Designing All Electric Ships

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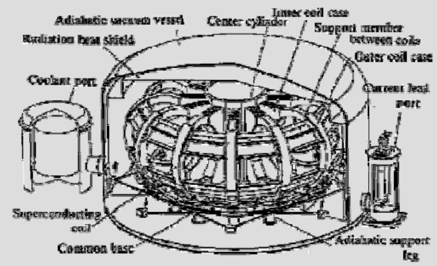
AGENDA

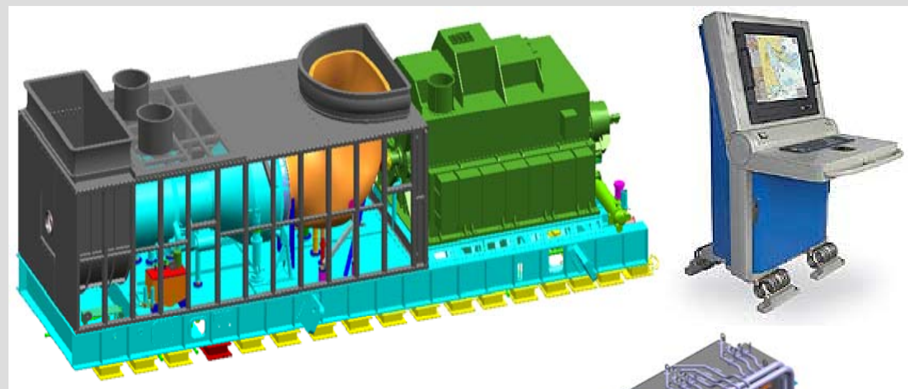
- Integrated Power System (IPS) Introduction
- IPS Design Opportunities
- IPS Design Considerations
- IPS Design Watch Items
- Conclusions
  - The Integrated Power System provides the naval architect with many opportunities to optimize ship design.
    - It's important that the Naval Architect take advantage of these opportunities, otherwise a sub-optimized IPS ship design may not outperform an optimized conventional mechanical drive ship design.
  - Improving the efficiency of prime movers and propulsors (along with drag reduction) can compensate for lower transmission efficiency of electric drive.

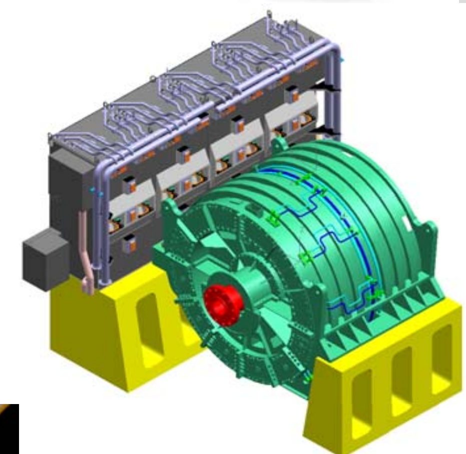
Integrated Power System (IPS)



IPS consists of an architecture and a set of modules which together provide the basis for designing, procuring, and supporting marine power systems applicable over a broad range of ship types:

- Power Generation Module (PGM)
- Propulsion Motor Module (PMM)
- Power Distribution Module (PDM)
- Power Conversion Module (PCM)
- Power Control (PCON)
- Energy Storage Module (ESM)
- Load (PLM)

