The Road to MVDC

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Setting the Scene

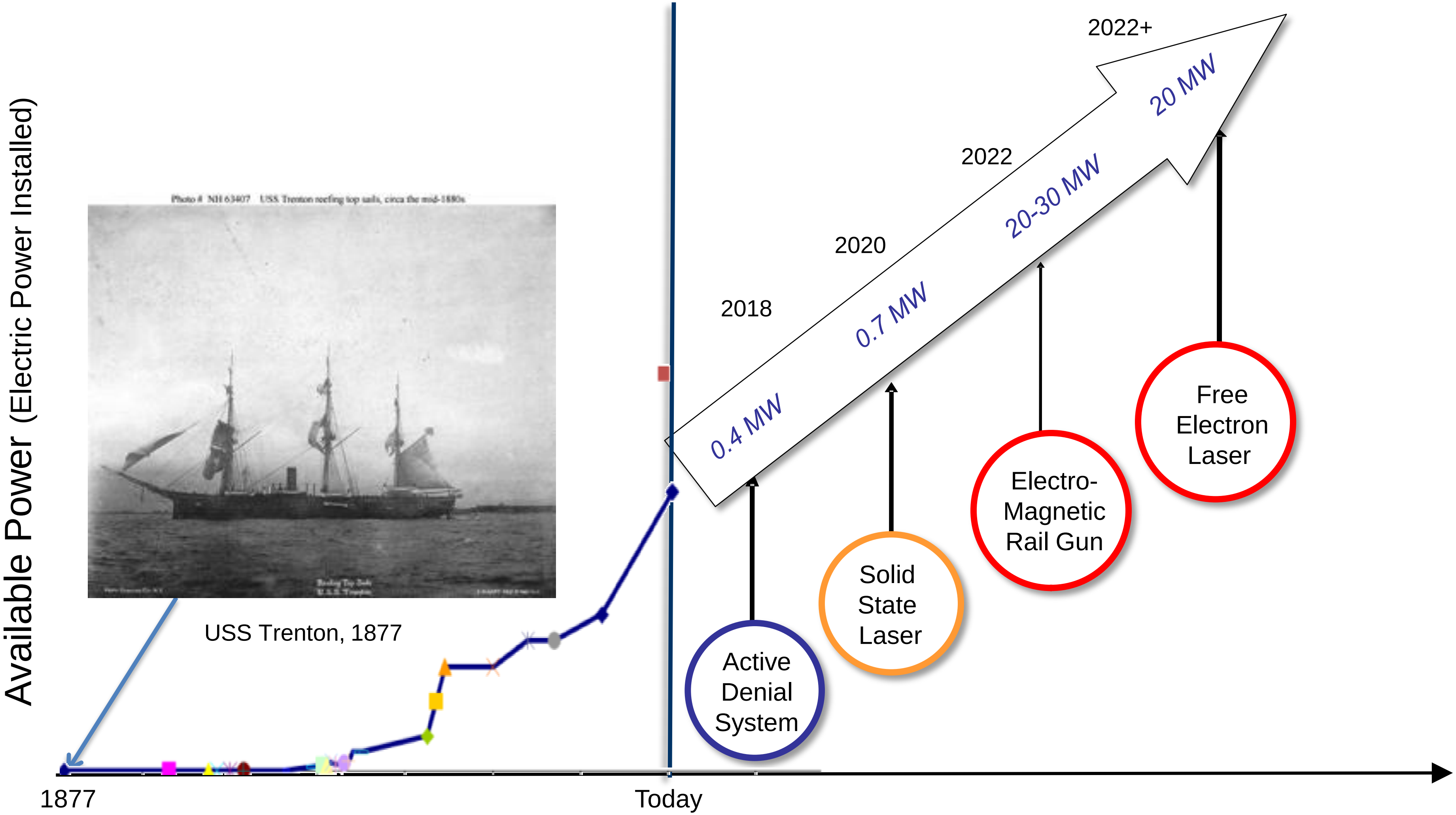
"In FY2030, the DON plans to start building an affordable follow-on, multi-mission, mid-sized future surface combatant to replace the Flight IIA DDG 51s that will begin reaching their ESLs [Estimated Service Life] in FY2040."

Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for FY2015

Big differences from DDG 51:
- High-energy weapons and sensors
- Flexibility for affordable capability updates

Photo by CAPT Robert Lang, USN (Ret), from site http://www.public.navy.mil/surfor/swmag/Pages/2014-SNA-Photo-Contest-Winners.aspx

