Balancing Shipboard Energy with Warfighting Needs

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The Situation

Energy management critical to controlling cost and maintaining capability in light of new load requirements.
Energy is an Optimization Function

- Power
- Speed
- Size
- Weapons
- Sensors

- Acquisition
- Maintenance
- Operational
- Reliability

Capability

Cost

Efficiency

- Fuel Burn
- Endurance Range

Significant Engineering is Necessary to Find the Right Cross-Section
Don’t Ships Have Lots of Power?

DDG-51 Flight 2A:
~9MW installed electric power; ~75MW installed mechanical propulsion

DDG-1000: ~78MW installed electric power

Accessing Power is Key…
Shipboard Electrical Power to Meet Mission Loads

Available Power (Electric Power Online) vs Age of Guns

- Integrated Architectures
  - Extra Power Available to Loads
- Traditional Architectures

Adapted from http://www.navsea.navy.mil/Portals/103/Images/TeamShips/PEOShips/ESO/Integrated_Architectures_figure2ex.jpg
Power availability by ensuring all prime movers are accessible to all loads offers:

- Additional and larger mission loads
- Power flexibility and optimization of plant loading
- Enhanced survivability if reconfigurable
Accessing Power is Key…Not just the ratings

**Gas Turbine Generator Transient Response**

Aerodynamic couple in two-spool GTG makes transient concerns greater; however, available large GTGs all use this architecture.

Makes energy storage buffers necessary…
Energy Storage: A Means to Get Fuel Savings and Operational Capability

Energy Surety
- Online storage devices for backup power
- UPS for protection of sensitive devices
- Closed, signature-free energy source

Fuel Savings
- Single Generator Operations (Shipwide UPS)
- Generator load optimization/scheduling
- Minimization of spinning assets
- Terrestrial distributions (microgrids)

Power Quality
- Advanced GTG Transient ridesthrough
- Load changes outside of design space for prime movers

Advanced Loads
- Pulsed applications
- Highly transient loads
- Cyclic load requirements

Distribution Statement A: Distribution is unlimited
Future Operational Mode

Optimize storage buffering prime movers to enable continuous Directed Energy Weapons operations with optimized, efficient loading of spinning assets...
Energy Storage Approaches

**Batteries**

- Typically Lithium-Iron Phosphate for Shipboard use
- Future innovations welcome
- High power, low impedance variants necessary; Power density and thermal performance emphasized
- Safety behaviors are critical
- Solid BMS and sensing

**Hybrids**

- Battery-Capacitor; Battery-Flywheel and Battery-Battery variants offer benefits in various applications
- Supports high rate and high ripple/noise applications
- Superior dispatch characteristics
- Mix and match at the LRU level

**Flywheels**

- Scales with square of rotational speed, which enables density advantages
- Efficiency, thermal management and safety are critical
- Advanced materials and shock tolerant designs are desirable to ensure life and performance
Battery Safety: Heat Release Under Abuse/Failure

Lithium Iron Phosphate (LFP) Identified as Near-Term Selection Li-ion Chemistry for High Power, Impedance and Safety

Electrolyte, separator and negative electrode are still thermal contributors

Source: Saft

Minimal positive electrode contribution

Source: SNL

LiCoO₂
Gen 2: LiNiₓCo₁₋ₓAlₓO₂
Gen 3: Li₁₋ₓ(Niₓ/3Co²/3Mnₓ/3)O₂
LiMn₂O₄
LiFePO₄
Similarity of Applications

Safe, efficient systems are critical to adoption and widespread use

Multiple-rate, high power/energy systems with appropriate thermal Characteristics are necessary for adoption

Commercial
- Storage at Grids Edge
- Transportation

Military
- Ships
- Subs
- Aircraft
- Vehicles

Commercial
- Grid Stabilization

Military
- Forward Operating Bases
- High Rate Weapons & Sensors
- Generator Ride Through
How to Balance Loads and Available Energy: Data and Decision Making

DATA SOURCES
- eRM
  - Sensors
    - Fuel Flow Meters
    - Electric Plant Load Sensors
    - AC Plant
- eLogBooks
  - Weather
  - Sea
- Combat Systems

DATA SOURCES
- How much fuel is being used?
- What power is being generated?
- Why is energy being used this way?

FUTURE CAPABILITY: WHAT ENERGY IS REQUIRED TO ACCOMPLISH THE MISSION?

ENERGIES MANAGEMENT:
Advanced Controls and Decision Making

Analyze
- Aggregate
- SEAS
  - Shipboard
  - Energy
  - Assessment
  - System

Advise

Perform

Users
- CO/XO: Fuel penalty of delayed maintenance.
- Most efficient / ready watch team.
- TAO: Availability of plant and resources to execute mission sets
- CHENG: Impact of current material status on energy usage
- MPA: Energy savings for defouling

Shipboard

Distribution Statement A: Distribution is unlimited
Combined Electric Ship With Storage

Plant Efficiency + Power Accessibility = Efficient, Available Power that is part of the Kill Chain

Optimization of Plant Genset Lineup and Loading + Future High-Efficiency Sources, e.g. Fuel Cells

Storage Components

Integration and Control

SEA 05D Rendition of a Notional Next-Generation Flex-Ship

Higher Efficiency of Power Utilization for Electrical and Propulsion Loads

Source: Doerry et. al, 2010
Opportunities for Innovation

- Safe, common, affordable batteries, capacitors, flywheels and other storage innovations
- Compact and efficient power conversion
- Innovative means of managing highly transient loads
- New approaches to improve engine (diesel & GT) response rates
- Thermal management
- Commonality
- Control
Conclusions

• Present and emerging threats will continue to increase the electrical power demand on warships

• Management of generation, quality, and load will enhance or, perhaps enable the fight

• The ideal power management architecture will harness all installed power yet provide the maximum flexibility
  – Margin in the form of quantity
  – Flexibility to quickly switch electrical power use between propulsion, weapons, sensors and more
  – Efficiency under all operations