Next Generation Power and Energy

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PMS 320 (ESO)
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**Abstract:** Presented during EXPONAVAL 2010, Nov 30-Dec 3, 2010, Valparaiso, Chile, Office of Naval Research Global Conference
Outline

• Brief History of Navy Electric Drive
• Challenges/Opportunities
• Next Generation Integrated Power System
• Open Architecture Business Model
• Intelligent Ship/Power Dense Technologies
• Hybrid Electric Drive (HED)
Electric Drive

USS Langley
Recommissioned 1922
- First US Aircraft Carrier -

USS Jupiter
Commissioned 1913
- Collier -

Photo # NH 81279  USS Langley off San Diego, California, with USS Somers, 1928
## PLATFORM RESULTS

<table>
<thead>
<tr>
<th>PLATFORM</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amphibious Assault (LHD 8)</strong></td>
<td>- The first U.S. Navy amphibious ship built with Gas Turbine Engines and Hybrid Electric Drive resulting in <strong>significant fuel savings compared with steam driven LHD</strong></td>
</tr>
<tr>
<td><strong>Combat Logistics Force (T-AKE)</strong></td>
<td>- T-AKE is powered by a commercial integrated power system, providing <strong>reduced acquisition and life cycle costs</strong></td>
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<tr>
<td><strong>Surface Combatant (DDG 1000)</strong></td>
<td>- ZUMWALT’s Integrated Power System (IPS) combines <strong>78MW of installed power</strong> generation for propulsion and ship service into a single unified electrical system.</td>
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</tbody>
</table>

**Meeting the Mission with Increased Power and Reduced Costs**
Other Naval Trends…

UK (23 + IPS/hybrid ships)
- Type 23 Frigate, in-service – hybrid electric/mechanical drive
- Type 45 Destroyer, in-service – full Integrated Power System
- Albion Class LPD, in-service – full Integrated Power System
- Wave Class Oiler, in-service – full Integrated Power System
- CV(F) under contract – full Integrated Power System

Netherlands (2 ships)
- LPD “Rotterdam” Class, in-service – full Integrated Power System
- IPS declared for future surface combatants

Germany
- U-212 Submarines
  - Diesel Electric w/ PM Motors
  - AIP systems using fuel cells

France
- BPC (LPD) in-service, Podded Integrated Power System
- Future CV in design – full IPS, maybe Pods

France, Italy, Greece, Morocco
- FREMM Frigate – Hybrid Drive
  (28 planned, 4 under construction)

Australia (2 ships)
- Canberra Class LPD - Podded IPS
- Collins Class SSG - diesel-electric

...many other Navies interested
Our Challenges

- Reduce Fuel Dependency
- Greater Demands for Power
- Control Costs
... Also The Challenge of New Technology

To Reduce Risk and Costs, Engineering Development Models Must Precede “Design and Technology Selection”
How Do We Meet Our Challenges

- Fleet-wide Analysis of Demand
- Early Investment in Technology
- Integrated System Demonstrations
Navy Fuel Usage and Trends

FY07 DON Fuel Usage
(38.8 Million Barrels)

- Energy (fuel) demand will increase
  - Combat / Weapons power
  - Force Structure changing – Higher fuel consumption
  - Operational requirements

- Fuel cost uncertainty – Probably

Expected FY09 fuel bill: $5.3B
Per bbl cost +400% since FY03

Distribution A: Cleared for Public Release
Support High Power Mission Systems

Sensor and Weapons Power Demands will Rival Propulsion Power Demands
Electric Ship Prototype
Innovation Naval Prototype
Integrated, Large Scale System Demonstrations: Electric Ship INP

Power System

- NGIPS Technology Development Roadmap
- Fuel Savings
- Operating and Support Cost Game Changer

Electric Ship Prototype
Innovation Naval Prototype

Electric Weapons

- High Power Weapons & Sensors
- Integrated Support Systems
- Acquisition Cost Game Changer
- Mission Capability

NEXT GENERATION INTEGRATED POWER IS KEY ENABLER OF FUEL EFFICIENCY AND ADVANCED WEAPON SYSTEMS
Outline

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"I direct the Program Executive Officer (PEO) Ships to establish an Electric Ships Office to assume responsibility for developing and executing an integrated power system (IPS) technology development and transition plan."