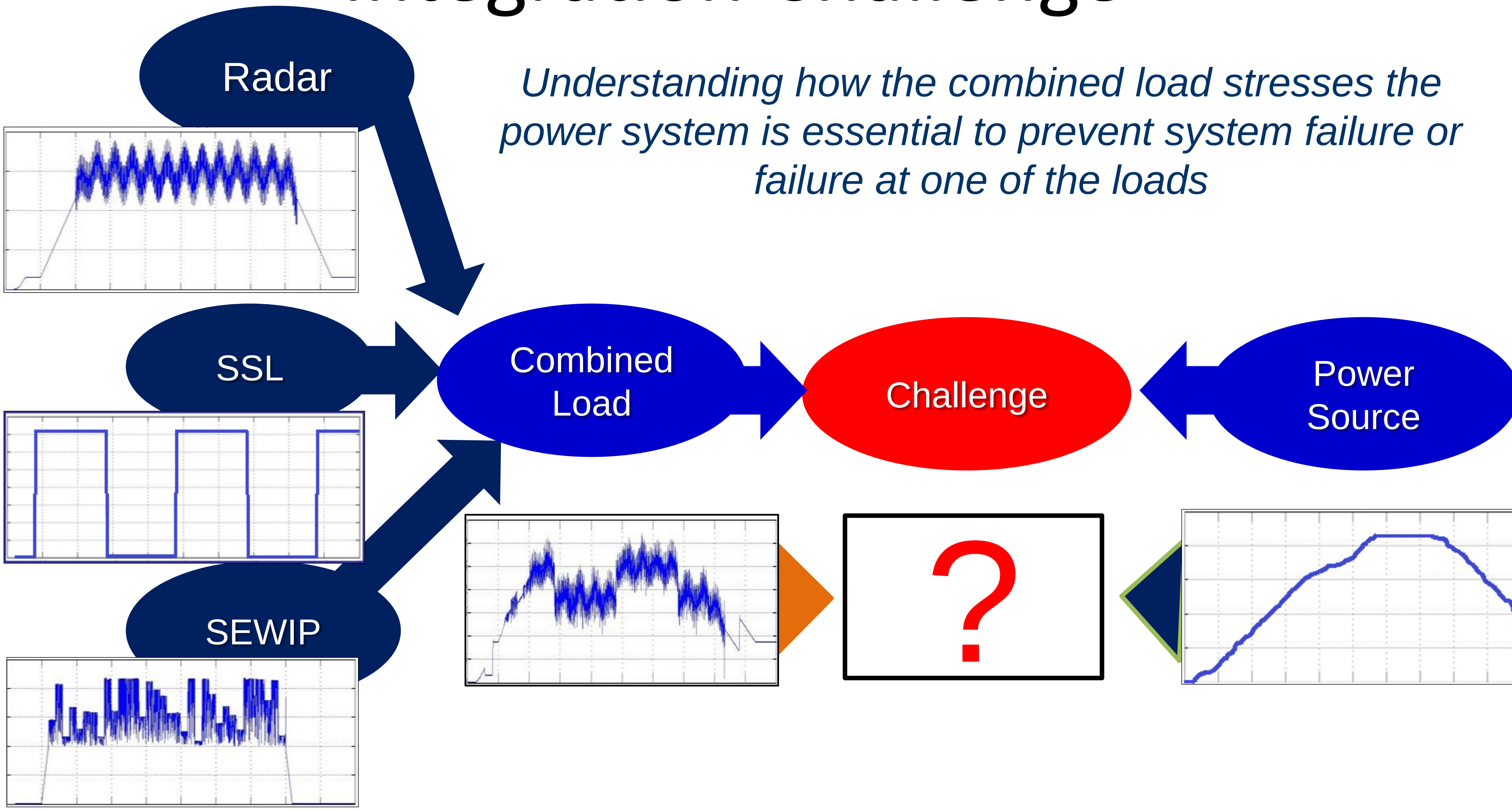
Increasing Electrical Power Demands



Sensor and Weapon System Power demands will soon rival Propulsion Power demands

High Energy Mission Systems Integration Challenge

Understanding how the combined load stresses the power system is essential to prevent system failure or failure at one of the loads

