MVDC Shipboard Power System Considerations for Electromagnetic Railgun

6th DoD EM Railgun Workshop
15–16 September 2015
Laurel, MD

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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

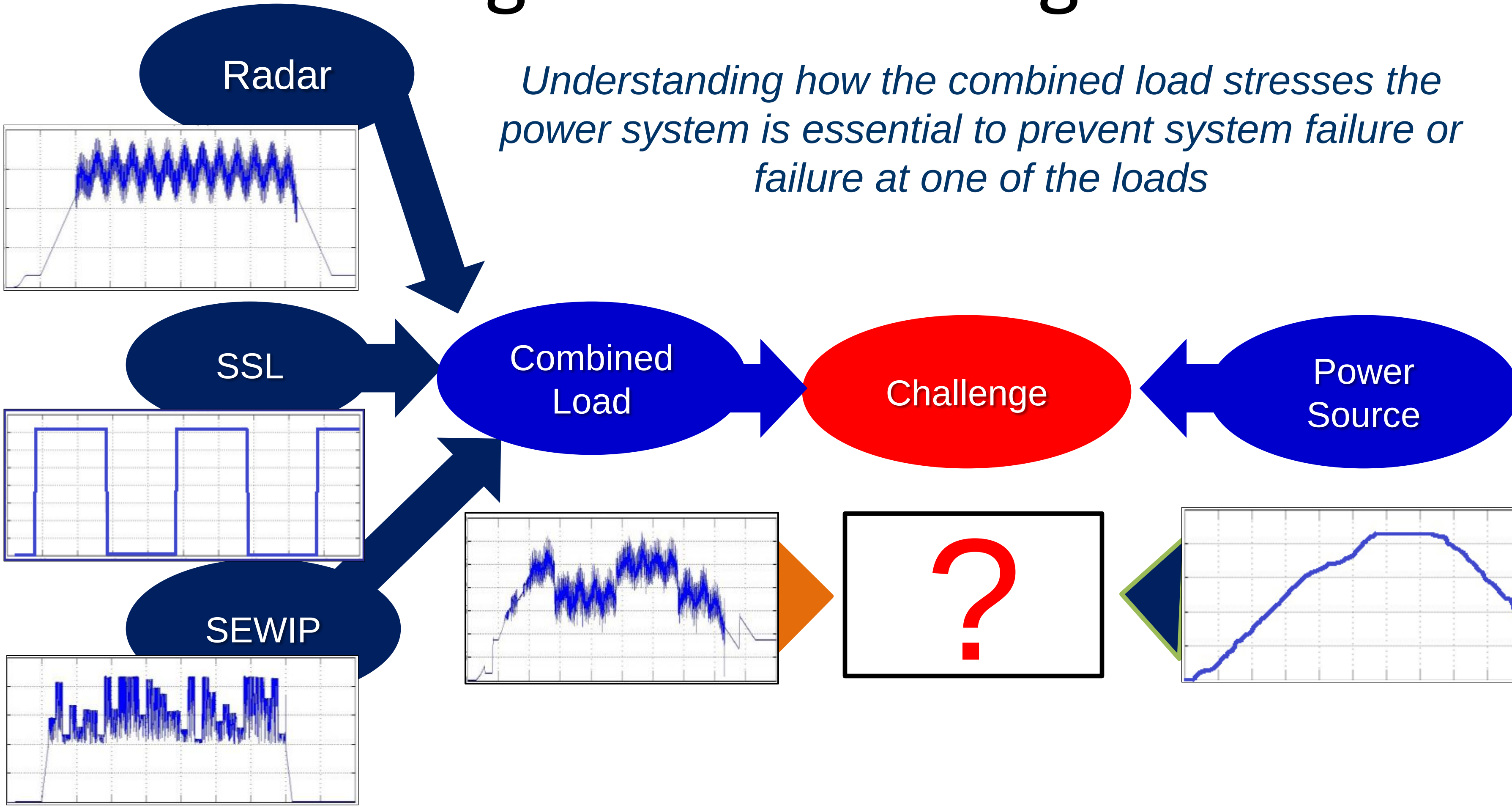
Big differences from DDG 51:

- 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

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 ship's Electric Power System and other ship systems

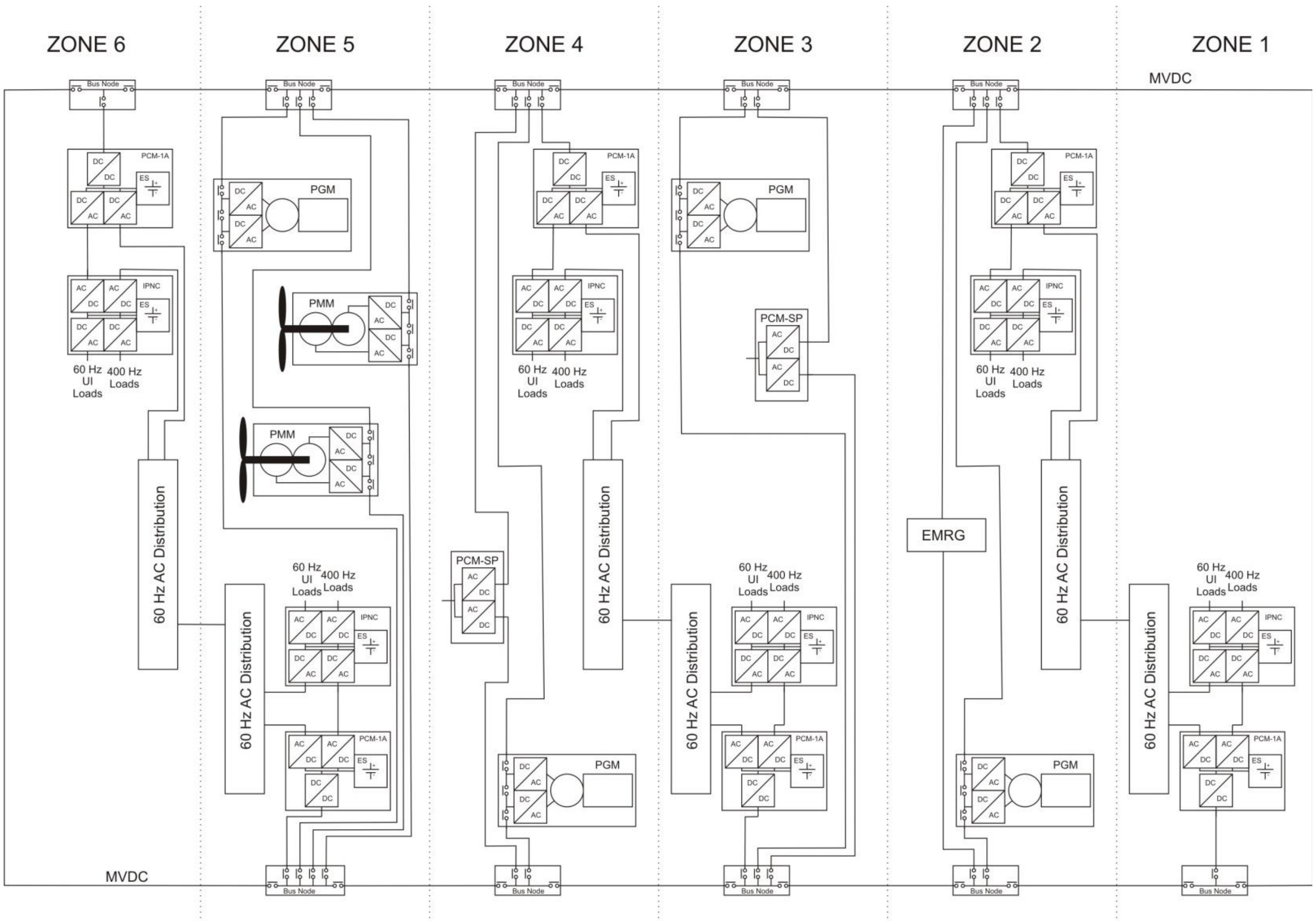
Why Medium Voltage DC?

