In-Zone Power Distribution for the Next Generation Integrated Power System

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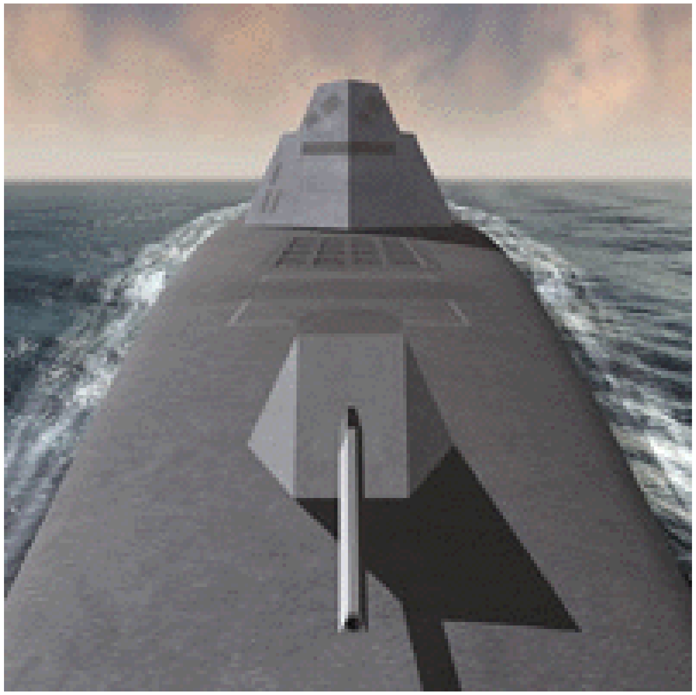
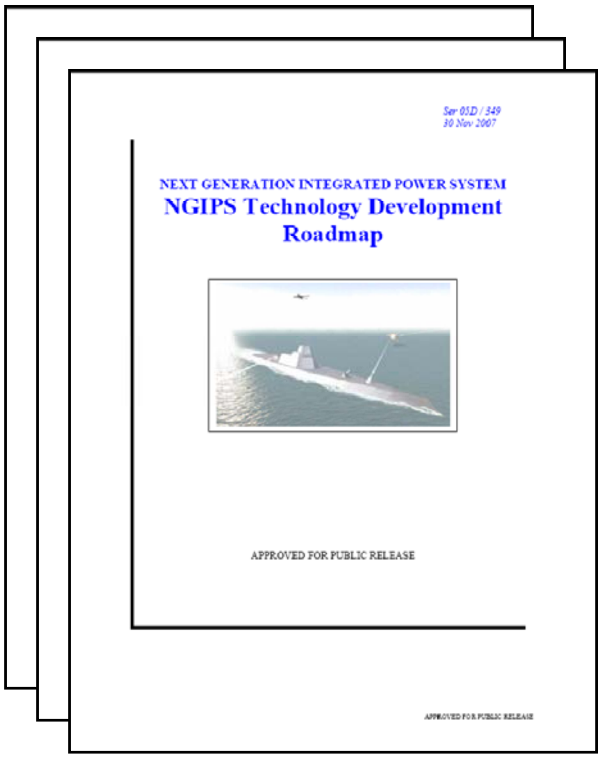
Agenda

- NGIPS Technology Development Roadmap
- Notional In-zone Power Distribution Architecture
- Survivability
- Quality of Service (QOS)
- Issues
  - Load Aggregation
  - Implementing QOS and Mission Priority Load Shedding
  - Power Control System Interface with Loads PCM Efficiency
  - Component Reliability
  - Maintainability
  - Galvanic Isolation / Grounding
  - Energy Storage
- Recommended Future Work