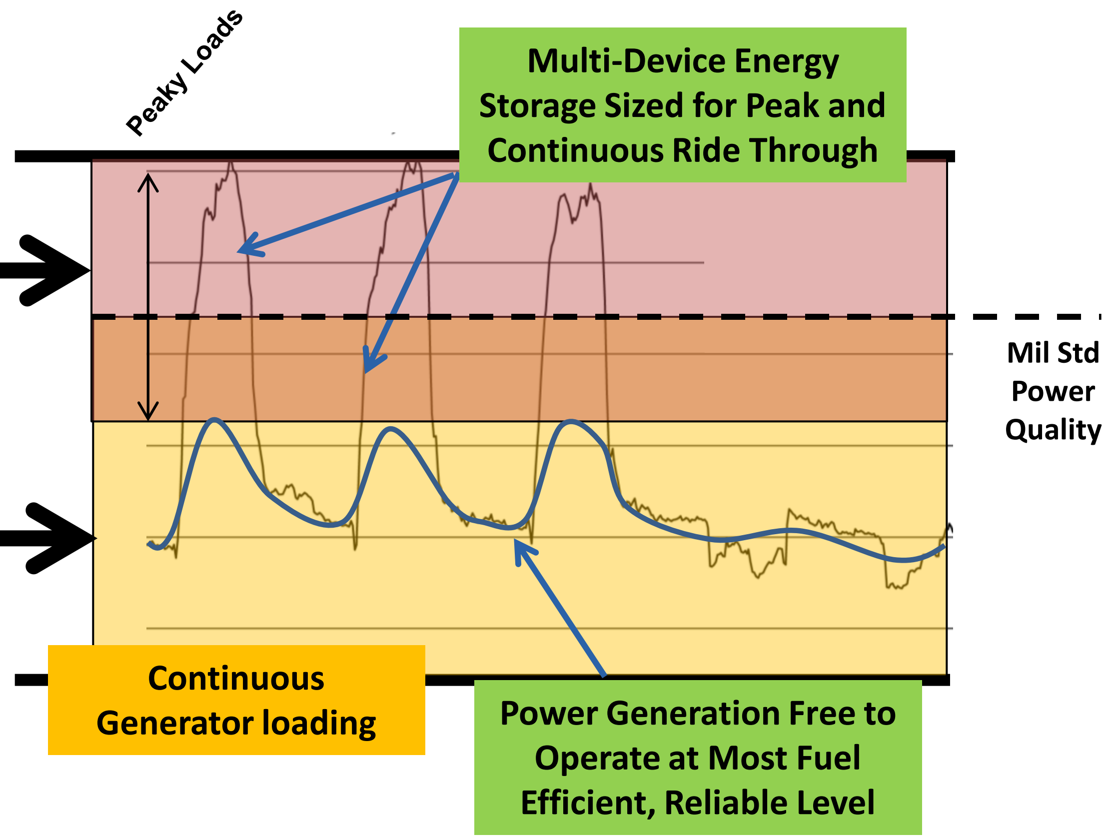


Ships cannot support High Power Systems without modifications to the ships Electric Power System and other ship systems

Future Operational Mode

Adv. Energy Storage

Generator



Load Profile

Optimize storage buffering prime movers to enable continuous DEW operations with minimal effect on engine mechanicals and power quality…

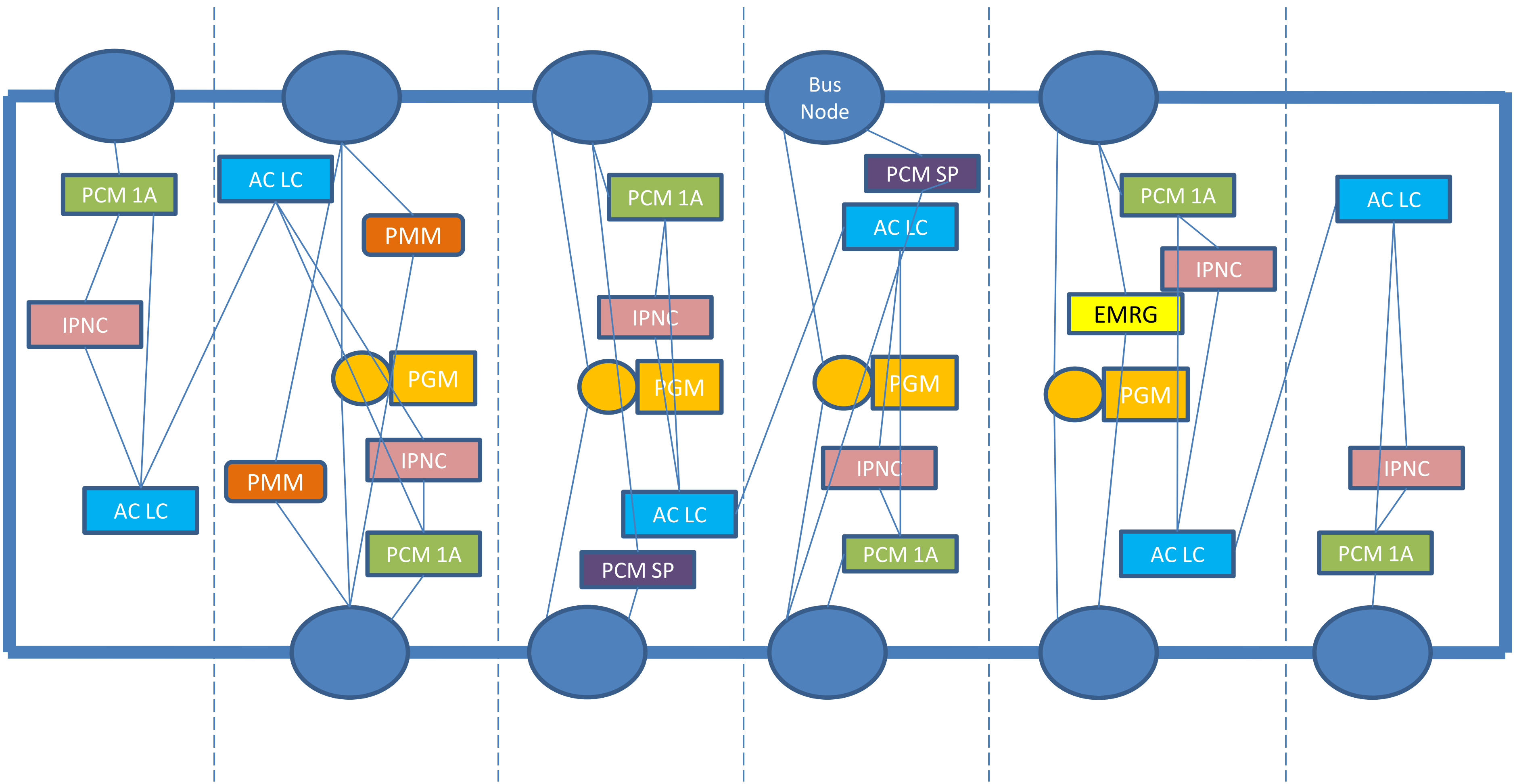
Why Medium Voltage DC?