- 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

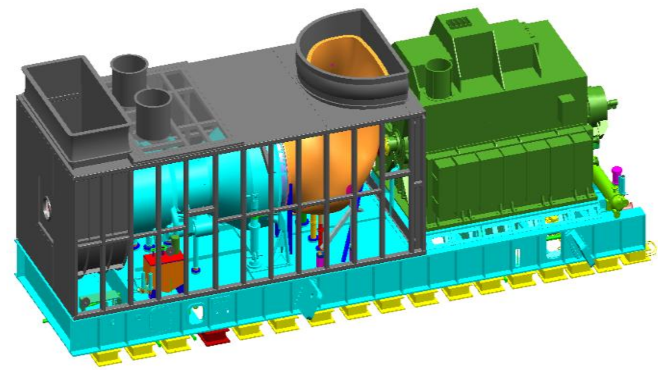
Affordably meet electrical power demands of future destroyer

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

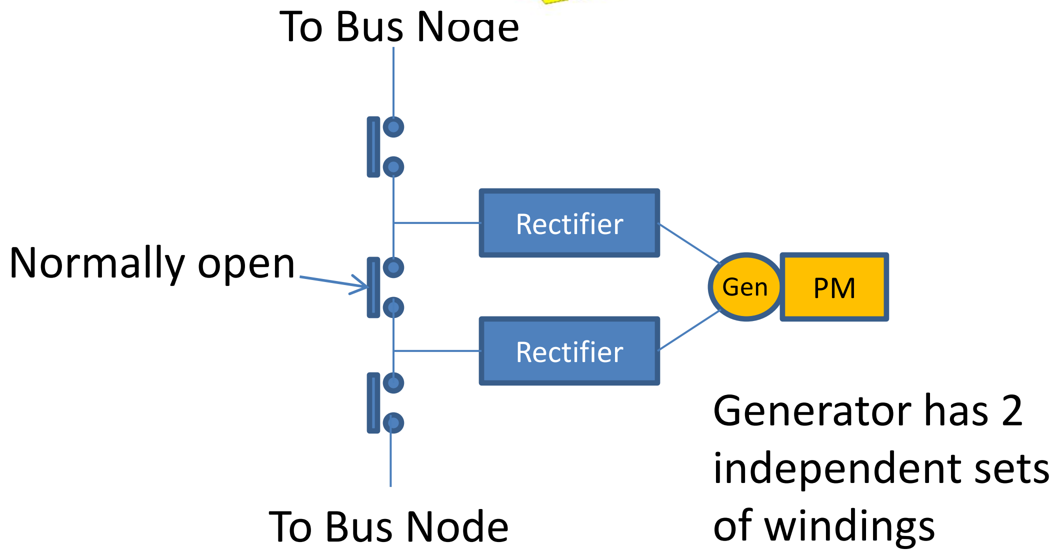
Candidate MVDC Reference Architecture



Power Generation Modules

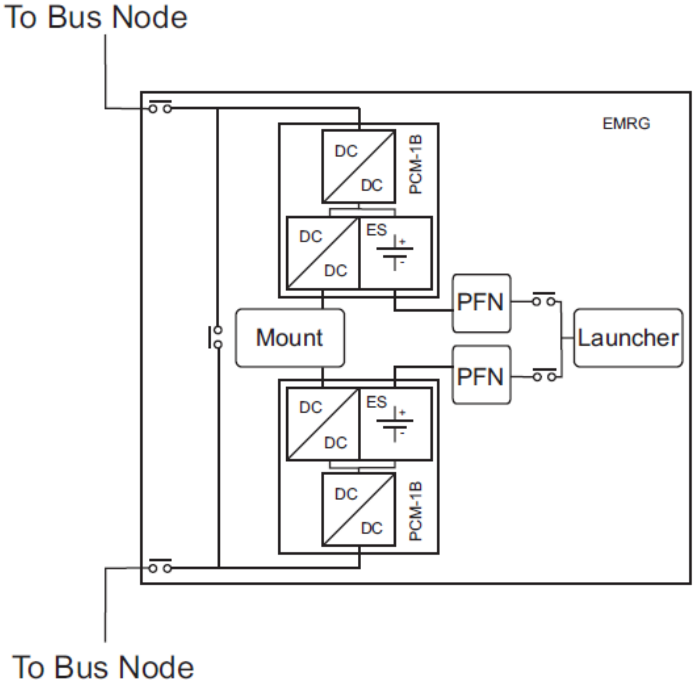


- Split Windings
  - Reduced Impact on prime mover due to fault on one MVDC bus
  - Simplifies “odd number of generators” dilemma
    - May enable reducing ampacity of MVDC bus
- Consider Fuel Cells in the future