NGIPS Technology Development Roadmap

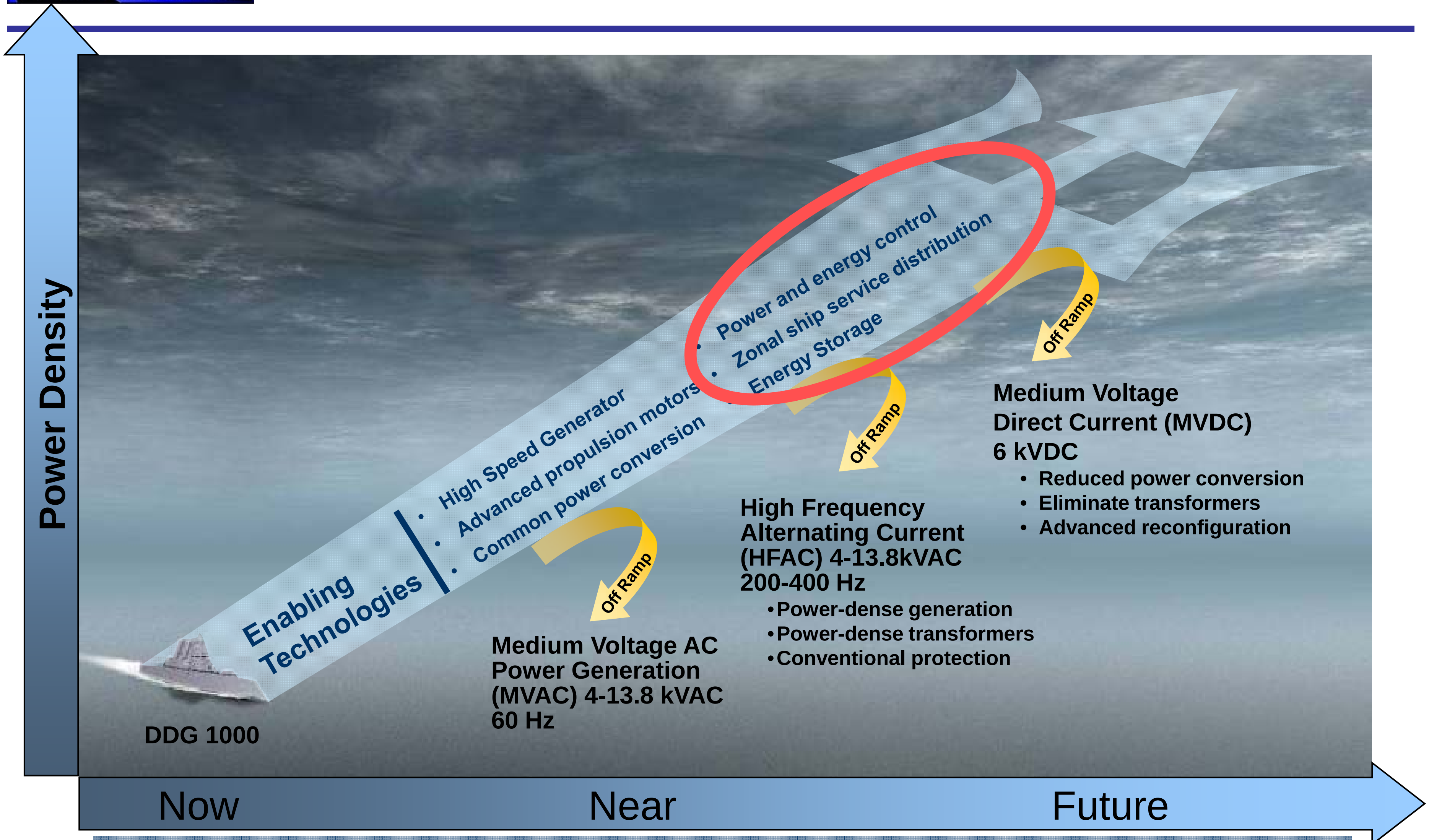
<u>Vision</u>: To produce affordable power solutions for future surface combatants, submarines, expeditionary warfare ships, combat logistic ships, maritime prepositioning force ships, and support vessels.



<u>The NGIPS enterprise approach will</u>:

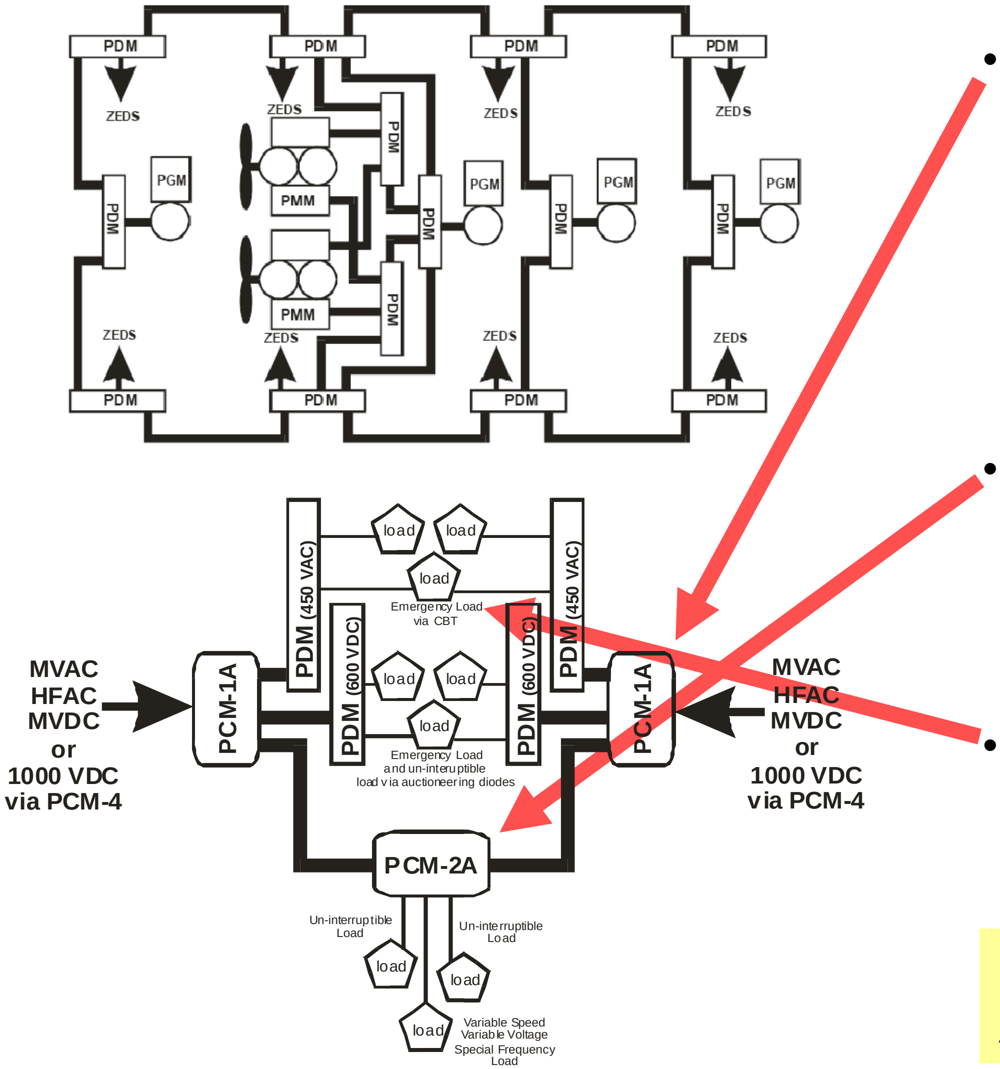
- Improve the power density and affordability of Navy power systems
- Deploy appropriate architectures, systems, and components as they are ready into ship acquisition programs
- Use common elements such as:
  - Zonal Electrical Distribution Systems (ZEDS)
  - Power conversion modules
  - Electric power control modules
- Implement an Open Architecture Business and Technical Model
- Acknowledge MVDC power generation with ZEDS as the Navy's primary challenge for future combatants

NGIPS Technology Development Roadmap



"Directing the Future of Ship's Power"

Notional In-Zone Architecture



- PCM-1A
  - Protect the longitudinal bus from in-zone faults
  - Convert the power from the longitudinal bus to a voltage and frequency that PCM-2A can use
  - Provide loads with the type of power they need with the requisite survivability and quality of service
- PCM-2A
  - Provide loads with the type of power they need with the requisite survivability and quality of service
  - IPNC (MIL-PRF-32272) can serve as a model
- Controllable Bus Transfer (CBT)
  - Provide two paths of power to loads that require compartment level survivability

Location of Energy Storage within Architecture still an open issue

Survivability

As applied to Distributed Systems

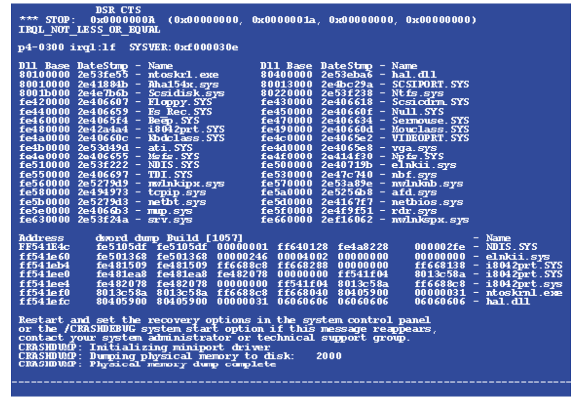
- Zonal Survivability
  - Zonal Survivability is the ability of the distributed system, when experiencing internal faults due to damage or equipment failure confined to adjacent zones, to ensure loads in undamaged zones do not experience an interruption in service or commodity parameters outside of normal parameters
    - Sometimes only applied to "Vital Loads"

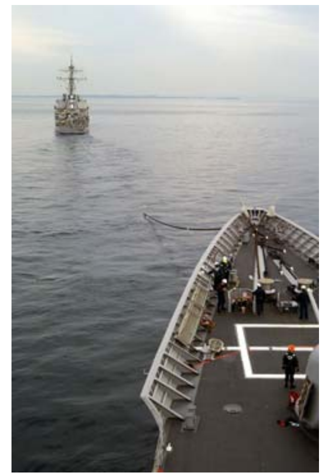
- Compartment Survivability
  - Even though a zone is damaged, some important loads within the damaged zone may survive. For critical non-redundant mission system equipment and loads supporting in-zone damage control efforts, an increase level of survivability beyond zonal survivability is warranted.
  - For these loads, two sources of power should be provided, such that if the load is expected to survive, at least one of the sources of power should also be expected to survive.