- Decouple prime mover speed from power quality
  - Minimize energy storage
- Power conversion can operate at high frequency – Improve power density
- Potentially less aggregate power electronics
  - Share rectification stages
- Cable ampacity does not depend on power factor or skin effect
- Power Electronics can control fault currents
  - Use disconnects instead of circuit breakers
- Acoustic Signature improvements
- Easier and faster paralleling of generators
  - May reduce energy storage requirements
- Ability to use high speed power turbines on gas turbines

Affordably meet electrical power demands of future destroyer

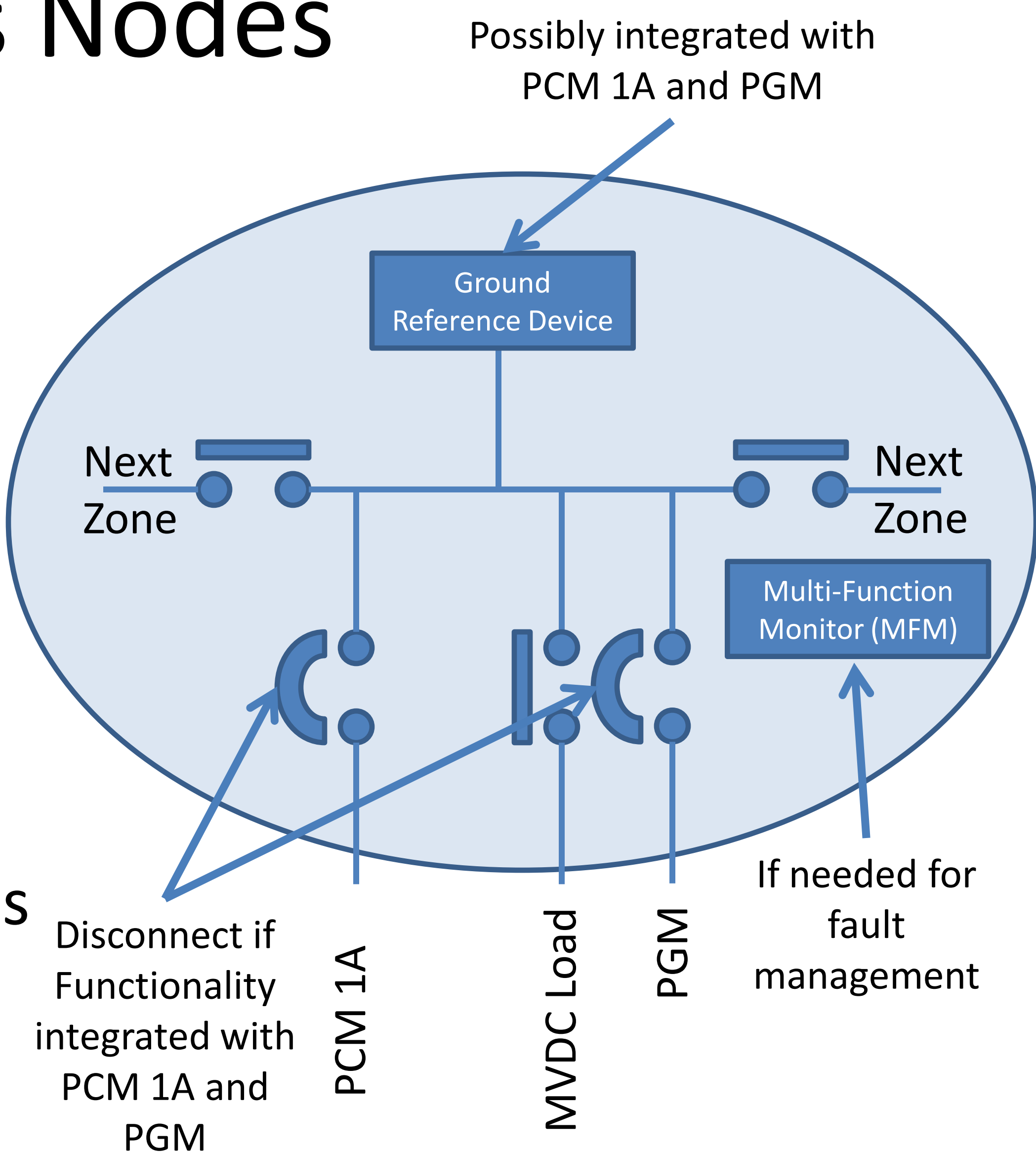
An AC Integrated Power System would likely require future destroyer to displace greater than 10,000 mt