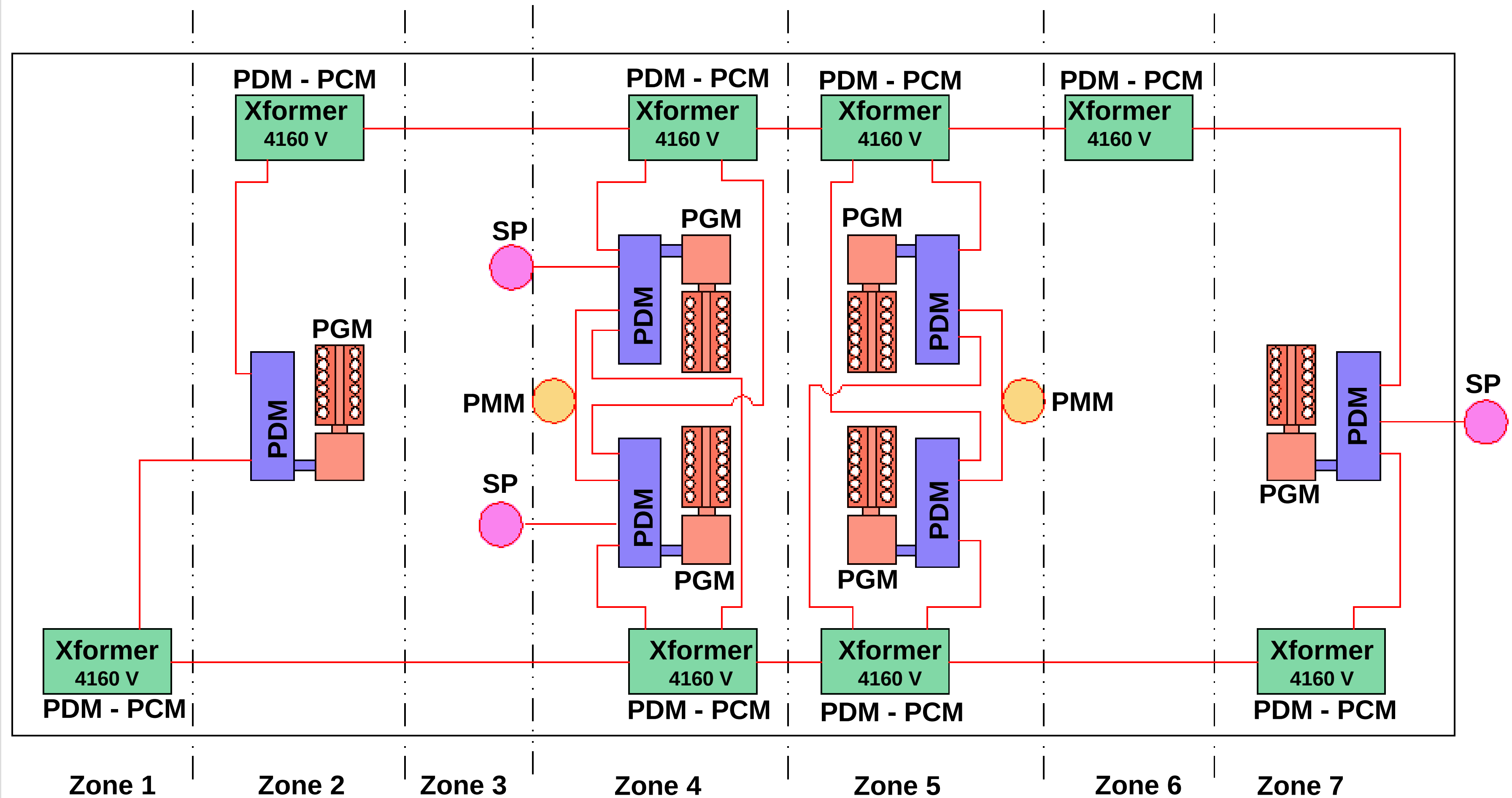




IPS Architecture

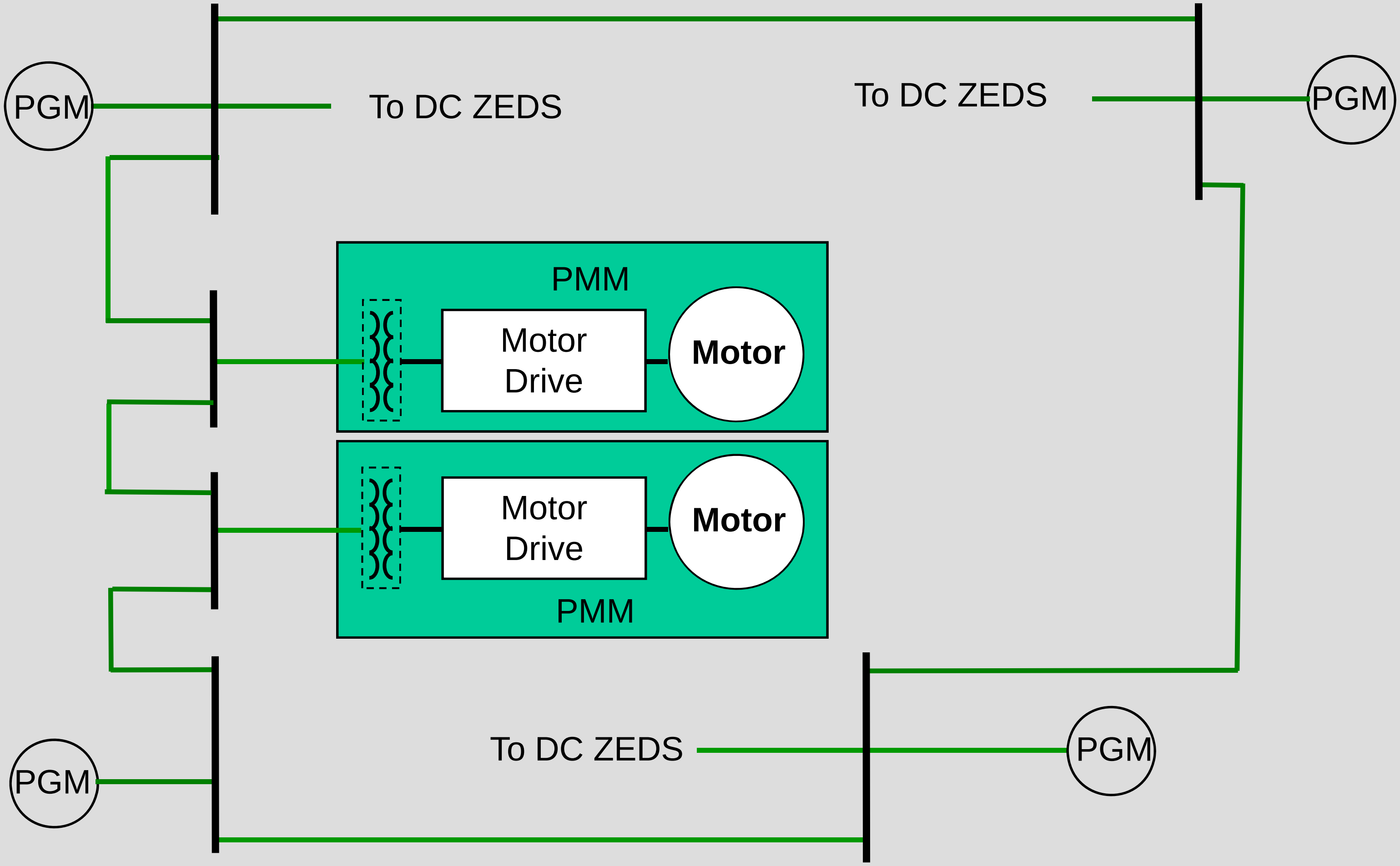
- Integrated Power
  - Propulsion and Ship Service Loads provided power from same prime movers
- Zonal Distribution
  - Longitudinal Distribution buses connect prime movers to loads via zonal distribution nodes (switchboards or load centers).