Message: Develop and Execute NGIPS Technology Development Roadmap
Next Generation Integrated Power System (NGIPS)
Technology Development Roadmap (TDR)

Roadmap defines path for NGIPS development, provides guidance to Navy and industry developing organizations and forms the basis for coordinated planning and future Navy investments.

- Medium Voltage, Medium Frequency (MVMF) Systems
- Medium Voltage AC (MVAC) Systems
- Low Voltage AC (LVAC) Systems

**Enabling Technologies**
- High Speed Generator
- Advanced propulsion motors
- Common power conversion

**Power Density**

**Navy Now**
- DDG 51 Flt IIA Virginia

**Next Navy**
- T-AKE 1
- CVN 78
- DDG 1000
- LHD(8)
- LHA(R)
- MLP
- DDG 51 Flt III?

**Navy After Next**
- Submarines?
- DDG(X)?
- LCS(X)?
- JHSV?
- T-AGOS(X)?
- DDG 51 Flt III?
- FSC?

**“Directing the Future of Ship’s Power”**
Older ships were ‘integrated’ on the steam side

‘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
Open Architecture Business Model

Navy Controls NGIPS Architecture and Interfaces; ‘What Pieces Will Be Needed and How They Fit Together’

Industry Competes for Components; ‘Submit Proposals for Their Piece of the Puzzle’
Outline

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Technology Development Overview
( ONR Advanced Naval Power )

Motors & Actuators
- Motors
- Actuators
- Electro-Mechanical Devices

Heat Transfer, Thermal Mgmt
- High Waste Heat Flux Removal
- Adv. Chiller Technologies / HVAC

Energy Storage
- Batteries
- Capacitors
- Flywheels

ONR Maintaining Robust S&T Investment

Power Generation
- Fuel Cells
- Advanced Generators
- Direct Conversion
- Photovoltaics
- Future Fuels

Power Distribution
Power Generation
Power Conversion
System Control
Power Load
Energy Storage

Distribution & Control
- Architecture
- Switching & Conditioning
Objectives

- Develop motor drive topology and components that lead to a **2-3X increase** in power density (to 2-3 MVA/m³), a reduction in harmonic distortion from ~9% to <1%, and an increase in efficiency from 94% to 98%, i.e., a 2X reduction in thermal losses.

- Develop a high power density **bi-directional PCM** that interfaces to energy storage modules, enabling wider system usage of installed energy storage with an Integrated Power System.

- Develop a **power management controller** that will provide ~2x increase in whole system dynamic reaction time and power partitioning from propulsion to ship service & weapons loads in <x ms.

S&T Products

- Large scale demonstration of multifunction converter in FY 2011
- Large scale demonstration of bi-directional power converter in FY 2011
- Large scale demonstration of power management controller in FY 2012
Solid State Power Substation (SSPS) Program
• DARPA, ONR, PEO-Carriers, ESO
• Team: GE, Cree, Powerex, LANL, IAP, GD-EB

Goal
• Compact, light-weight replacement for 2.7 MVA, 13.8 kV/465 Vac, 60 Hz iron-core transformers
• ~3X improvement in weight
• Demonstrate high voltage, high frequency electronic power conversion (10 kV @ 20 kHz)

Status
• SSPS building block tested to full power at GE
• Navy testing completed at NSWC (Phila. LBES) from October 2010

Enabling technology for other applications: radar power, MVDC circuit breakers
Reduction in SiC prices will open up large commercial markets!
Intelligent Ship/Power Dense Technologies: Adaptive Automation for Control

**Requirement**
- Battlespace Situational Awareness
- Ship Capability Awareness
- Ship Systems Situational Awareness
- Resident Instantiated Modeling
  - Shipboard to enable Real Time Analysis
  - Predictive Performance based on Condition and Context (mission)