Candidate MVDC Reference Architecture

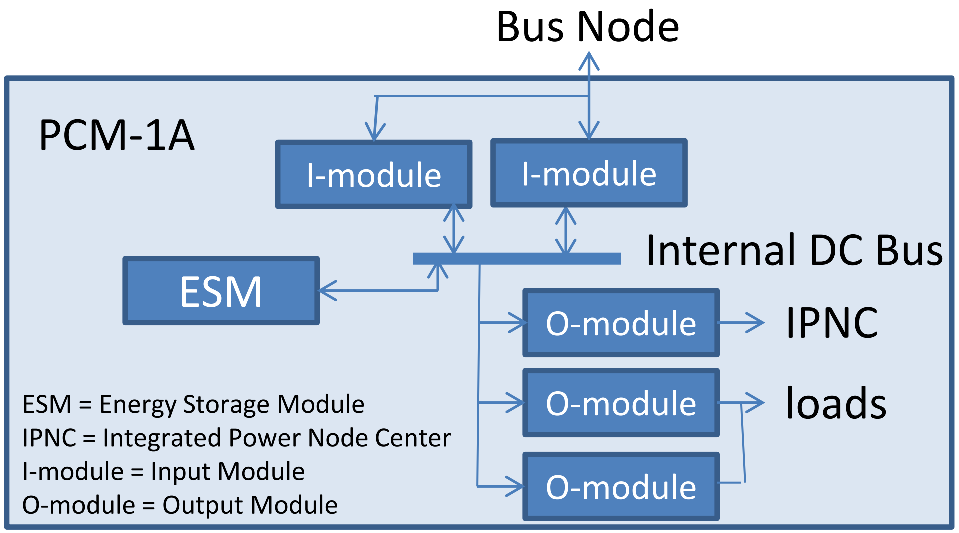


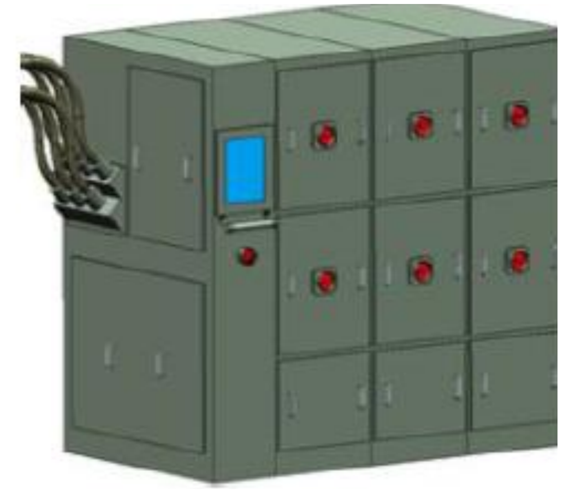
Bus Nodes

- Segment MVDC Bus
  - Disconnects
- Isolate loads
  - Disconnects
- Isolate sources
  - Breaker
  - Disconnect if Breaker functionality in source
- Establishes Ground Reference for MVDC Bus
  - If functionality not provided in source



PCM-1A

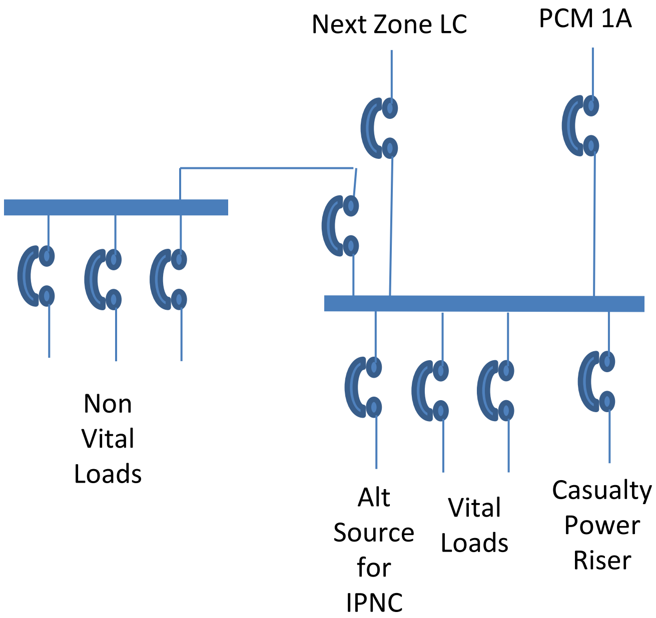




- Protects the MVDC bus from in-zone faults
- Provides hold up power while clearing faults on the MVDC Bus
- If desired, provides hold up power while standby generator starts
- If desired, contributes to energy storage for pulse power loads
- Provides conditioned power to loads
- Provides power to loads up to several MW (Lasers, Radars, Electronic Warfare)
- Provides power to “down-stream” power conversion (IPNC)
- Near term applications could use I-modules with AC inputs in “Energy Magazine” configuration