IPS: Medium Voltage AC Design

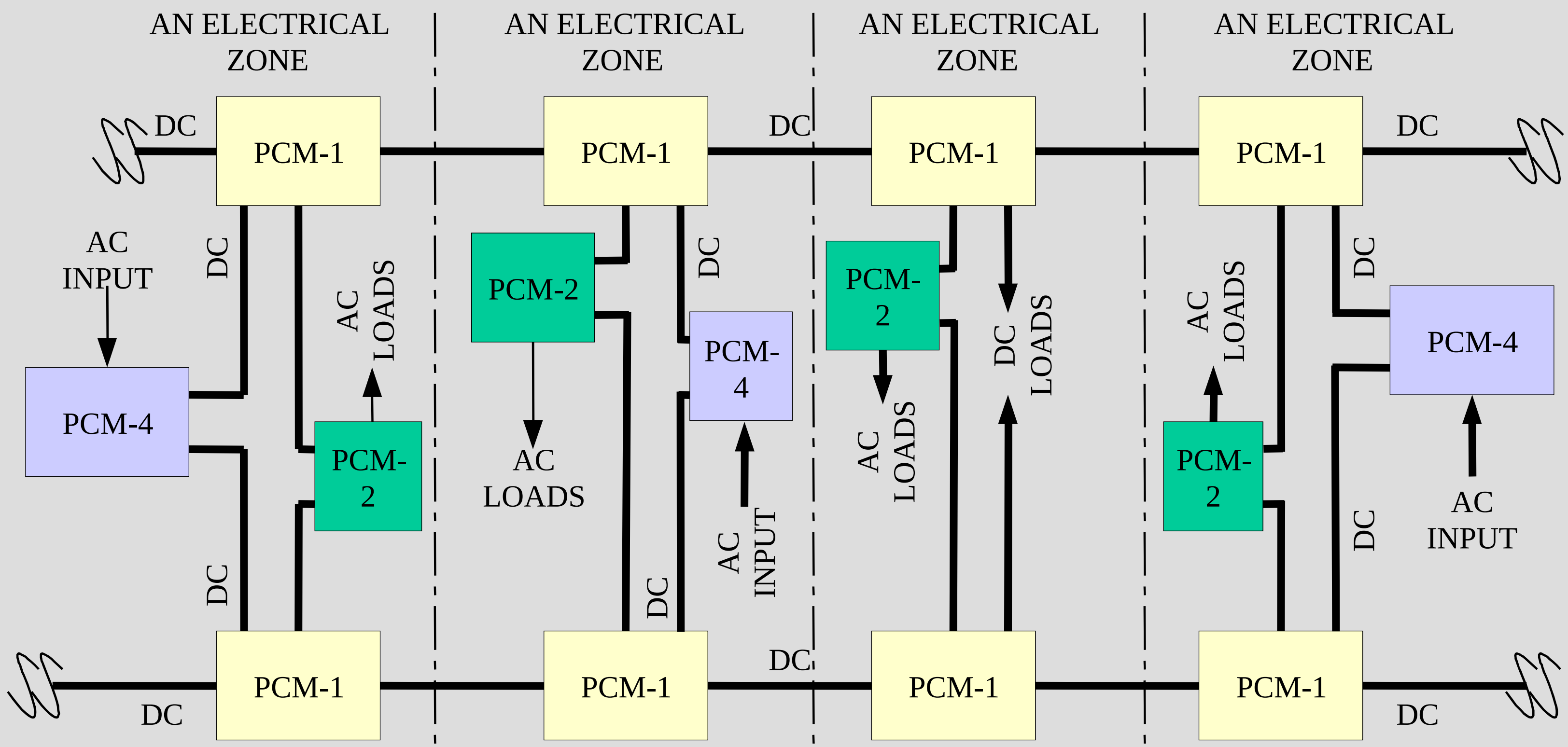


SP = Shore Power

IPS with DC Zonal Electrical Distribution: Medium Voltage AC Distribution System



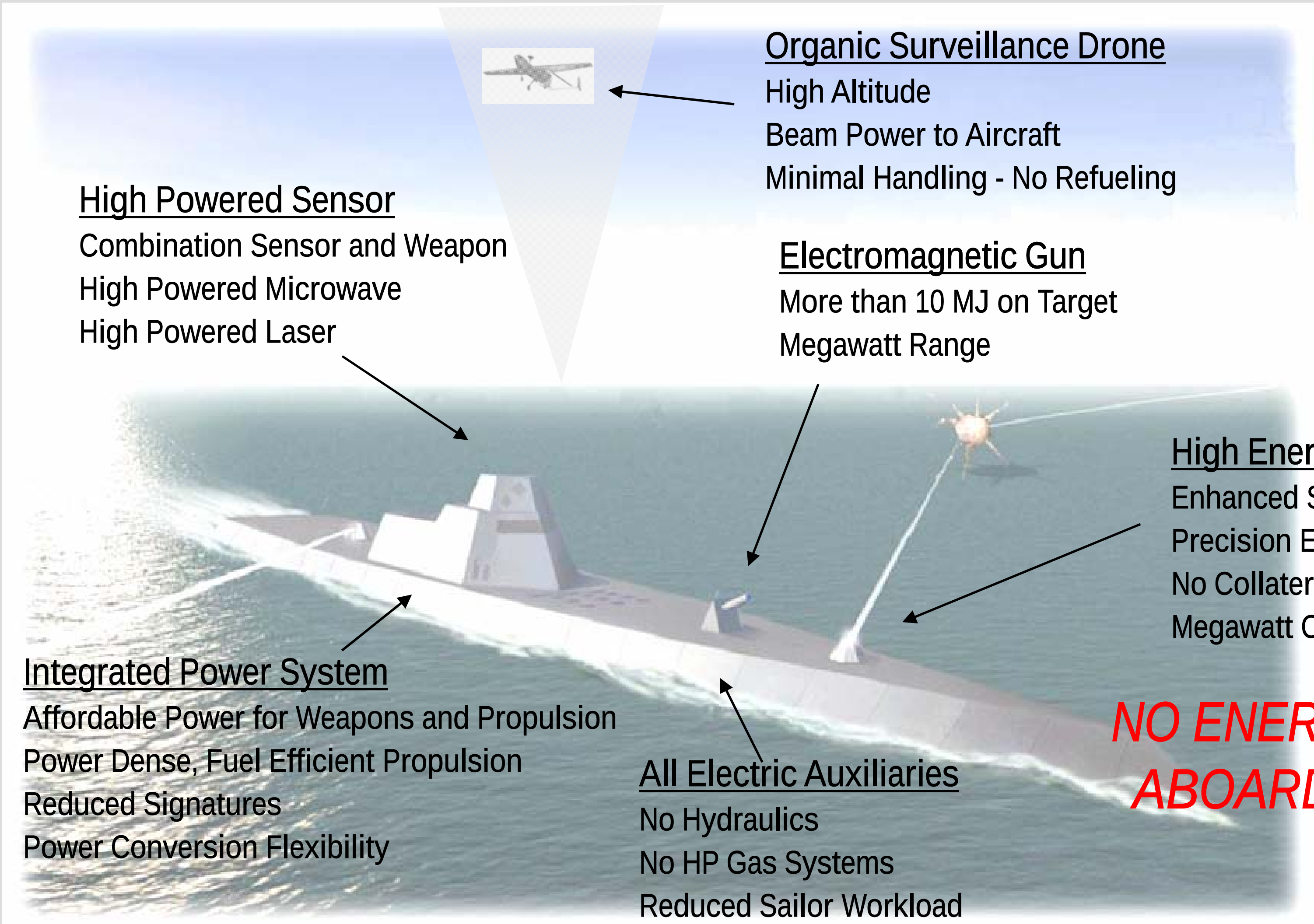
DC Zonal Electrical Distribution System



IPS Design Opportunities

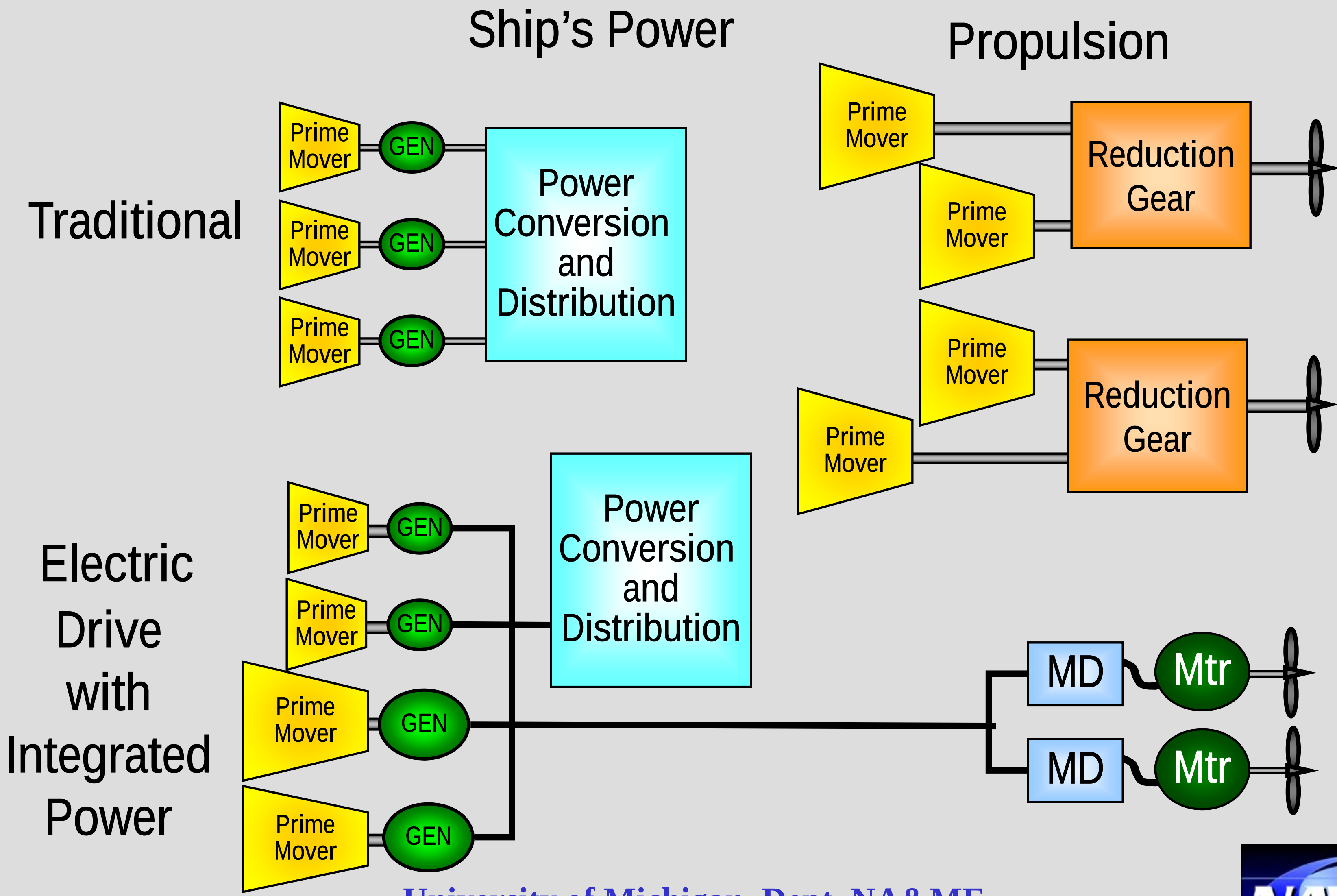
- Support High Power Mission Systems
- Reduce Number of Prime Movers
- Improve System Efficiency
- Provide General Arrangements Flexibility
- Improve Ship Producibility
- Support Zonal Survivability
- Facilitate Fuel Cell Integration

Support High Power Mission Systems



NO ENERGETICS ABOARD SHIP!