SURVIVABILITY DEALS WITH PREVENTING FAULT PROPOGATION AND WITH RESTORATION OF SERVICE UNDER DAMAGE CONDITIONS

Quality of Service

- Quality of Service is a metric of how reliable a distributed system provides its commodity (electricity) to the standards required by its users (loads).
- A failure is any interruption in service, or commodity parameters outside of normal parameters, that results in the load not being capable of performing its function.
  - Interruptions in service shorter than a specified amount for a given load are NOT a failure for QOS calculations.
- For NGIPS, Three time horizons …
  - Uninteruptible loads
    - Interruptions of time t1 – on the order of 2 seconds – are NOT tolerable
  - Short-term interruptible loads
    - Interruptions of time t1 – on the order of 2 seconds – are tolerable
    - Corresponding to fault detection and isolation
  - Long-term interruptible loads
    - Interruptions of time t2 – on the order of 2-5 minutes – are tolerable
    - Corresponding to time for bringing additional power generation on line.





QUALITY OF SERVICE DEALS WITH ENSURING LOADS RECEIVE A RELIABLE SOURCE OF POWER UNDER NORMAL OPERATING CONDITIONS

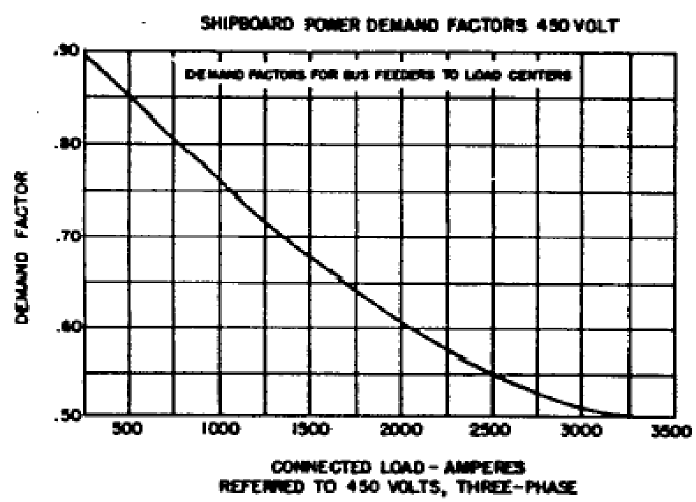
Issues

- Load Aggregation
- Implementing QOS and Mission Priority Load Shedding
- Power Control System Interface with Loads
- PCM Efficiency
- Component Reliability
- Maintainability
- Galvanic Isolation / Grounding
- Energy Storage

Load Aggregation

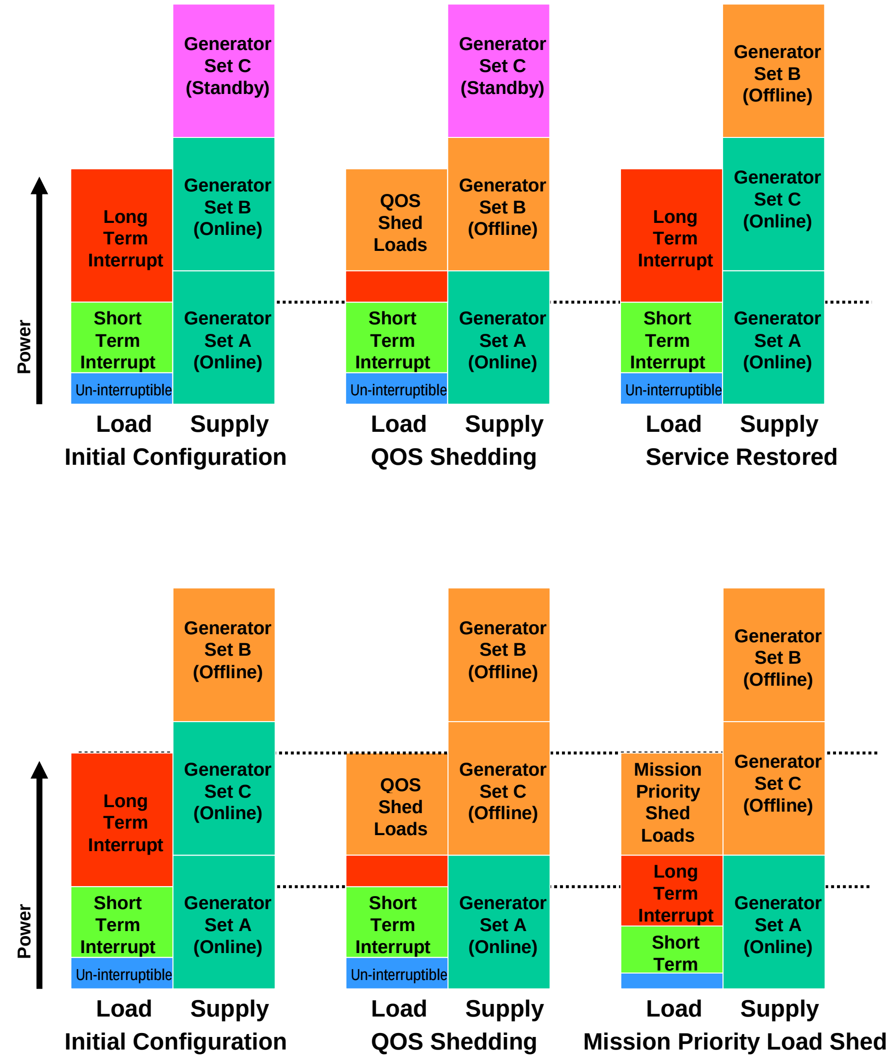
- Load Aggregation is needed to size power electronics and power distribution system elements.
- Traditional Methods assume a large number of relatively small loads – Law of Large Numbers
    - Load Factors
    - Demand Factors
- The relatively small number of loads of a given QOS level within a zonal system violates the Law of Large Numbers assumption.
    - Calls for stochastic approaches.
    - See Amy, John, "Modern, High-Converter-Populations Argue for Changing How to Design Naval Electric Power Systems," presented at IEEE Electric Ship Technologies Symposium, July 25-27, 2005, Philadelphia, PA.
    - Stochastic methods require a well defined machinery system Concept of Operations (CONOPS).