**Capability**
- Faster Time to Optimal Decision
  - Cognitive Decision Aids
  - Situational Awareness
- Faster Time to Optimal Action
  - Autonomous/Reflexive Operations
- Increased Survivability
  - Pre-Hit Reconfiguration
- Increased Recoverability
  - Service Restoration
  - Damage Mitigation
- Reduced Cost
  - Reduced Watchstanding
  - Reduced Maintenance

**System Of Systems**
- Total Ship Software Model
  - Functional Models
  - Physics Based Models

Enables

*Predictive and Adaptive*

Machinery Monitoring and Control
Technical Objectives:
• Develop technologies to address incipient fault detection, fault accommodation and self-healing of electric drive systems
• Provide automated integration between the PHM technologies and fault accommodation / self healing approaches
• Demonstrate the developed technologies in a realistic hardware-in-the-loop test bed and with actual component faults/data
• Provide a logical path for technology transition in a ship systems application in Phase II and Phase III commercialization

S&T Challenges
• Identification of practical and cost effective failure precursor features and methods
• Determination of failure precursors directly linked to failure progression
• Development of dynamic fault accommodation strategies
• Development of physics-based failure progression modeling

Deliverables and Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Q3 2006</th>
<th>Q4 2006</th>
<th>Q1 2007</th>
<th>Q2 2008</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Select Platform and Develop Test Strategy</td>
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<td>2</td>
<td>Conduct motor drive seeded fault testing</td>
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<tr>
<td>3</td>
<td>Identify incipient fault indicators and develop signal processing</td>
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<tr>
<td>4</td>
<td>Develop fault accommodation strategies</td>
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<tr>
<td>5</td>
<td>Develop demonstration and draft transition plan</td>
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When is an IGBT Going to Fail?
Power Generation: Fuel Cells
(Power Generation Module)

- Many Advantages
  - Highly Efficient (35-60%)
  - No Dedicated intakes-uptakes; use ventilation

- Challenges
  - Reforming Fuel into Hydrogen – Onboard Chemical Plant.
  - Eliminating Sulfur from fuels.
  - Slow Dynamic Response - Requires Energy storage to balance generation and load
  - Slow Startup – Best used for base-loads
Motors and Actuators: (Propulsion Motor Module)

- **Permanent Magnetic Motor (PMM)**
  - Load testing completed June 08
    - Full power on one stator ring (18MW)
  - No plans for additional testing

- **High Temperature Superconducting Motor (HTS)**
  - Full Power Testing Complete (December 08)
  - Motor Achieved Design Rated Torque @ Rated Speed for 36.5 MW!
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Hybrid Electric Drive (HED) (for DDG-51 Flt IIA)

Background

- NAVSEA 21 sponsored HED industry studies and Navy Trade Space Analysis for DDG 51 Class fuel economy

- NAVSEA Congressional Adds to design, build & test a HED proof of concept system to be demonstrated at Navy Land Based Engineering Site

- Leveraging ONR investments in shipboard energy storage and dynamic controls to be demonstrated at LBES (NSWC Philadelphia)

- Hybrid Electric Drive established as a top-priority for the Navy’s energy task force to demonstrate the capability at the Navy’s Land Based Engineering Site (Philadelphia, PA) in 2011 and at-sea in a DDG-51 Class ship in 2012.
Fuel Efficiency Technology Enablers

Hybrid Electric Drive & Energy Storage improves energy efficiency of in service surface combatant power plants
• Energy storage enhances hybrid drive savings & enables single generator ops
• Eliminates “Dark Ship” condition
• De-Risks future Next Generation Integrated Power System Energy Storage Modules

• Hybrid drive dynamic analysis ensures power quality capability and control
• Develop and de-risk control approaches to address DDG-51 Machinery Control System requirements

ENERGY STORAGE INTEGRATED INTO THE HYBRID ELECTRIC DRIVE SYSTEM PROVIDES THE GREATEST FUEL SAVINGS For NAVY SHIPS
Conclusion

"Valley of Death"

Questions?