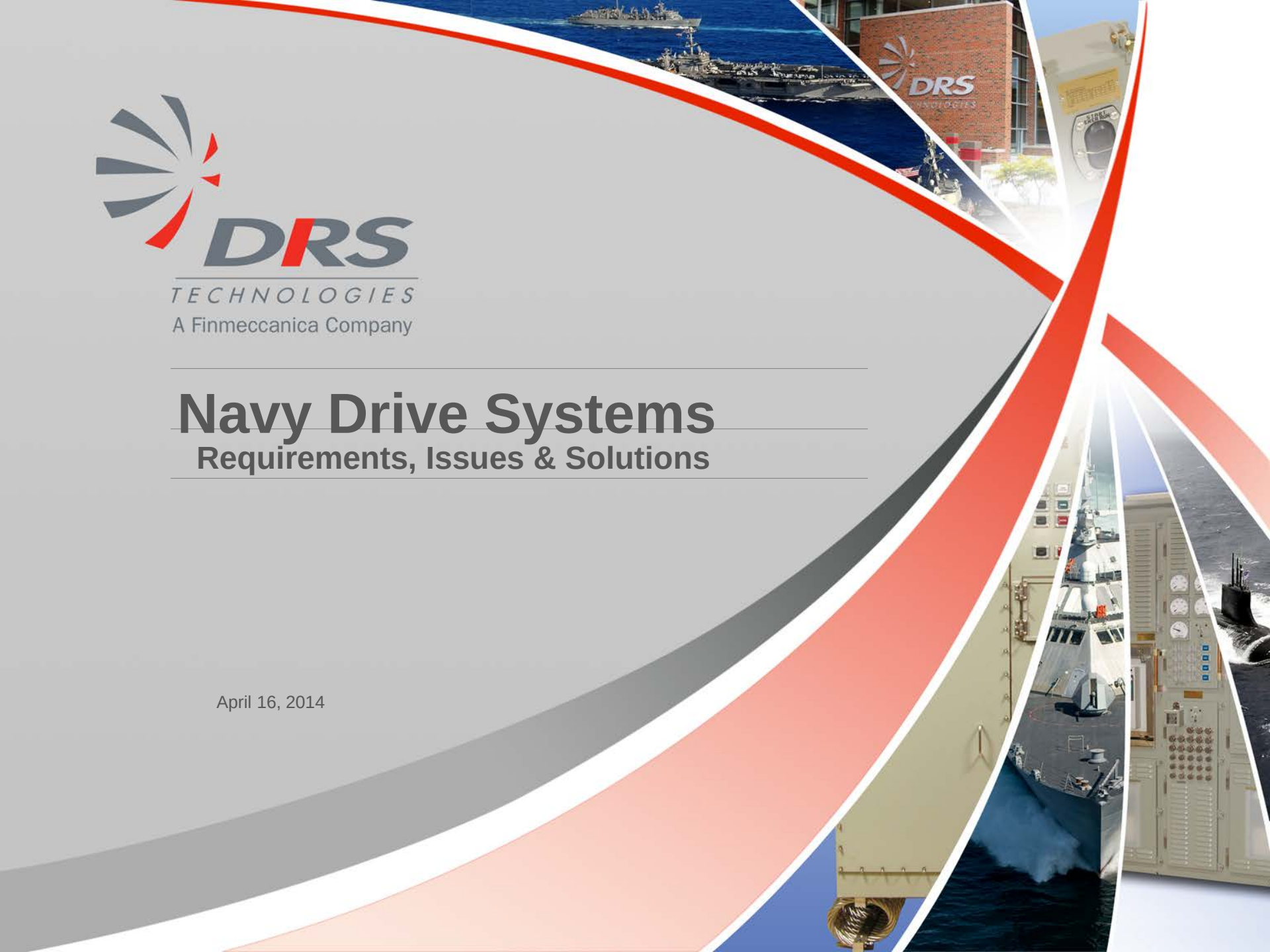
DRS TECHNOLOGIES
A Finmeccanica Company

Navy Drive Systems

Requirements, Issues & Solutions

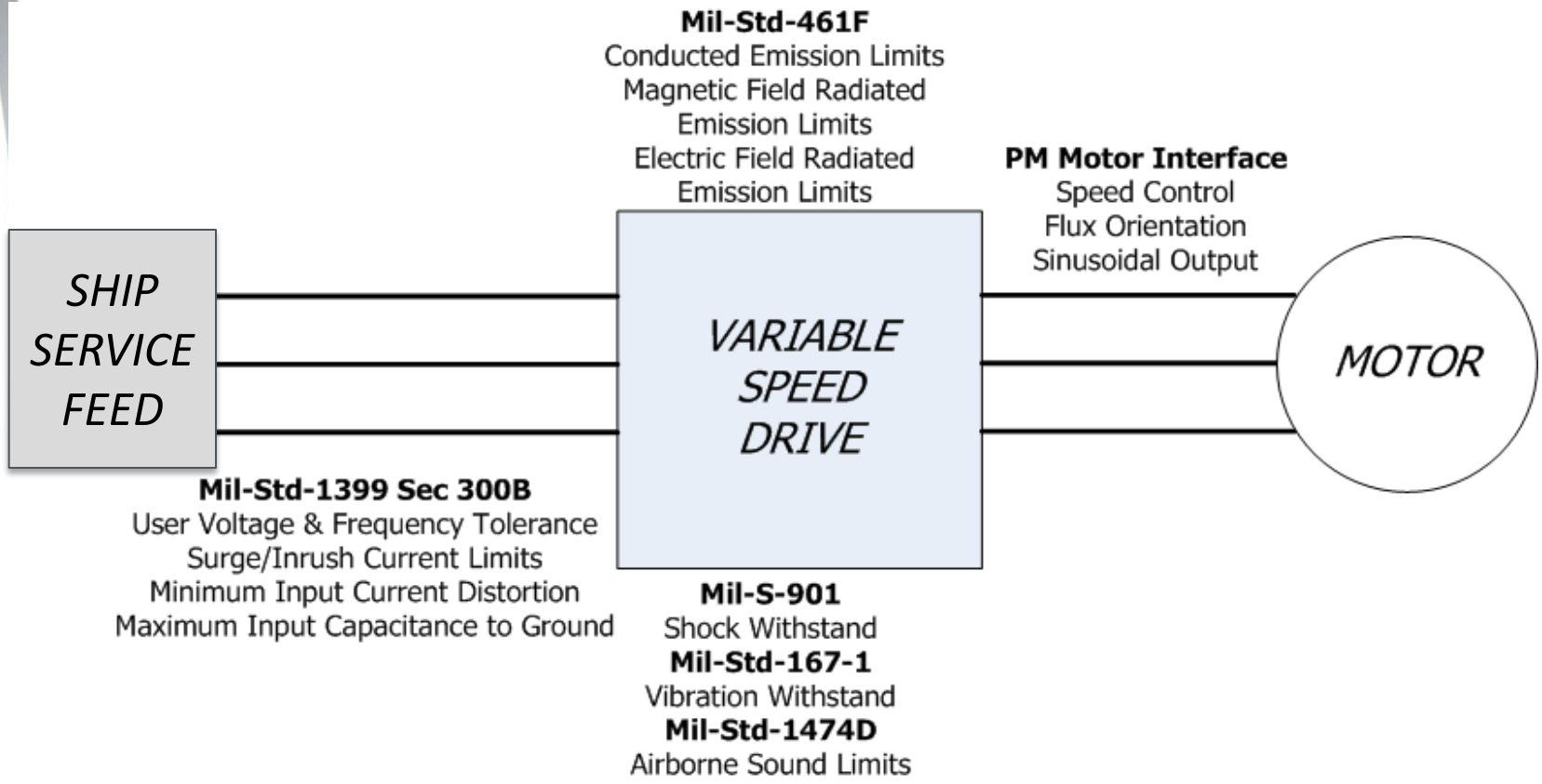
April 16, 2014



OVERVIEW

- **Shipboard Variable Speed Drive (VSD) System Requirements**
- **High HP VSD Solution Drivers:**
  - **Gaps and Dilemmas**
- **Previous and Future VSD Solutions**

SHIPBOARD INTERFACE REQUIREMENTS



HIGH HP VSD SOLUTION DRIVERS

- **Power Density**
  - For retro-fit solutions, must fit into the existing space
  - For new platforms space is limited
- **Motor Load**
  - Permanent Magnet Motor is more power dense
  - Low leakage inductance
    - Good from a power density perspective
    - Bad from the perspective that it drives high power quality requirements into the motor
  - Voltage level
    - High voltage drives significant risk and qualification costs
    - Insulation system needs to be over-designed for the rating
    - Lower voltage through >3 phase or multi-level VSD strategies puts cost and reliability burden on the VSD

HIGH HP VSD SOLUTION DRIVERS (CONT.)