Reduce Number of Prime Movers



Improve System Efficiency

- A generator, motor drive and motor will generally be less efficient than a reduction gear ….
- But electric drive enables the prime mover and propulsor to be more efficient, as well as reducing drag.

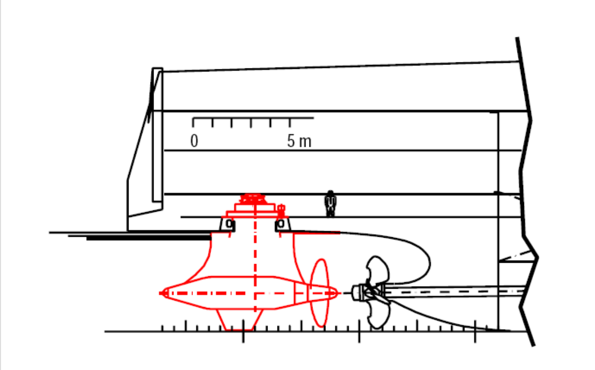
	Mechanical Drive	Electric Drive
Gas Turbine	30%	35%
Reduction Gear	99%	
Generator		96%
Drive		95%
Motor		98%
Propeller	70%	75%
Relative Drag Coefficient	100%	97%
Total	21%	24%
Ratio		116%

Representative values: not universally true

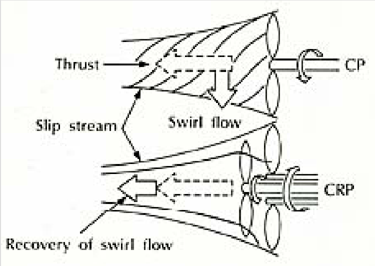
TRADE TRANSMISSION EFFICIENCY TO REDUCE DRAG AND IMPROVE PRIME MOVER AND PROPELLER EFFICIENCY

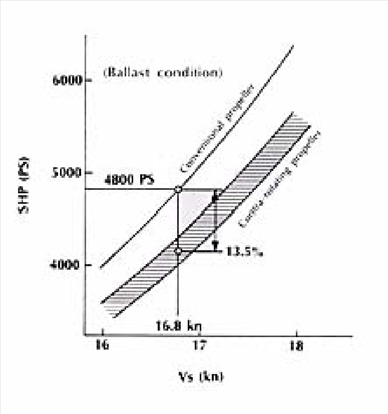
Improve System Efficiency: Contra-Rotating Propellers

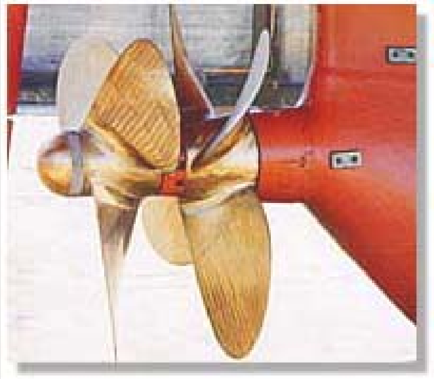
- Increased Efficiency
  - Recover Swirl Flow
  - 10 – 15% improvement
- Requires special bearings for inner shaft if using common shaft line
- Recent examples feature Pod for aft propeller



Anders Backlund and Jukka Kuuskoski, "The Contra Rotating Propeller (CRP) Concept with a Podded Drive"