Load Centers

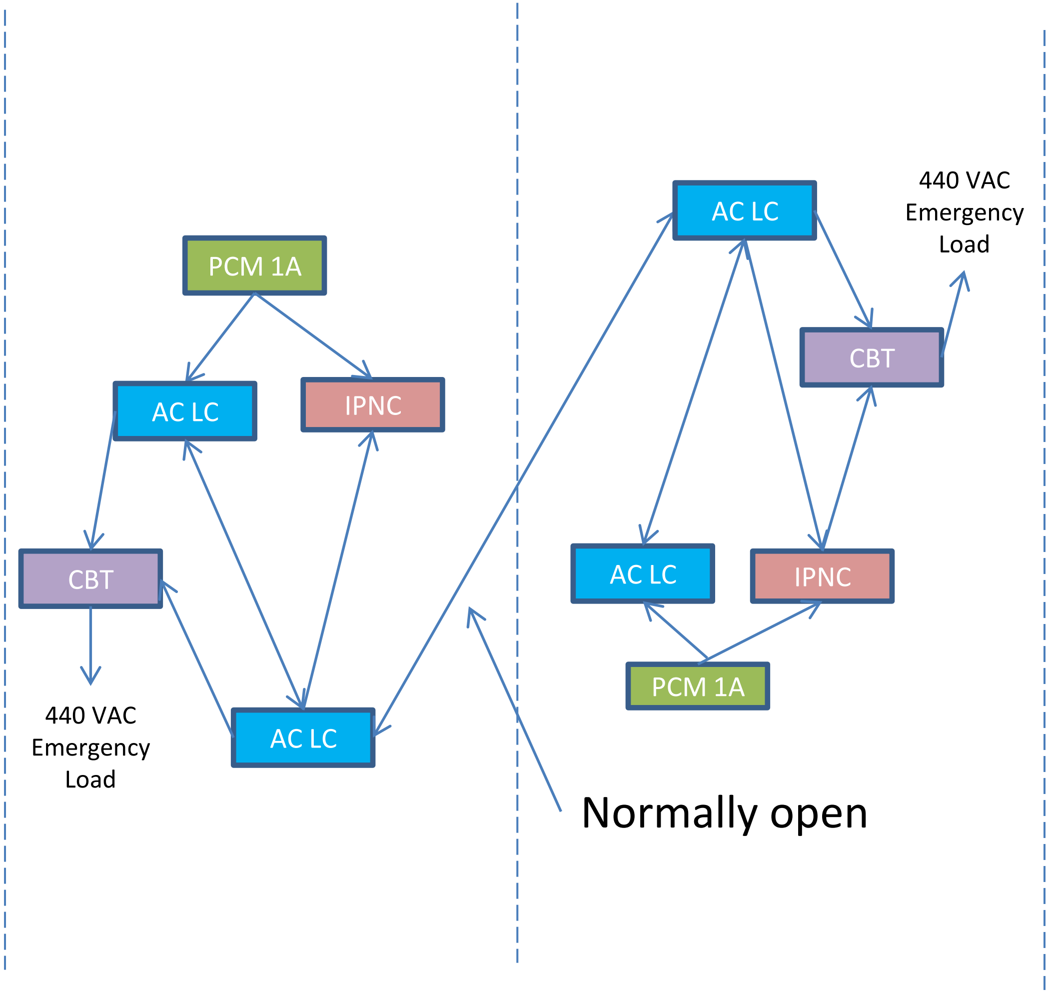
- Traditional 450 VAC switchgear
  - May need modification for limited fault current
- Normally powered by PCM 1A.
  - Breaker to next zone Load Center (LC) normally open
- Upon loss of PCM 1A
  - Machinery Control System switch source to the next zone's LC
  - May require load shedding
  - Provide alternate source to IPNC for uninterruptible loads
- Casualty Power Riser
  - Enables interconnection of LC to jumper over damaged zones.
  - Possibly use 450 VAC shore power connectors



U.S. Navy: 120110-N-DR144-521

Compartment Level Survivability

- May employ more than 1 AC Load Center (AC LC) in a zone
  - Physically separated to minimize probability that multiple LC are lost at same time due to battle damage
  - Careful routing of feeder cables required to maximize survivability
- Provide multiple methods of routing power from in-zone PCM 1A and adjacent zone PCM 1A
  - Use Controllable Bus Transfer (CBT) for Emergency Loads not physically near an AC LC (or if powered by an IPNC, not physically near the IPNC)
- Normally only power loads in a zone from the in-zone PCM 1A.