Load Type	***Load Factor***
Electronics	1.0
Lighting	0.4 – 1.0
Receptacles	.1
Ventilation	.9
Continuous Pumps	.9
Cycling Pumps	.1 to .2
Equipment that is off	0



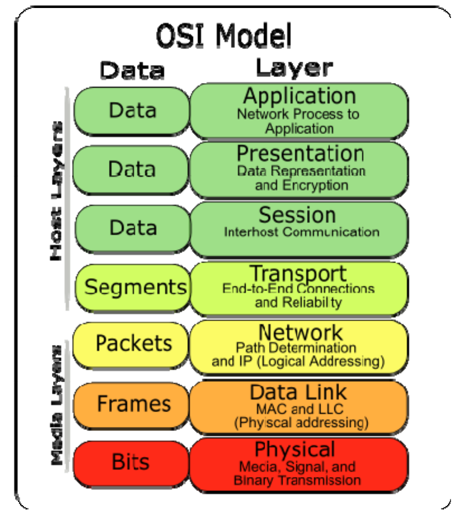
Implementing QOS and Mission Priority Load Shedding

- Two different prioritization of loads
  - Quality of Service
    - Short term source – load imbalance
  - Mission Priority
    - Long term source – load imbalance
- Must be able to control small groups or individual loads
  - Controllable switches / breakers in power-panels / switchgear / PCM
  - Power Control (PCON) control interface with loads



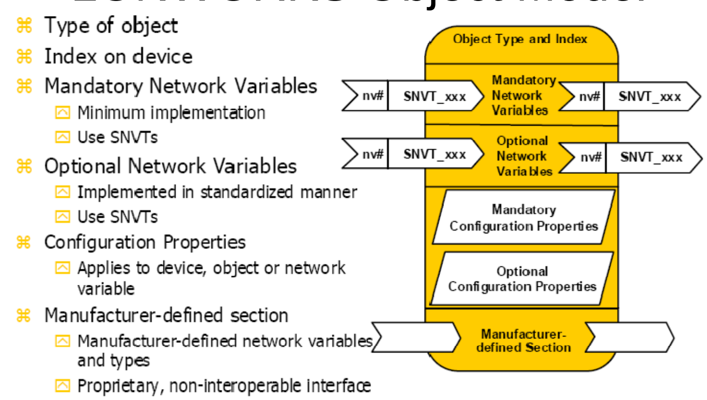
Power Control System Interface with Loads

- PCON interface with loads facilitates adaptive (QOS and Mission Priority) load shedding
- Must Specify all layers of the OSI Model.
  - Appropriate Standards exist for all but the Application Layer.
  - LONWORKS (ANSI/EIA 709.1 Control Networking Standard) could be a model for the Application Layer.
  - Using power cables for the Media Layers can reduce costs by eliminated dedicated signal cables.
    - ANSI/EIA 709.2-A-2000 Control Network Powerline (PL) Channel Specification
    - IEEE P1901 Draft Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications



