DC Interfaces for Naval Applications

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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

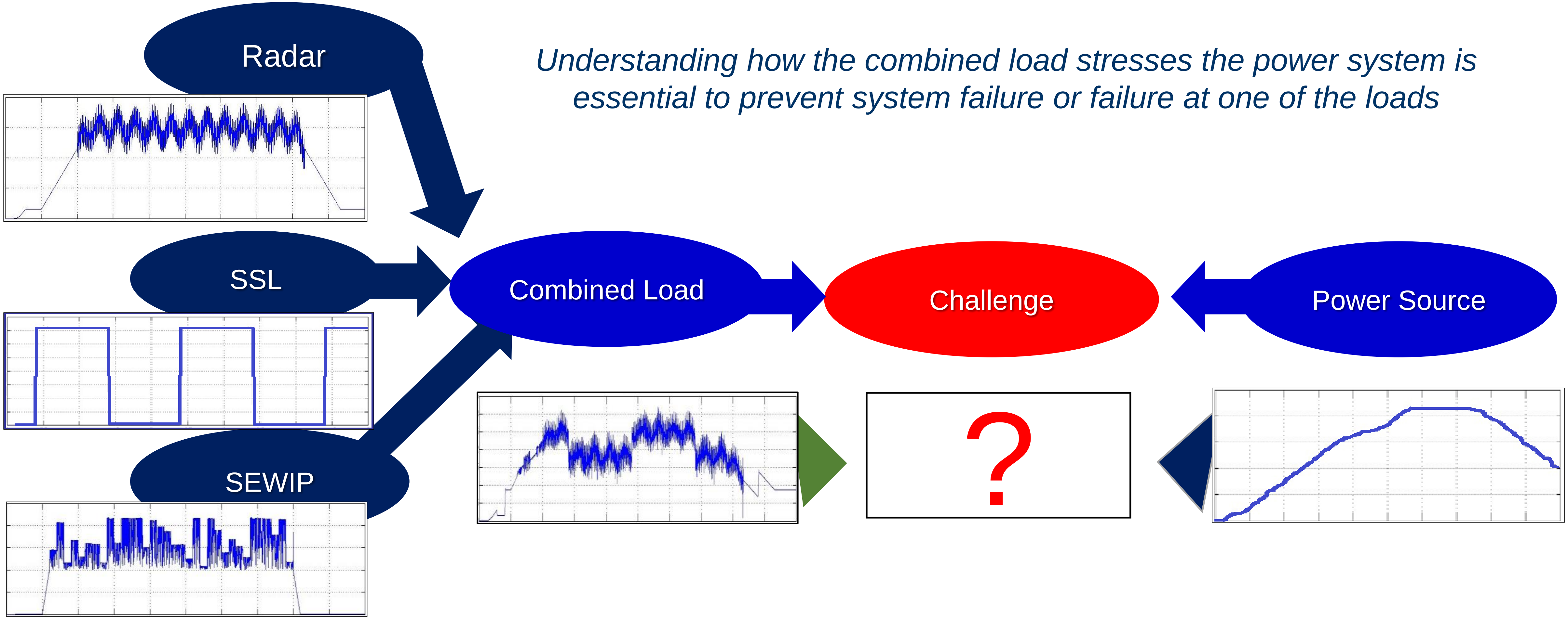
Big differences from DDG 51:

- 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

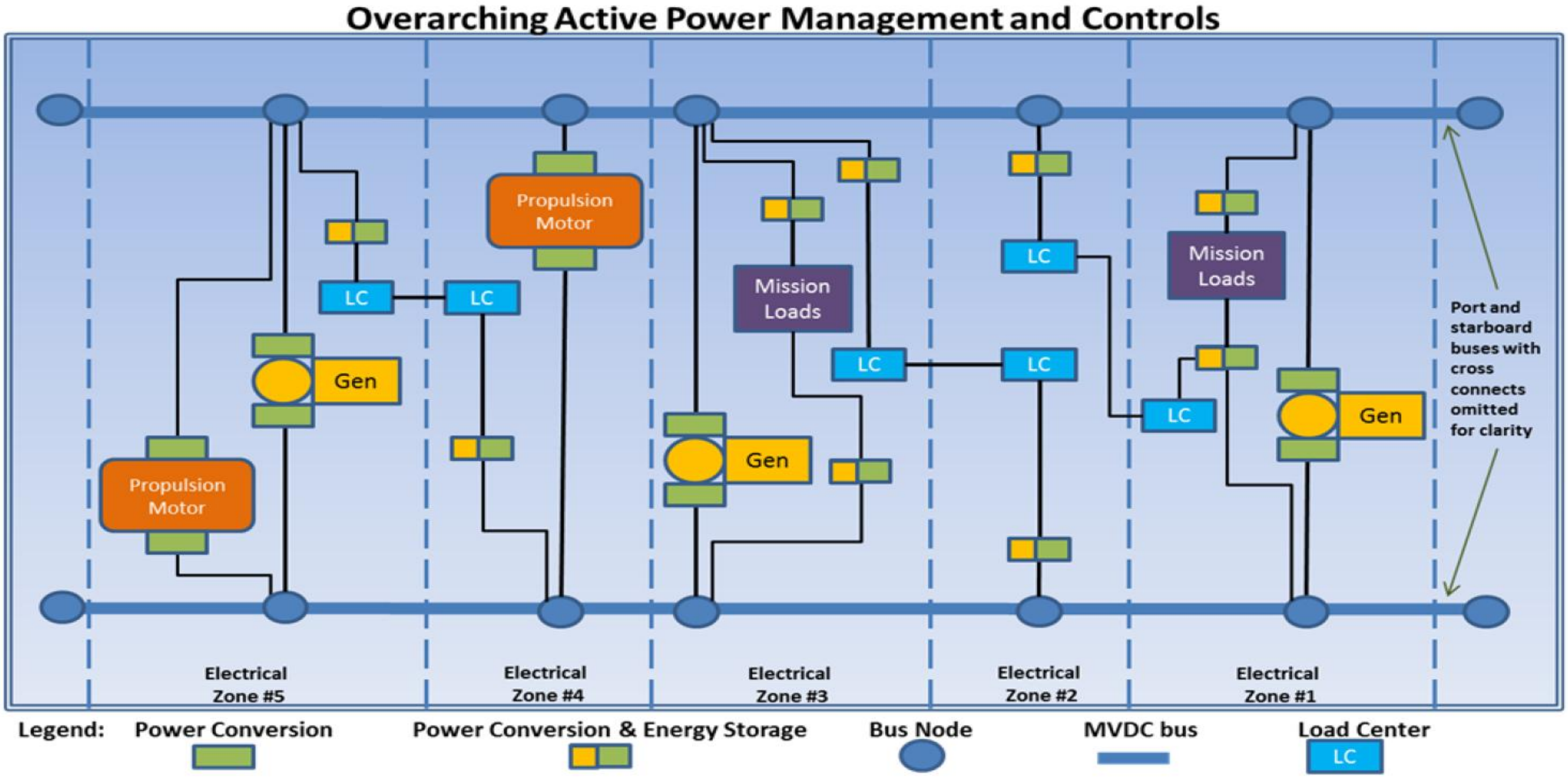
Why Medium Voltage DC?

- Decouple prime mover speed from power quality
  - Minimize energy storage
  - Avoids large currents to restore synchronism (in a.c. systems) during disturbances / pulses.
- 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