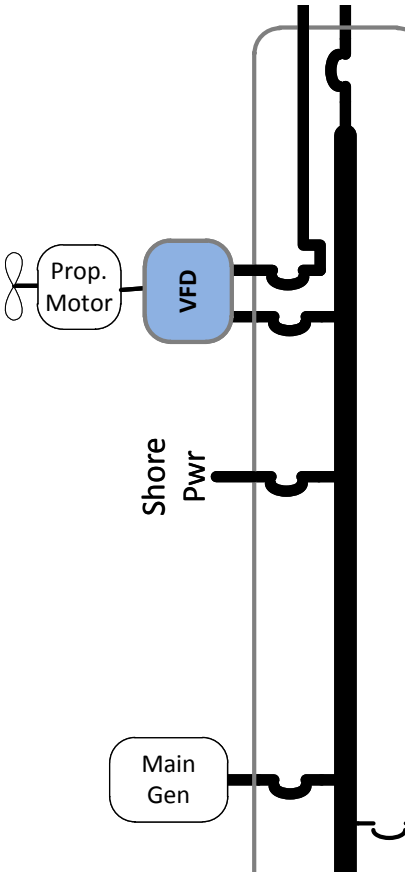
- **Ship Service Power Interface**
  - Must meet high input power quality (IHD<3%)
  - Must withstand large input voltage fluctuations without impacting down-stream processes
  - Multi-Pulse Transformer-Rectifier solution impacts power density
  - Active front-end solution adds significantly to VSD cost and increases the conducted and radiated EMI (which must be mitigated)
- **Environment**
  - Shock/Vibration mitigation requires mil-hardened design or “cocooning” of commercial solutions
  - Temperature usually drives the VSD design more than the motor design
  - Availability of Water cooling
    - Drives need for “cocooning” to provide self-contained controllable environment
    - A water-cooled motor is a costly, custom design
    - Imposes requirement on shipboard auxiliaries that impacts every aspect of shipboard system design and CONOPS

HIGH HP VSD SOLUTION DRIVERS (CONT.)

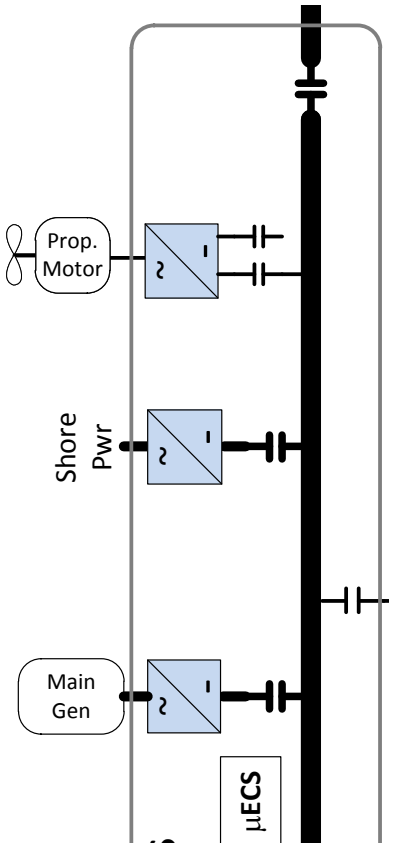
- **Serviceability**
  - Obsolescence of replacement parts
  - Identification of the Lowest Replaceable Unit (LRU)
  - Modular multi-phase VSD designs are desirable but impose significant cost and reduce power density
  - Fault tolerant VSD and motor combination a plus
  - VSD MTBF becomes an unexpected cost
    - Often missed in the proposal stage
    - Must be verifiable in terms of existing norms
    - The Navy should adopt new paradigms that allow for technology advancements in how reliability is managed
- **Cost**
  - External pressures to reduce spending favor COTS solutions and overshadows compliance during procurement phase
  - COTS solutions generally fall short in meeting shipboard requirements
  - VSDs often “get a black eye” because of high integration costs:
    - Lack of system integration experience by the VSD supplier
    - Lack of Navy shipboard experience with power conversion
    - Unexpected and missed requirements