http://www.3mfuture.com/network_security/arp-guard-arp-spoofing.htm

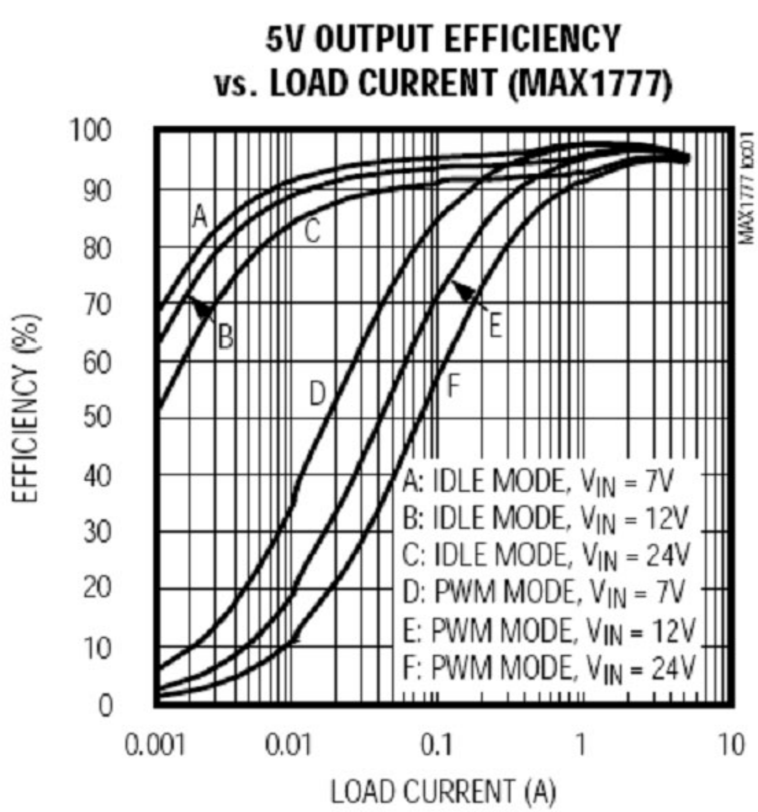
LONWORKS Object Model



Echelon 1999

PCM Efficiency

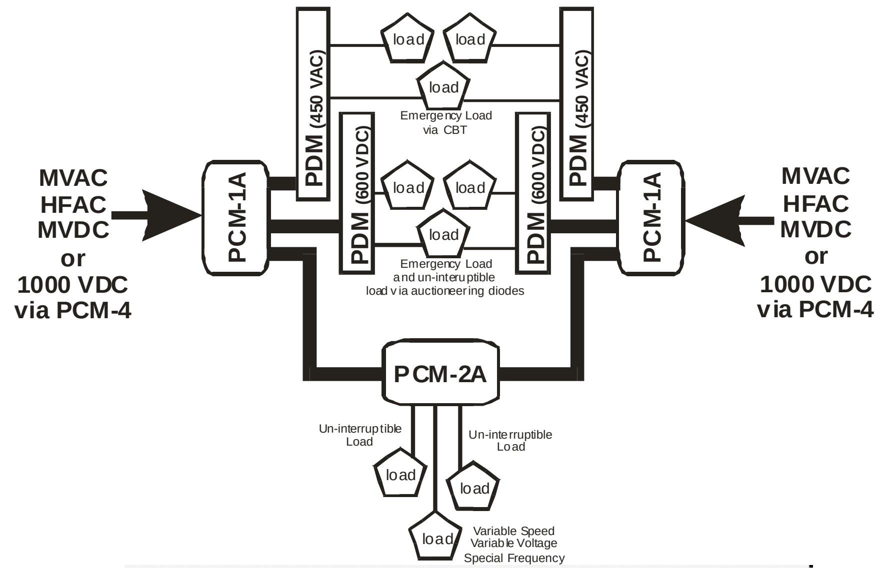
- Improving the efficiency of the input and output modules of PCM 2A and PCM 1A is important to reducing demands on the ships Heating Ventilation and Air Conditioning (HVAC) System and equipment cooling systems.
- It's important to consider part load efficiency as well as full load efficiency.
- The efficiency and reliability of the total thermal management system should be considered.
  - Air Cooling vs Chill Water Cooling
  - System Startup

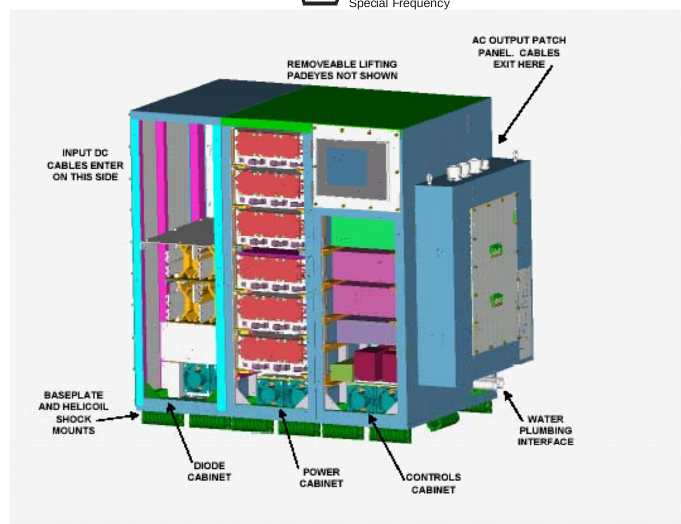


http://powerelectronics.com/spotlight/power_primer/PP-switch-mode-ps-2-Figure03.jpg