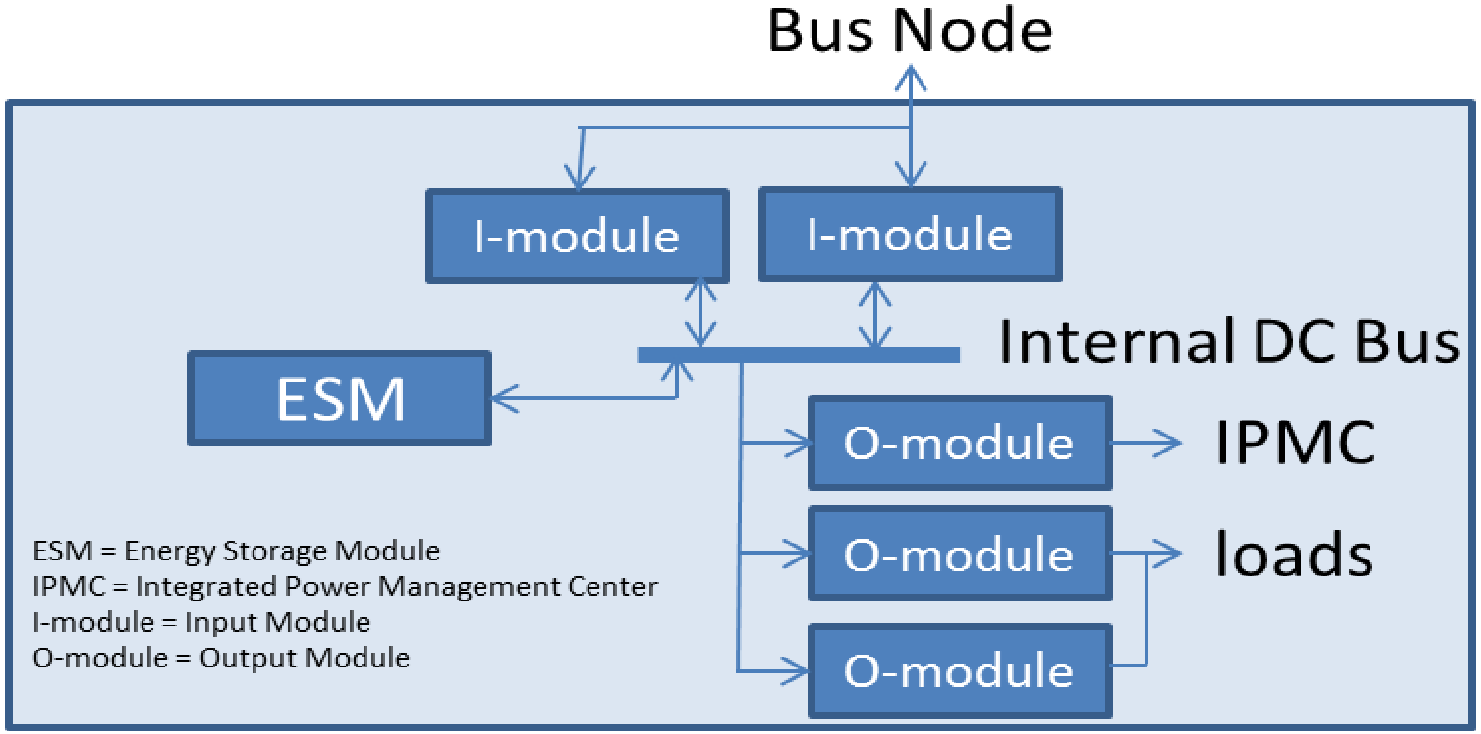
MVDC Reference Architecture



MVDC Voltage Standards

- 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 buses
- Power Quality requirements TBD
  - MIL-STD-1399 section under development