VSD VS. NEXT GENERATION INTEGRATED POWER SYSTEMS

MVAC Fed Architecture

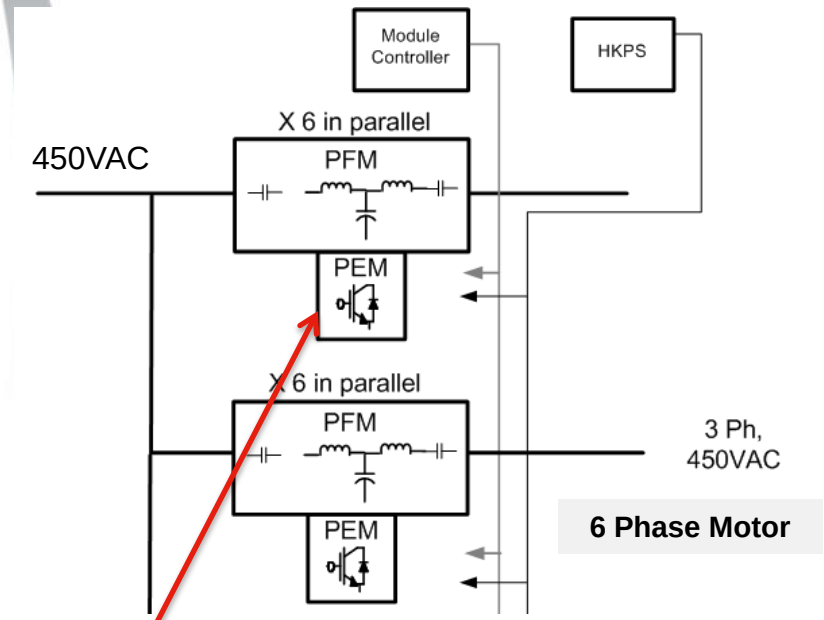


MVDC Fed Architecture



PRIOR HIGH POWER VSD SOLUTIONS
PM MOTOR VSD SYSTEMS

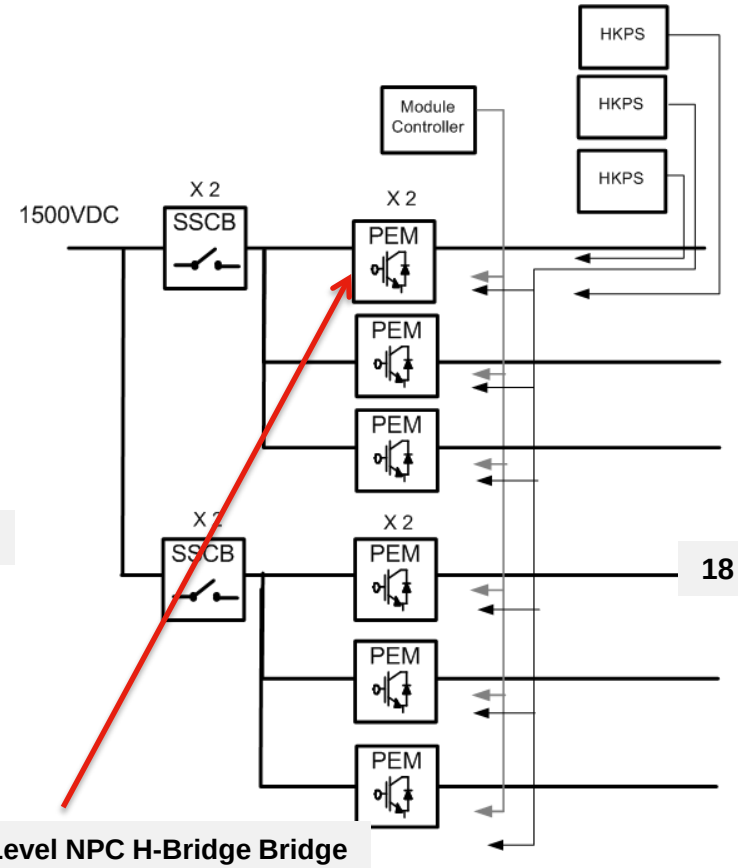
Non-Isolated AC-Fed



6 Phase Motor

3-Level 3-Phase NPC Bridge

DC-Fed



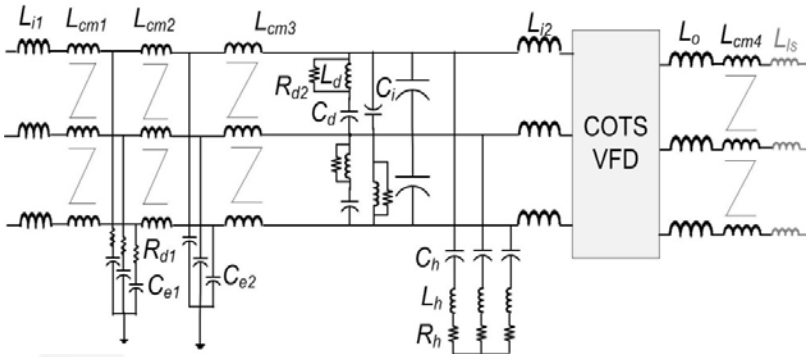
18 Phase Motor

3-Level NPC H-Bridge Bridge

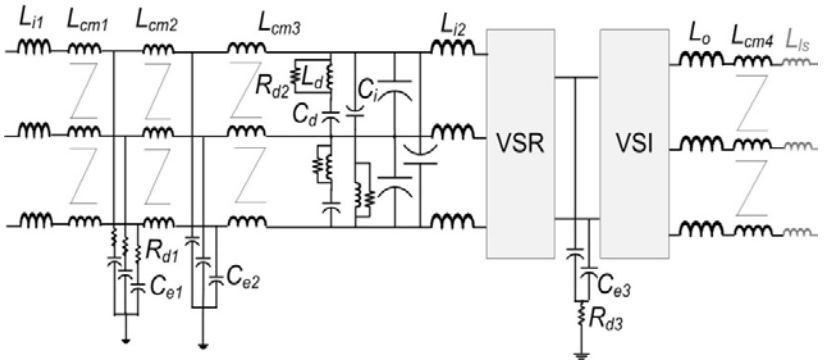
SHIPBOARD DRIVES DEVELOPMENT GOALS

- Development of MIL compliance, platform based drives family to provide solutions which are cost effective and address the obsolescence issues for the Navy and DRS-PCT.
  - Utilizing the latest power electronics/control technologies
  - Utilizing next generation power semiconductor modules
  - Extend the technology to SiC
- Develop a technology platform in hardware and software for a high level of modularity and use common parts for cost reduction.