Component Reliability

- Affordably achieving Quality of Service depends on reliability of the in-zone power systems equipment.
  - Components that have a reliability much less than 30,000 hours MTBF should be provided with N+1 redundancy
  - Redundancy is likely not needed for components with a MTBF of about 30,000 hours and a short Mean Time to Repair (MTTR) and a short Mean Logistics Delay Time.
  - The ability to hot swap modules can reduce MTTR.
- Output modules of PCM 2A and potentially PCM 1A can directly provide power to loads.
  - 30,000+ hours MTBF desirable
  - Hot swap modules desirable



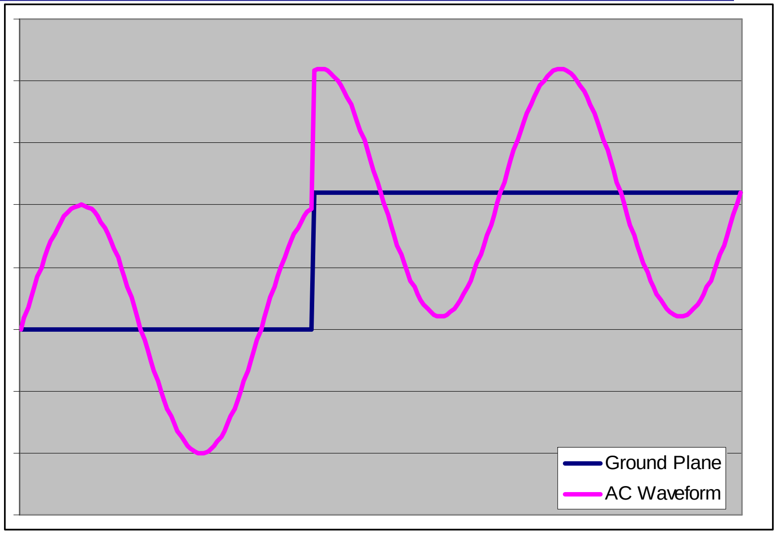


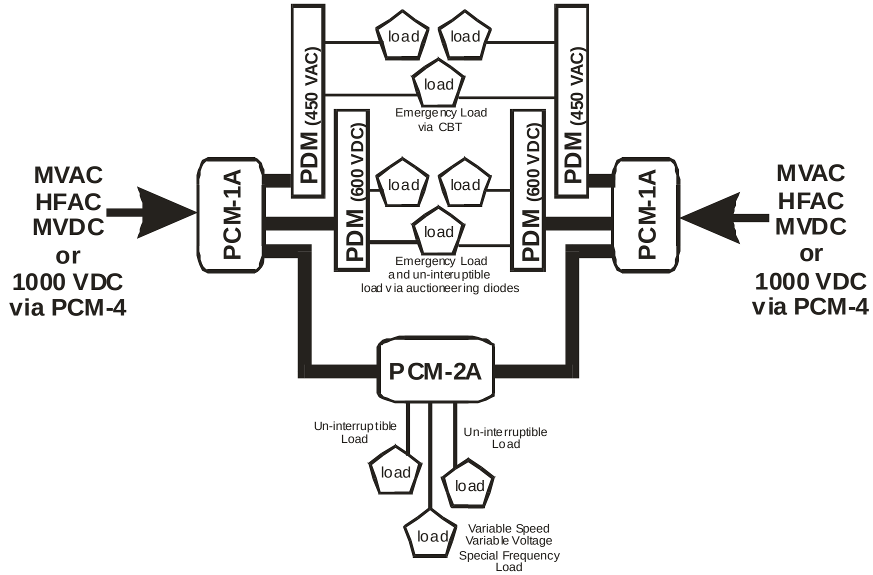
Maintainability

- Integrate equipment tag-out procedures into Power Control System (PCON), Power Distribution, PCM-1A and PCM-2A.
- Provide hot-swappable input and output modules in PCM-2A to minimize the number of loads impacted by maintenance action on the PCM-2A. (and possibly PCM-1A too)
- Minimize scheduled maintenance on NGIPS modules – especially those that are non-redundant in the power system.
- Integrate Condition Based Maintenance into
  - Power Control System (PCON)
  - Control interface for NGIPS modules
  - Power Control System – Load control interface.

