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Outline

- Brief History of Electricity in the US Naval Fleet

- Today’s Marine Power System Drivers
  - Naval Ships
  - Commercial Ships

- Shipboard Power Systems vs. Terrestrial Power Systems

- Ongoing Developments

- Summary
Constitution: Congress shall “raise & support Armies”
...but shall “provide & maintain a Navy”
(Article I, Section 8)

“Without a Navy the Nation’s commerce will be at the mercy
Of any who would choose to prey upon it” - Alexander Hamilton
US Navy Electric Ships History

1970s

- USS Trenton;
- USS Langley;
- USCGC Modoc;
- USS New Mexico;
- T-2 Tanker

1980s

- Subscale superconducting ship applications analyses, including pod designs.
- 1984 - Integrated electric propulsion evaluated for FFX—ship program cancelled
- 1988 - CNO ADM Trost designated IED for surface combatants
- 1988-1989 - Advanced and Integrated Electric Propulsion developed for NAVSEA

1990s

- 1995 – IPS Full Scale Advanced Development
- Commercial IPS T-AKE

2000s

- 2000 – SECNAV determines DDG 1000 will be IPS
- 2007 - Next Generation IPS Roadmap Published
- Advanced Sensors (AMDR)
- EMALS / AAG
- Whole Ship UPS Architecture
- 400hz Point of Use Power Conversion
- Improved Fuel Efficiency and Increased Power Density
- Electric Weapons Support
- Open Architecture Systems

2010

- 2010

2020

- Navy After Next

A History of Successful Development and Transition
History of U.S. Navy Electric Ships

**USS JUPITER (AC 3)**
Commissioned 1913
Collier

**USS LANGLEY (CV 1)**
Recommissioned 1922
First U.S. Navy Aircraft Carrier
USS NEW MEXICO (BB 40)  Commissioned 1918
U.S. Navy’s First Electric Propulsion Combatant
For Surface ships, ‘Integration’ was lost when we transitioned to internal combustion engines.

IPS brings back ‘integration’ on the electrical side, enabled by:
- Solid State Power Electronics
- Multi-Megawatt Motor Drives
- Automated Controls
Surface ships account for 40% of Navy fuel consumption

Fuel cost uncertainty (~400% per bbl increase since FY03)

Energy (fuel) Demand Increasing
- Combat / Weapons Power
- Force Structure Changing: Higher Fuel Consumption
- Operational Requirements

Why focus on DDG 51 Class?
- Provides best opportunity for long term payoff given platform age, production restart, and quantity
Opportunities for Energy Savings

- **Prime Movers**
  - Technical advances
  - Combined cycles
- **Ship Propulsion**
  - Propulsor efficiency
  - Hullform resistance
  - Energy Recovery
- **Electrical Loads**
  - Fans / Pumps
  - Mission Systems
  - Lighting
  - Variable Frequency Drives
- **Operating Concepts**
  - Alternate Architecture optimizes Fuel Consumption

Alternate Architectures Maximizes Energy Savings
Increased demands for power will continue for the foreseeable future.
Mission Systems: Increasing Electrical Power Demands

Deployed Mission Capability

- **2014**: 0.4 MW
- **2016**: 0.7 MW
- **2020**: 30 MW
- **2020+**: 20 MW

**Weapon System Development**
- **TRL=6**
  - Solid State Laser

**Weapon Development**
- **TRL=4/5**
  - Active Denial System

**Technology Development**
- **TRL=3/4**
  - Free Electron Laser
  - Electro-Magnetic Rail Gun

**Power Demands per Mount**
- Multiple Mounts per ship

Sensor and Weapon System Power Demands will soon rival Propulsion Power Demands.
Example Ship Power System Loads

Idealized Aircraft Launch Power Pulse

Energy = 122 MJ

Idealized Rail Gun Power Pulse

Energy = 115 MJ

Placeholder for Videos
Loads Behaving Badly

Pulse Comparison

- Rail Gun
- EMALS

Notional Radar Power
Commercial Marine Power Systems
Design Drivers

- IMO MARPOL Annex VI Emissions Regulations
  - Limits NO\textsubscript{x} Emissions
  - Limits Fuel Sulfur Content
  - Requires implementation of:
    - Energy Efficiency Design Index (EEDI), for new ships
    - Ship Energy Efficiency Management Plan (SEEMP) for all ships.

MARPOL Annex VI NO\textsubscript{x} Limits\(^1\)

MARPOL Annex VI Sulfur Limits\(^1\)

\(^1\) www.dieselnet.com
Commercial Marine Power Systems
Design Drivers

- Increasing Fuel Prices

Bunker Fuel Price Index\(^1\)

Crude Oil Price History\(^2\)

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\(^1\) www.bunkerworld.com

\(^2\) US Energy Information Administration

Content subject to Distribution Statement on cover page.
Terrestrial vs. Marine Power Systems

Terrestrial Power Systems
- Structure – generally radial
- Large numbers of generators, busses, transmission lines, loads
- Constant frequency – linearized about an operating point
- Load flow analysis
- Market Implications

Marine Power Systems
- Structure – zonal / mesh
- Small number of generators, busses, negligible transmission lines
- Large transients, often not linearizeable
- Frequency domain analysis
- No market implications
Ongoing US Navy Power System Developments

- Reduce DDG 51 Class in-service fuel consumption
- Provides propulsion at low ship speeds without the need for LM 2500 main engines
- Assure mobility, lighten the load, expand tactical reach, and green our footprint

- Provide fuel efficient and affordable power to meet power requirements for advanced sensors and future weapons
- Reduction in weight and lower life cycle costs
- Up to 17% reduction in fuel consumption over the DDG 51 FLT IIa GTG

- Power conversion from ship current to 1000 VDC for the AMDR
- Potential for faster switching frequencies and higher temp. operation
- Smaller footprint

- De-risking Single Generator Operations
- High efficiency GTGs used with no electrical system degradation
- Support pulsed power requirements of advanced weapons

Hybrid Electric Drive Electric Propulsion System

Advanced Power Generation Module & Gas Turbine Efficiency Improvements

Affordable P&E Solutions

Power Conversion Module (PCM-1A)

Energy Storage Module

Propulsion Derived Ship Service

Ship Service electrical power from propulsion system through reduction gear
Summary

- Shipboard Power Systems are evolving due to increases in load demands, environmental regulations and fuel prices

- Terrestrial Power Systems are evolving due to increases in load demands, environmental regulations, fuel prices and market deregulation

- Incorporation of distributed, renewable generation sources and smart grid technologies may make terrestrial systems behave more closely to shipboard systems
Questions?