PCM-1A / Energy Magazine



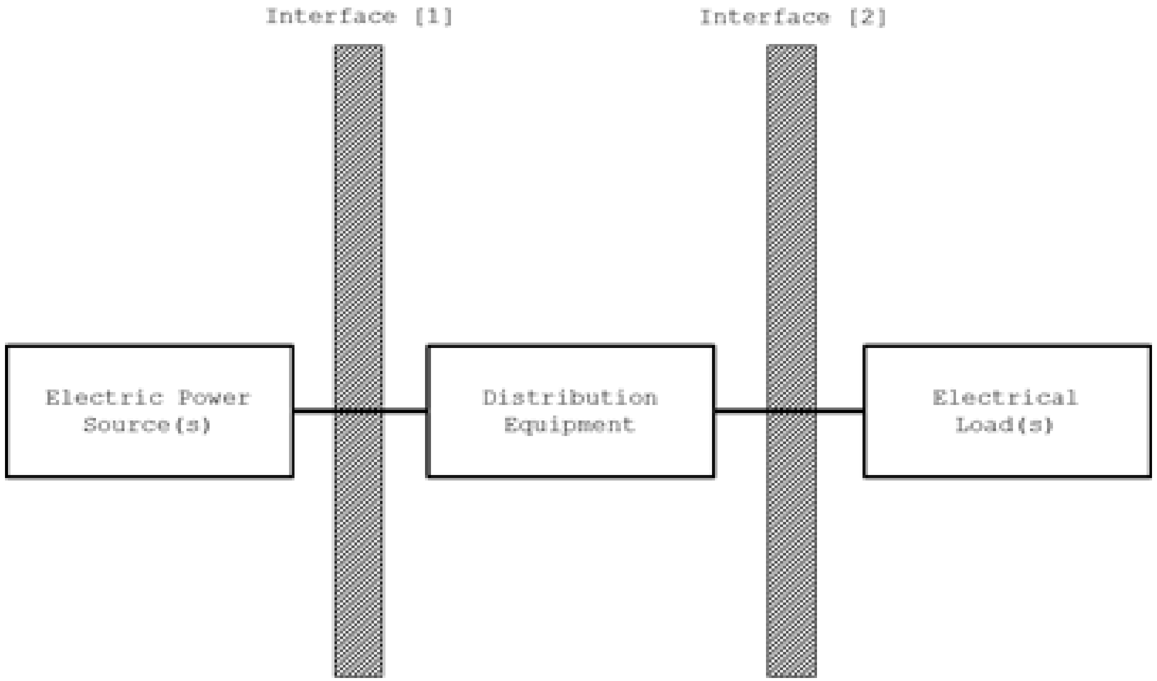
ESM = Energy Storage Module
IPMC = Integrated Power Management Center
I-module = Input Module
O-module = Output Module

LVDC Voltage Standards

- LVDC Nominal Voltages based on DDG 1000 and discussions with mission system engineers
  - 375 VDC
  - 650 VDC
  - 1000 VDC
    - Type 1: Tight tolerance
    - Type 2: Looser tolerance
- One goal is to lower overall costs by eliminating power conditioning stages in load equipment
- Legacy a.c. interfaces will remain
  - 440 VAC
  - 120 VAC

MIL-STD-1399 Sections

1. Scope
2. Applicable Documents
3. Definitions
4. General Requirements
5. Detailed Requirements
   - 5.1 Electrical Power System Characteristics
   - 5.2 Load Requirements
   - 5.3 Load Verification Methods
   - 5.4 Source Requirements
   - 5.5 Source Verification Methods
6. Notes



[1] The source interface as it concerns the characteristics of DC Electric Power is located at the output terminals of the electric power source(s).

[2] The load interface as it concerns the characteristics of DC Electric Power is located at the input terminals of the electrical load(s).

Request for Information

- Naval Sea Systems Command (NAVSEA), “Request for Information for Electrical Interface Standards for Naval DC Power Systems,” Solicitation N00024-17-R-4202, Nov 8, 2016.
    - Available from https://www.fbo.gov
    - Draft standards provided
    - 16 Specific questions were asked
- Responses due December 15, 2016
    - Many comments provided

Key MVDC Findings

- Debate on whether a tight steady-state (< 1%) voltage tolerance or a looser steady-state tolerance should be allowed (2 to 5%)
- Differentiating among transients, pulse loads, and ripple is challenging
- Need a better understanding of "spikes"
- Verification methods may prove challenging
  - Temperature Stability Criteria can be cost drivers
  - Use of Resistive Load banks vice programmable loads
- Stability requirements needed, but no agreement on the form
- Load voltage interruption tolerance time depends on fault detection, localization, and isolation method
- Need better definition of load behavior under fault
- Grounding and common mode impedance should be better defined
- Inrush current needs better definition
- Pulse load definition needs better definition

Key LVDC Findings

- Context for Type 1 and Type 2 power desired
- Load voltage transient Interruption Time depends on nature of distribution between source and load
  - If a load has a dedicated source, should not be defined.
  - Otherwise, depends on Fault Detection, Localization, and Isolation
- No agreement on Load maximum current rate of change
  - Energy storage must have power rating of load if the rate of change is greater than generator sets can handle.
- EMI and MIL-STD-461 needs to be studied in greater detail
- One reviewer noted that if output modules can provide custom power, then no need to develop LVDC interface standards … dedicate an output module to each load.
- Pulse load provisions need better definition.
- Considerable discussion on Load maximum current ripple.

Summary

- Extensive feedback indicates continued discussion among Government engineers, academia, warfare systems developers, power system developers, and EMI engineers is warranted.