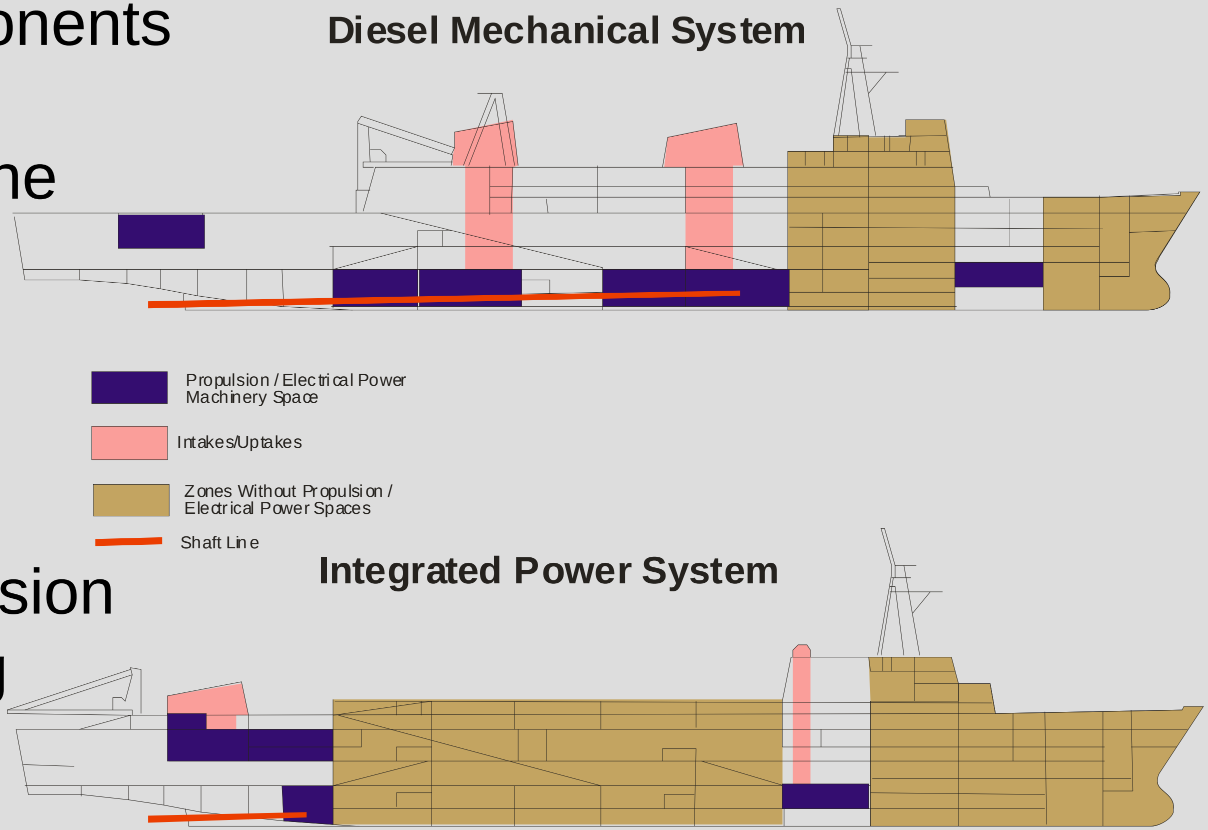




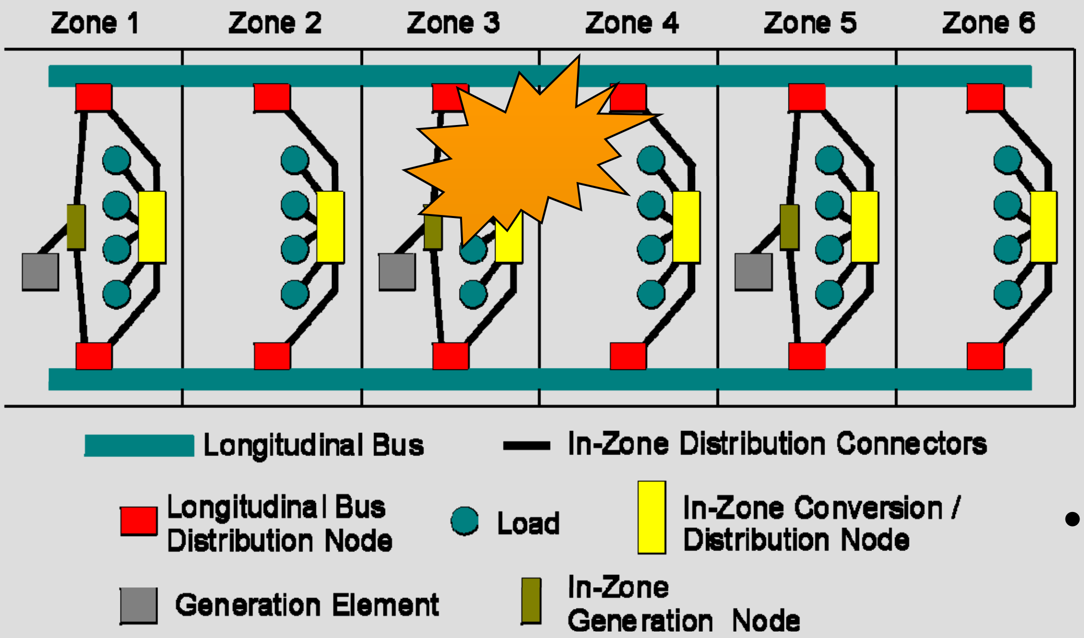
http://www.mhi.co.jp/ship/english/htm/crp01.htm

General Arrangements Flexibility Improve Ship Producibility

- Vertical Stacking of Propulsion Components
- Pods
- Athwart ship Engine Mounting
- Horizontal Engine Foundation
- Engines in Superstructure
- Distributed Propulsion
- Small Engineering Spaces