Notional Electromagnetic Railgun

- PCM-1B = Modular Power Conversion
  - 10'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

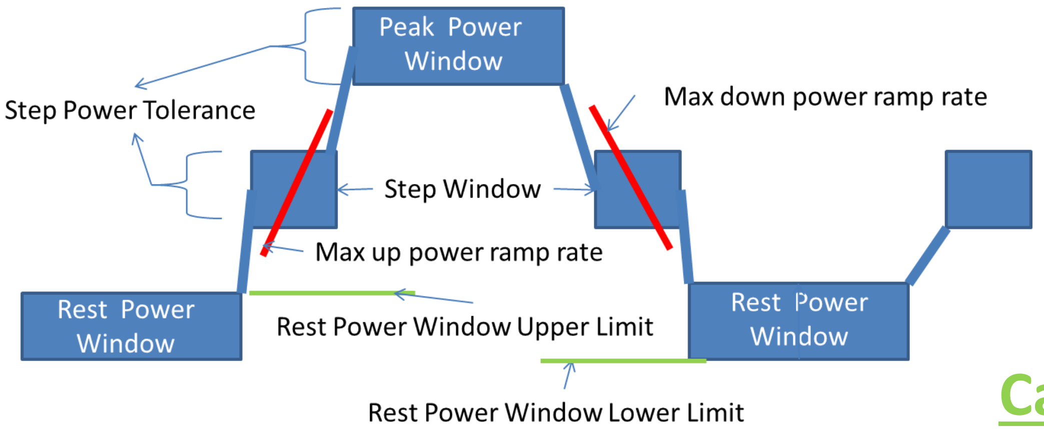


MVDC Voltage Standards

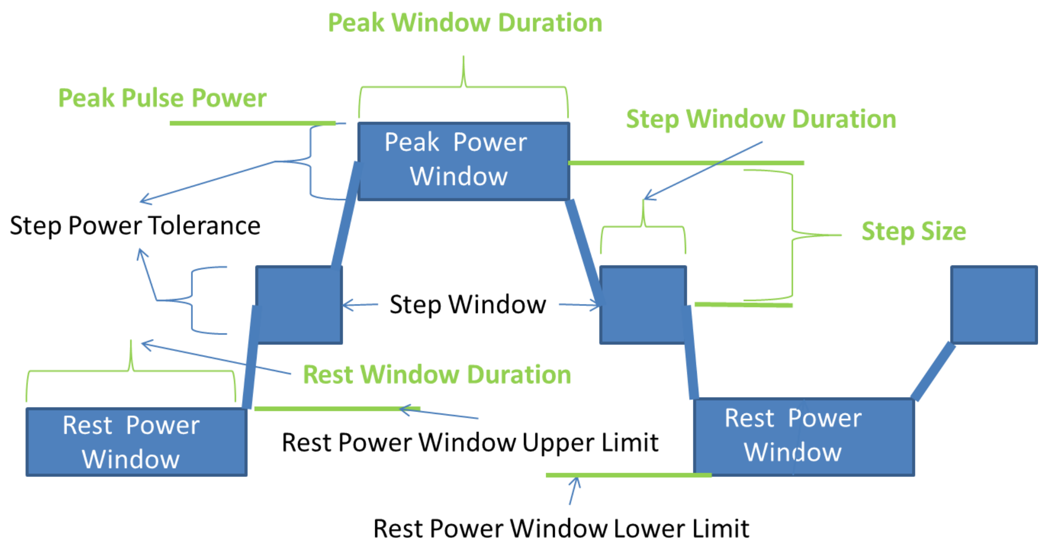
- Proposed MVDC nominal voltages based on IEEE 1709
  - 6000 VDC
  - 12000 VDC
  - 18000 VDC
- Current levels and Power Electronic Devices constrain voltage selection
  - 4000 amps is practical limit for mechanical switches
  - Power electronic device voltages increasing with time (SiC will lead to great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