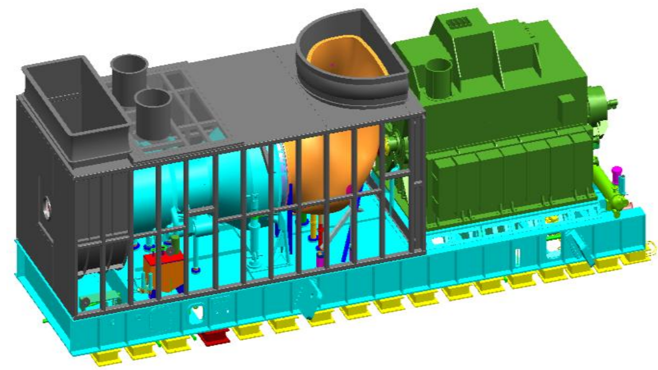


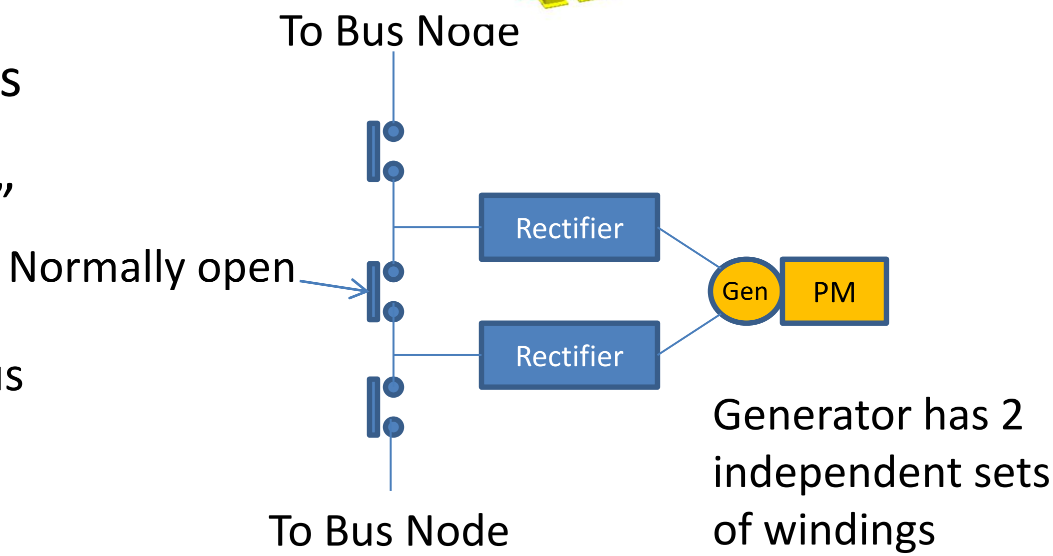
Integrated Power Node Center (IPNC)

- Update MIL-PRF-32272
  - Include 1000 VDC input modules
  - Include provision for energy storage for ~1 second
    - allow 450 VAC LCs in zone and in adjacent zone to reconfigure.
- Zone may have multiple IPNCs
- Supply
  - Un-interruptible loads
  - Supply loads with special power needs.
    - 400 Hz.
    - VSD motor loads
    - Perhaps Low voltage DC Loads

Power Generation Modules

- IEEE 1826 “Overlay Zone”
- Split Windings
  - Reduced Impact on prime mover due to fault on one MVDC bus
  - Simplifies “odd number of generators” dilemma
    - May enable reducing ampacity of MVDC bus
- Consider Fuel Cells in the future