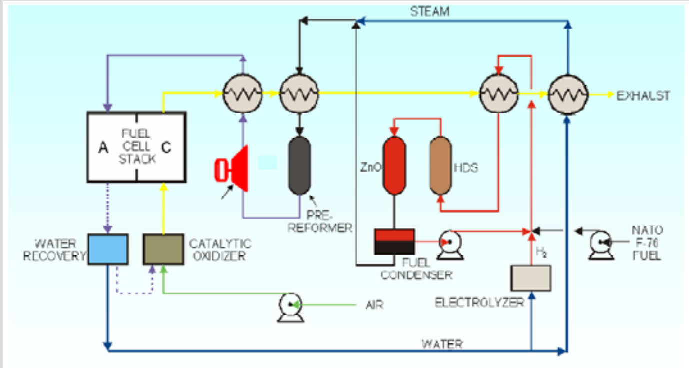
Support Zonal Survivability

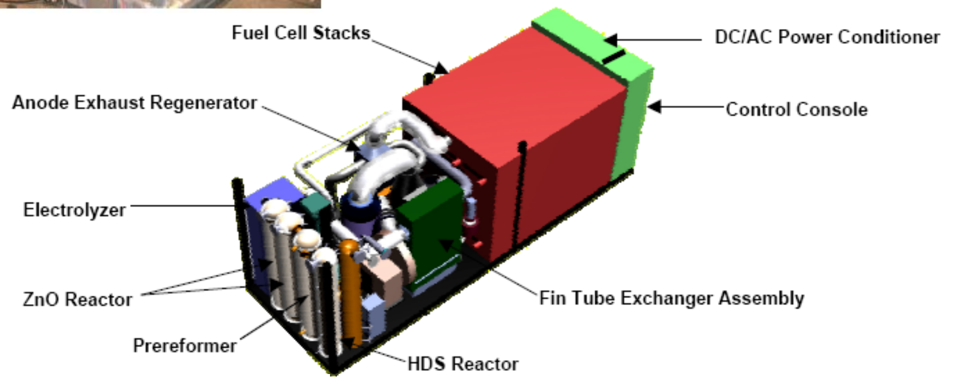


- Zonal Survivability is the ability of a distributed system, when experiencing internal faults, to ensure loads in undamaged zones do not experience a service interruption.
  - Sometimes applied to only Vital Loads.
  - Usually requires one longitudinal bus to survive damage.
- Limits damage propagation to the fewest number of zones.
  - Enables concentration of Damage Control / Recoverability Efforts.

Facilitate Fuel Cell Integration

- 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





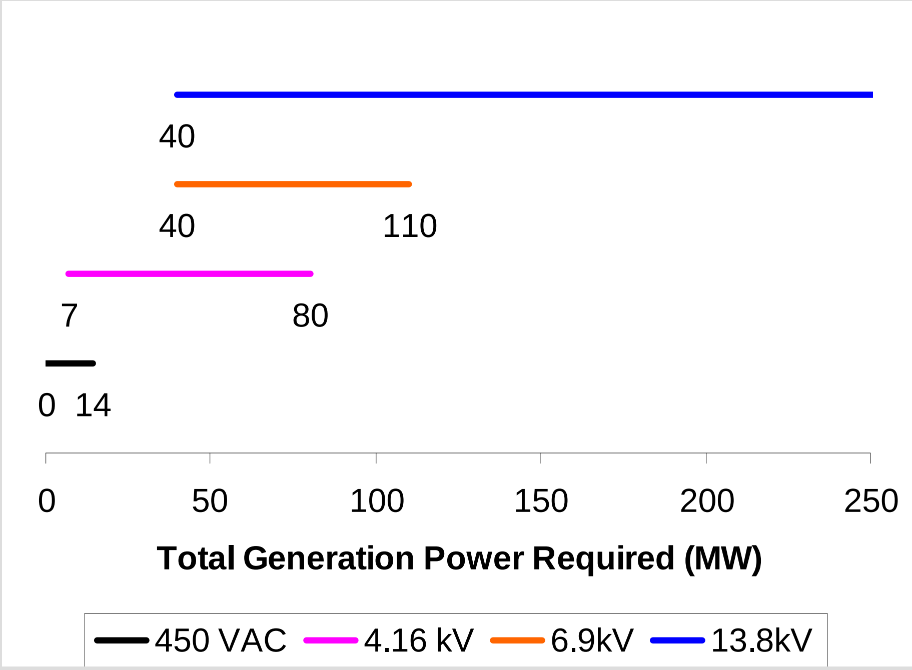
FuelCell Energy 625kW 450V, 3ϕ, 60 HZ, MC SSFC Power System

IPS Design Considerations

- Selection of High Voltage Bus Voltage
- Number and Type of Power Generation Modules
- Propulsion Motor Module Technology
- Propulsor Architecture
- AC or DC Zonal Electrical Distribution

Selection of High Voltage Bus Voltage

- Higher Voltages Desired
  - Circuit Breaker Rating
  - Reduced Cable Weight
  - Generator Reactance
- Lower Voltage Desired
  - Reduce risk for corona
  - Possible elimination of transformer for propulsion motor module
  - Insulation and Thermal design of Generator
- Shore Power
  - 450 V, 4.16 kV or 13.8 kV desired



Selecting the bus voltage is a compromise

Number and Type of Power Generation Modules

- Past studies have shown that 4 to 6 power generation modules generally provide the most cost effective solutions.
  - Typically have at least 2 larger "Main generators" and 2 smaller "auxiliary generators"
- Auxiliary Generators sized to be efficient between the minimum operating conditions (with 2 online) and the point where the main generators are efficient.
  - Often Diesel Generators
  - Should be self-starting
- Main Generators sized to provide maximum power requirements along with auxiliary generator sets
  - Often Gas Turbine Generators
  - An even number simplifies bus architecture
- May also need small emergency generators for dark-ship start

Propulsion Motors:

General Observations

- Propulsion Motors are typically custom designed for the application based on standard "Frame Sizes".
  - Frame size determines rotor diameter.
  - Variables are length and shaft speed.
- The Motor Drive has a large impact on both the Propulsion Motor and the High Voltage Distribution System.
  - Harmonics and Power Quality
  - Part Load Efficiency
  - Number of Motor Phases
  - Need for Propulsion Transformer
- Motor Designs have changed significantly in past 15 years to take advantage of new high voltage and current power electronics.
  - Permanent Magnet (PM) and Advanced Induction Motors (AIM) have largely displaced DC and Synchronous Motors for high power applications.
  - Homopolar Motors and Superconducting Motors are still being developed.