Characterizing Pulses

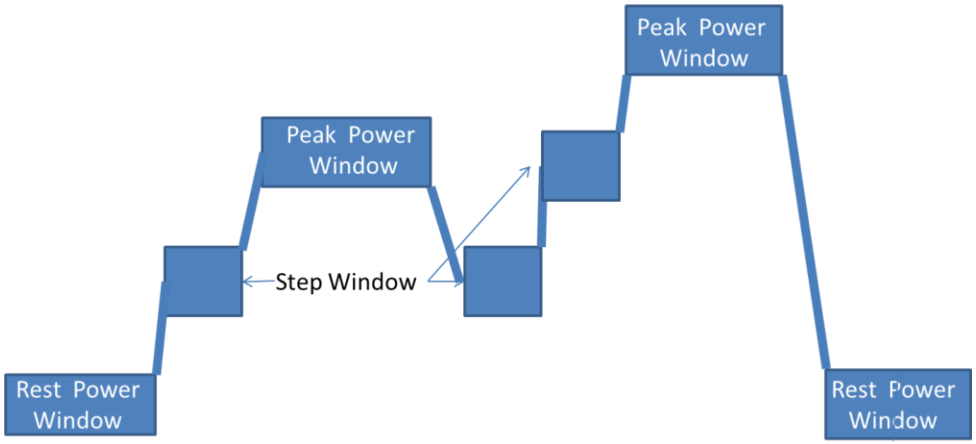
Predefined Values

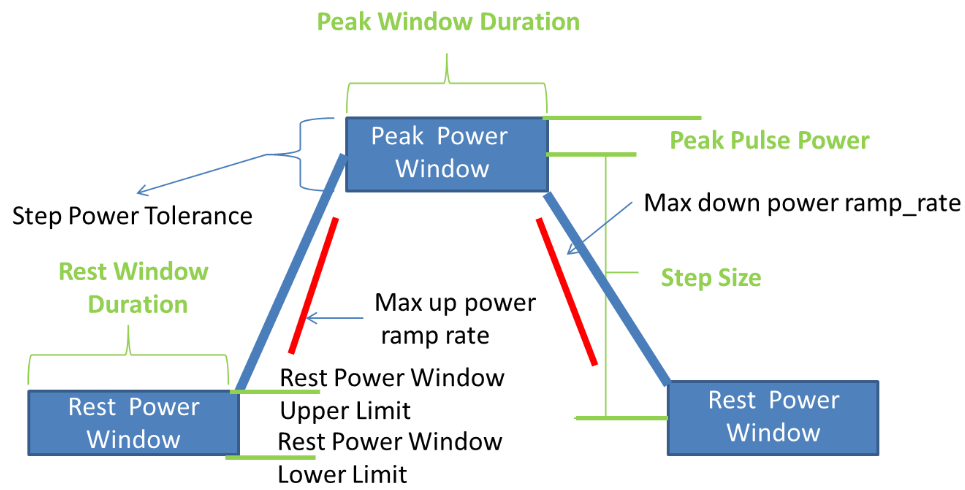


Calculated Values



Pulse Load Variations





Pulse Characteristics

- Upper limit for Rest Power Window
- Lower limit for Rest Power Window
- Maximum up power ramp rate
- Maximum down power ramp rate
- Step power tolerance
- Minimum pulse rest time
- Minimum step hold time
- Minimum peak hold time
- Maximum step size
- Maximum Peak Pulse Power