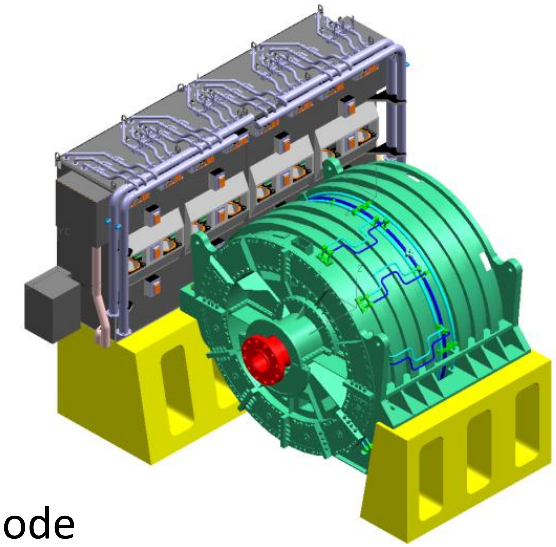


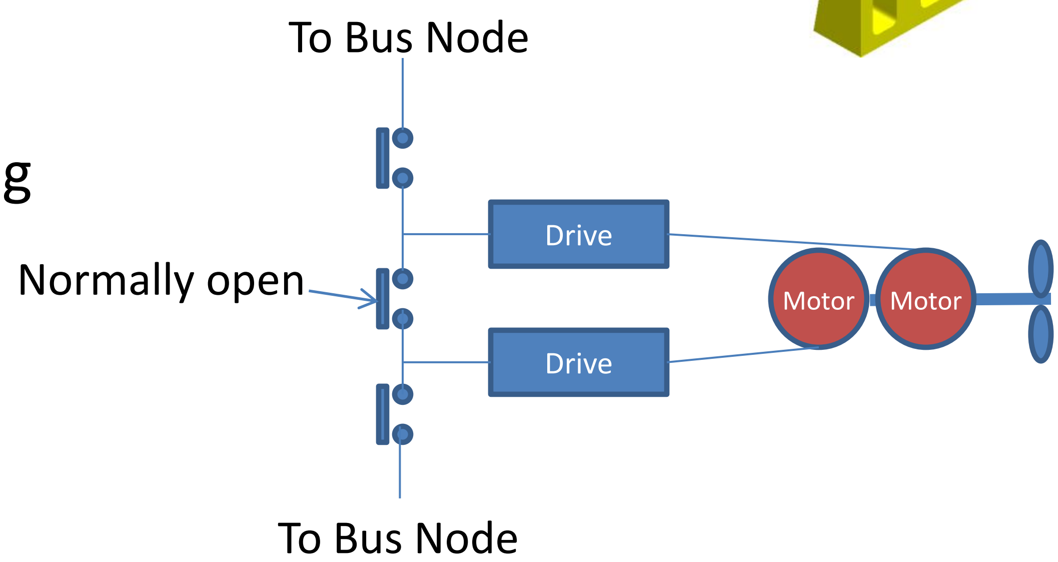


PGM may include circuit breaker functionality and ground reference device functionality

Propulsion Motor Modules

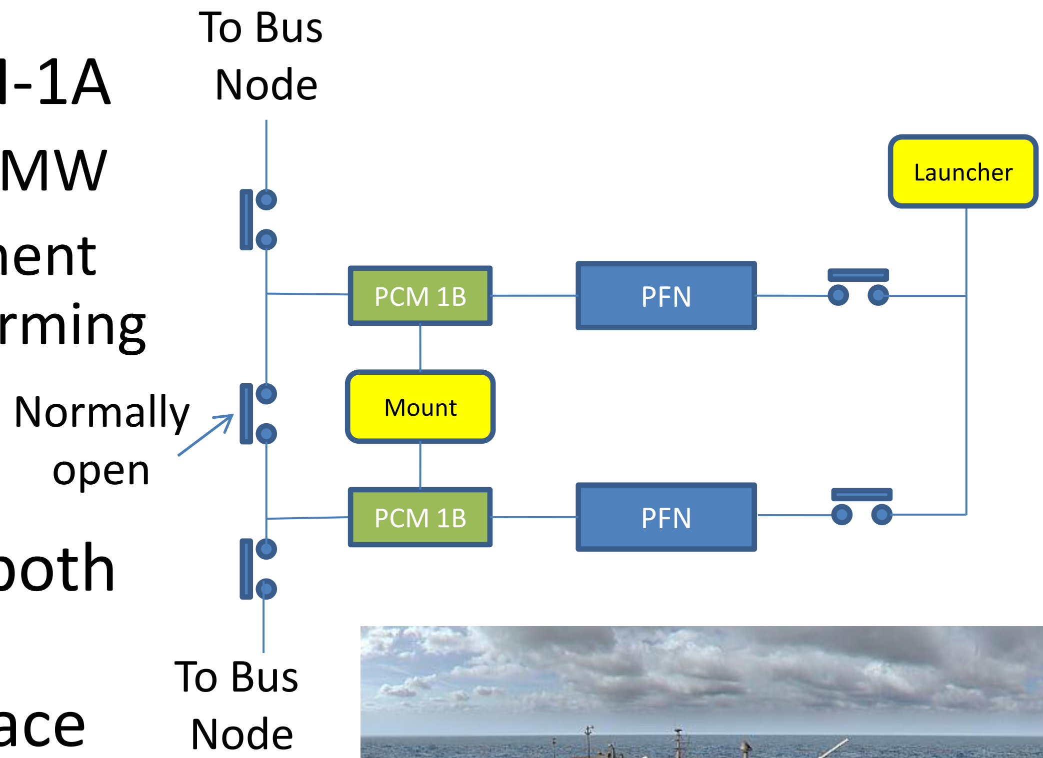
- Typically two motors for reliability
  - May share housing
- Normally powered by both MVDC busses
- Requires control interface for load management
- Consider contra-rotating propellers for fuel efficiency and minimizing installed electrical power generation capacity





Electromagnetic Railgun

- PCM-1B similar to PCM-1A
  - 10’s of MW vice 1’s of MW
  - Powers Mount equipment in addition to Pulse Forming Networks (PFN)



- Normally powered by both MVDC busses
  Requires control interface for load management

MVDC Voltage Standards

- Proposed MVDC nominal voltages based on IEEE 1709
  - 6000 VDC
  - 12000 VDC
  - 18000 VDC
- Current levels and Power Electronic Devices constrain voltage selection
  - 4000 amps is practical limit for mechanical switches
  - Power electronic device voltages increasing with time (SiC will lead to great increase)
- For now, 12000 VDC appears a good target …
  - 4000 amps per bus enables 96 MW on 2 busses
- Power Quality requirements TBD

Issues needing resolution

- Power Management
- Energy Storage / Energy Management
- System Stability
- Bus Regulation
- Prime Mover Regulation
- Fault Detection, Localization and Isolation
- System Grounding
- Magnetic Signature
- Affordability

Need resolution by 2025 to support 2030 Lead Ship Contract Award

Summary

- Power and energy density needs of a future destroyer with large pulse loads suggest a preference for MVDC
- An MVDC system must be affordable
- A number of technical issues need to be resolved in the next decade