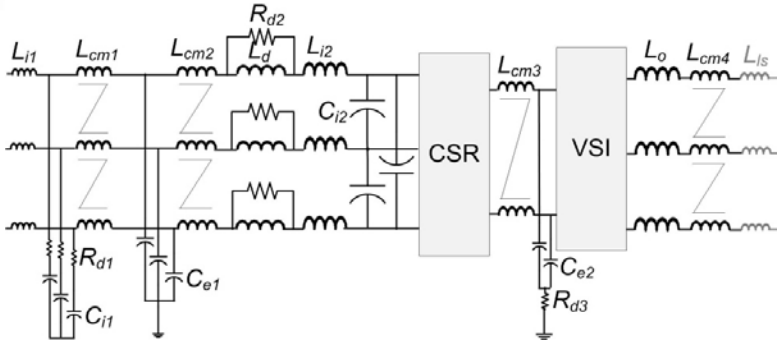
NEXT GENERATION VSD SOLUTIONS:
WHICH TOPOLOGY YIELDS LOWEST SIZE/WEIGHT/COST?



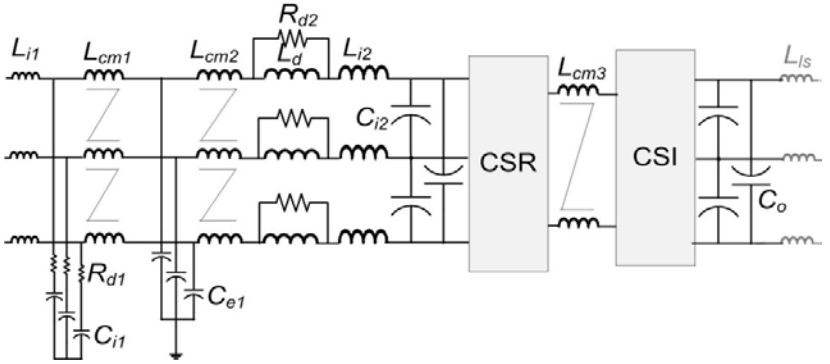
"Cocooned" COTS VFD (Buck)



VSR-VSI (Boost-Buck)



CSR-VSI (Buck-Buck)



CSR-CSI (Buck-Boost)

NEXT GENERATION SHIPBOARD IPS CHALLENGES

- MVDC (10-20kVDC) Platform:
  - High voltage motor vs. cost of Solid State Transformer to reduce motor voltage
  - Multi-Level VSD topologies
  - Maximize device voltage rating vs. allowable switching frequency (>5kHz is desirable)
- MVAC (13.8kVAC) Platform:
  - Focus technology on transformer-rectifier front end design
  - With appropriate focus on AC interfaces, risks in VSD topology can be reduced
- Legacy (450VAC, 4160VAC) Platforms:
  - Ship service feed compatibility
  - Cost vs. compliance vs. performance