Determining Preference for an Operating Point: Interface Space

- Each element of the Pulse Characteristics set is assigned either a set of discrete points or minimum and maximum values for defining the domain of the element.
- The variation across all the Pulse Characteristics form an Interface Space
- The pulse load defines a preference function across the Interface Space. This function provides a value in the interval [0 1]

  0 = pulse load has no capability

  1 = pulse load has full capability

  (0 1) = pulse load has reduced capability
- The power system also defines a capability function across the Interface Space

  0 = Power System cannot support pulse characteristics

  1 = Power System can fully support pulse characteristics

  (0 1) = Power System can support the pulse characteristics, but must impact other loads.

Determining Preference for an Operating Point: Intersections

- Possible Rule Set
  - Choose a robust point where preference and capability both equal 1
  - Otherwise choose a point with preference 1 and a capability above a threshold (say 0.8)
  - Otherwise choose a point with the highest product of capability and preference
- Alternates could include fuzzy logic, etc.

Examples

Preference

		Characteristic A			
		0.5	0.7	0.9	1.0
Characteristic B	0.4	0.0	0.0	0.4	0.7
	0.6	0.0	0.3	0.7	0.9
	0.8	0.2	0.4	0.9	1.0
	1.0	0.4	0.6	1.0	1.0

		Characteristic A			
		0.5	0.7	0.9	1.0
Characteristic B	0.4	0.0	0.0	0.4	0.7
	0.6	0.0	0.3	0.7	0.9
	0.8	0.2	0.4	0.9	1.0
	1.0	0.4	0.6	1.0	1.0

		Characteristic A			
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Characteristic B	0.4	0.0	0.0	0.4	0.7
	0.6	0.0	0.3	0.7	0.9
	0.8	0.2	0.4	0.9	1.0
	1.0	0.4	0.6	1.0	1.0

Capability

		Characteristic A			
		0.5	0.7	0.9	1.0
Characteristic B	0.4	1.0	1.0	1.0	1.0
	0.6	1.0	1.0	1.0	1.0
	0.8	1.0	1.0	1.0	1.0
	1.0	1.0	1.0	0.9	0.8

		Characteristic A			
		0.5	0.7	0.9	1.0
Characteristic B	0.4	1.0	1.0	1.0	1.0
	0.6	1.0	1.0	1.0	0.8
	0.8	1.0	1.0	1.0	0.8
	1.0	1.0	0.9	0.9	0.6

		Characteristic A			
		0.5	0.7	0.9	1.0
Characteristic B	0.4	1.0	1.0	1.0	0.6
	0.6	1.0	1.0	0.9	0.4
	0.8	1.0	0.9	0.4	0.4
	1.0	0.9	0.8	0.4	0.4

Power Management & Power System Design – How It's Done Now

- Power Management
  - Present Actual Load < 0.95 x (Online Generating Capacity)
- Designing installed generation capacity
  - Generator Rating ≥ ((1+Service Life Allowance) x ((1+Margin) x Maximum Load)) ÷ (0.95 x (n-1))
- Indirect stability design: Design the system, analyze its model, re-design if stability cannot be concluded

Power Management & Power System Design – Affordability Approach

- Active Power Management – More Flexibility
  - Online Generating Capacity + Available ESM Discharge + Available Actual Propulsion Load Decrement – Present Actual 'Rest' Load = Available Pulse Load + Available ESM Charge
- Designing installed generation capacity
  - Select Generator Ratings then use Active Power Management
  - Close control loop on Generators' Loading capacity
- Presence of many power converters and 'pulsing loads' requires focus on current limits
- Direct stability design
  - Employ impedance techniques to ensure small signal stability
  - Design the power system controller to be stabilizing (techniques under development)

Summary

- MVDC is a key enabler for supporting pulse power weapons in ships less than 10,000 mt
- A common taxonomy for describing pulses is needed and proposed
- A method for determining pulse characteristics dynamically is proposed
- Power Systems will need new approaches to design