Galvanic Isolation / Grounding

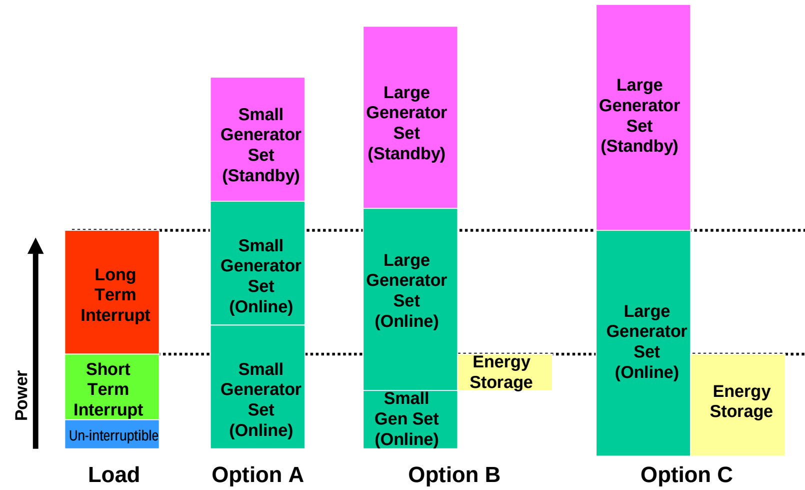
- Should PCM-1A provide galvanic isolation between the Medium Voltage (MV) Bus and the In-Zone Distribution?
- PCM-1A WITH GALVANIC ISOLATION
  - Prevents Voltage Offsets from ground faults on MV bus from propagating into the In-Zone Distribution
  - Weight of isolation transformers can be reduced by using high-frequency transformers.
- PCM-1A WITHOUT GALVANIC ISOLATION
  - Potentially lighter, smaller, and cheaper.
  - May require fast removal of ground faults on the MV Bus to prevent insulation system failure in the In-Zone Distribution.

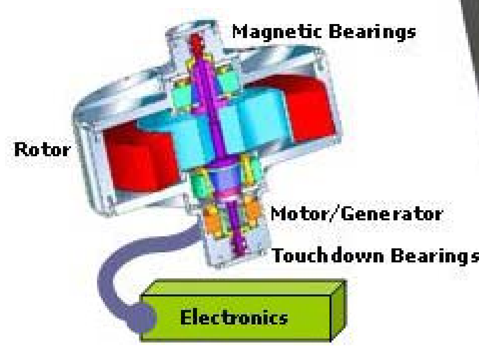




Energy Storage

- Many Potential Uses for Energy Storage
  - Reduce rolling-reserve requirements by providing short-term hold-up of loads while a generator is being brought online.
    - Could be important for pulse power loads
  - Holding up a bus while long-term interrupt loads are shed in an orderly manner.
  - Providing startup power to generator sets in a "dark ship" start.
  - Provide pulse power to loads.
  - Level loading to delay bringing on an additional generator.





SAFT DAUPHIN Module
E: > 9 kWh
U average: 3.5V
Mass: 120 kg
Volume: 60 liters
Li-Ion

Recommended Future Work

- Update MIL-PRF-32272 (IPNC) to fully define PCM-2A. Incorporate "switching modules"
- Develop a Performance Specification for PCM-1A.
- Produce an in-zone electrical distribution system design and criteria handbook.
- Develop a control system interface between the power system and loads.
- Determine the viability of producing affordable militarized hybrid breakers capable of detecting and isolating faults and coordinating with other breakers in less than .5 ms.
- Conduct tests to determine if ANSI/EIA 709.2-A-2000 Control Network Powerline (PL) Channel Specification is suitable for shipboard applications. Produce an application guide for applying ANSI/EIA 709.2-A-2000 to shipboard applications.
- Develop an open interface in PCM-1A and PCM-2A for integrating control system hardware such as Programmable Logic Controllers, Control Network Switches and Routers, and control system processors.
- Conduct a study to determine the best approach to implementing the PCON software. Produce an application guide for producing the PCON software for a given ship application
- Determine if upon a deficiency of power generation capacity, loads can be shed fast enough to ensure stable operation. If not, propose design rules for sizing and integrating energy storage to ensure stability.
- Develop and document a method for aggregating loads for sizing power distribution equipment
- Develop and document a method for characterizing and estimating loads during early stage design to support distribution equipment sizing, design for QOS, and design for Survivability.
- Determine the reliability of the Input and Output Power Modules of the IPNC. If not greater than 30,000 hours, identify opportunities to improve the reliability.
- Improve the efficiency of the input and output power modules of the IPNC.
- Coordinate with the HVAC community to ensure future advancements in HVAC technology are consistent with NGIPS design implementations.