode Voltage and Current (Estimation, Measurement, and Modeling)
- Cooling systems
- Machinery Arrangements
- Class Rules, Regulatory Requirements, Standards, and Specifications

Shipboard Electric Power System Design and Integration Part 1

- Concept Design
- Preliminary and Contract Design
- Detail Design
- Design Activity Modeling
- Vibration
- Shock – shock envelopes – design for shock
- Temperature, cooling systems, humidity, salt content
- Creepage and Clearance
- Partial Discharge, Corona
- Space Charge in DC
- Arc faults in AC and DC and protection strategies
- Maintenance strategies
- Repair Strategies
- Tag out systems
- Cathodic Protection Systems
- Modernization strategies (include flexibility and modularity)
- Ship Integration – interface control documents
- Machinery Arrangements
- Shipboard Testing (system commissioning – grooming – sea trials)
- Land Based Testing (Factory acceptance testing – integrated test facilities)
- Test Plans, Test Procedures, Test Reports
- Digital Engineering
- Digital Twins
- Standards, Regulatory Requirements, Classification Societies
- Shipbuilding Specifications and equipment specifications

Shipboard Electric Power System Design and Integration Part 2

- Machinery Control Systems
- Electric Plant Control and Management Systems
- Control Hierarchy – time scale separation
- Reliability Requirements
- Reliability Modeling
- Mean time between failure vs Maintenance Free Operating Period
- Reliability Design of shipboard power and propulsion systems (discuss power quality)
- Classification Society categorization of redundancy requirements
- Reliability for unmanned systems
- Survivability
- Emergency operations and safe return to port
- Casualty Power Systems
- Electrical Power System Safety
- Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC)
- Human Engineering
- Manpower Estimation
- Cost Engineering
- Standards, Regulatory Requirements, Classification Societies
- Shipbuilding Specifications and equipment specifications

Resources

- IEEE 45 series, IEEE 1826, IEEE 930, IEEE 3000 series, IEEE 1110
- MIL-HDBK-289, MIL-HDBK-299, MIL-STD-461, MIL-HDBK-419, MIL-STD-2003
  - https://quicksearch.dla.mil/
- SNAME *Marine Engineering* (Both Harrington version (1992) and new updated chapters)
  - https://www.sname.org/publications
- Patel, Mukund, *Shipboard Electrical Power Systems*, CRC Press, 2012
- NAVSEA DDS 200-1 Rev 1 (T9070-AW-DPC-010/200-1), " Design Data Sheet: Calculation of Surface Ship Endurance Fuel Requirements, " 4 October 2011.
  (Available from DTIC ADA550279) https://discover.dtic.mil/
- NAVSEA DDS 200-2 (T9070-AW-DPC-020/200-2), " Design Data Sheet: Calculation of Surface Ship Annual Energy Usage, Annual Energy Cost, and Fully Burdened Cost of Energy," 7 August 2012. (Available from DTIC ADA565827) https://discover.dtic.mil/
- NAVSEA DDS 310-1 Rev 1 (T9070-A3-DPC-010/310-1), " Design Data Sheet: Electric Power Load Analysis (EPLA) for Surface Ships," 17 September 2012.
  (Available from DTIC ADA568950) https://discover.dtic.mil/
- ABS Marine Vessel Rules , IACS unified requirements (https://iacs.org.uk/)