Motors: Basic Scaling Law

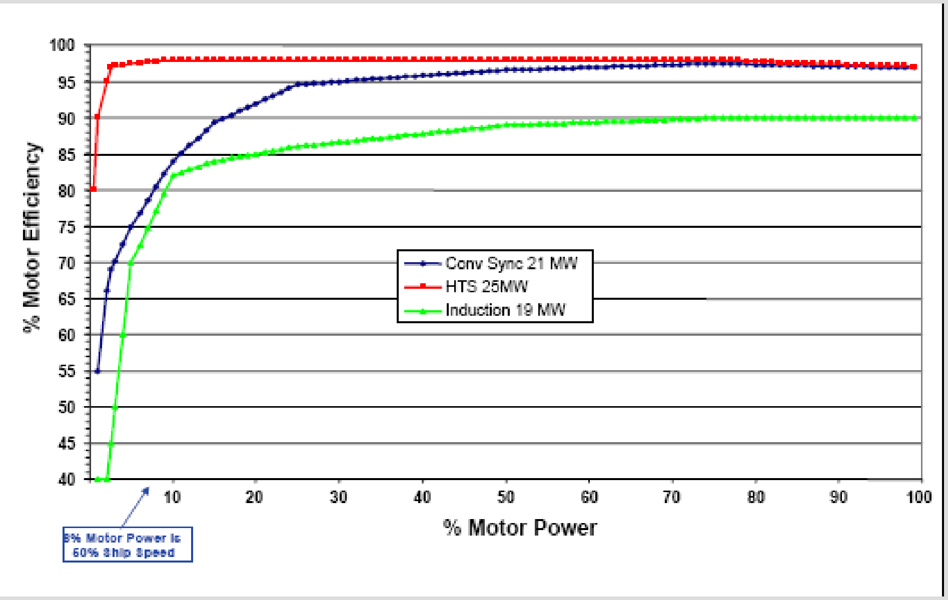
$$HP \propto D^2 \cdot L \cdot A \cdot B \cdot RPM$$

HP	**Power Rating**
D	**Rotor Diameter**
L	**Rotor Active Length**
A	**Surface Current Density (Conductor Material & Cooling Method)**
B	**Rotor Flux Density (Saturation of Magnetic Material)**
RPM	**Shaft Speed**

Propulsion Motor Thumb Rules

- For a given technology, cost is roughly proportional to Torque.
- Maximum Rotor Diameter is limited by shaft rake considerations, manufacturability, and transportability.
- Motor efficiencies at design power typically fall in range of 90-98%.
- Below about 15-35% rated power, the efficiency of a conventional motor drops rapidly.
  - Can be improved through advanced motor design and proper integration with motor drive

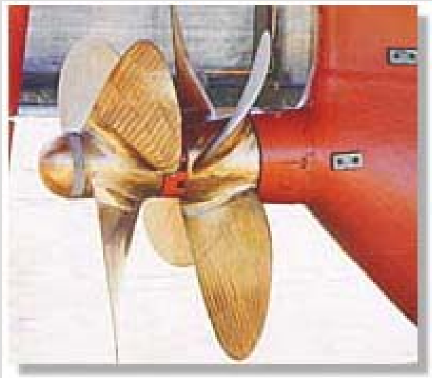
Representative Efficiency Curves

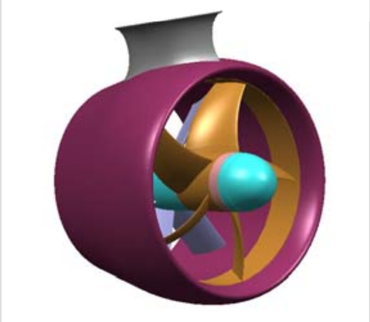


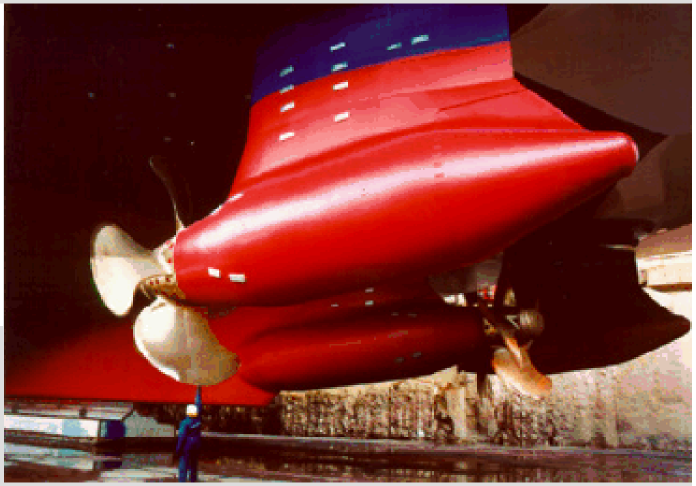
http://www.amsuper.com/products/library/HTS_efficiency_advantage.pdf

Propulsor Architecture

- Improve Efficiency
  - Fixed Pitch vs. CPP
  - Contra-rotating
  - Pods
  - Tandem Motors
- Maneuverability
  - Trainable Pods
  - Thrusters
- Survivability
  - Distributed Propulsion
- Support innovative Hull Design
  - SWATH
  - Multi-Hulls







AC or DC Zonal Electrical Distribution

- AC Zonal Electrical Distribution is preferred when
  - Power Quality of the high voltage bus is good enough such that ship service loads receive power meeting MIL-STD-1399 section 300A Interface standards.
    - Depends on Motor Drive Technology
    - Depends on Harmonic Filtering on high voltage bus
  - The number of un-interruptible loads is small.
- Otherwise, DC Zonal Electrical Distribution (or Integrated Fight Through Power – IFTP) is generally preferred

IPS Design Watch Items

- Part Load Efficiencies
- Dark-Ship Starts
- Shore Power
- Power Generation Module Start Time
- Component Reliability
- Common Mode Failure
- Transformer In-Rush Current

Conclusions

- The Integrated Power System provides the naval architect with many opportunities to optimize ship design.
  - It's important that the Naval Architect take advantage of these opportunities, otherwise a sub-optimized IPS ship design may not outperform an optimized conventional mechanical drive ship design.
- Improving the efficiency of prime movers and propulsors (along with drag reduction) can compensate for lower transmission efficiency of electric drive.