OVERVIEW

Shipboard Variable Speed Drive (VSD) System Requirements

High HP VSD Solution Drivers:
• Gaps and Dilemmas

Previous and Future VSD Solutions
SHIPBOARD INTERFACE REQUIREMENTS

SHIP
SERVICE
FEED

VARIABLE
SPEED
DRIVE

MOTOR

Mil-Std-461F
Conducted Emission Limits
Magnetic Field Radiated
Emission Limits
Electric Field Radiated
Emission Limits

PM Motor Interface
Speed Control
Flux Orientation
Sinusoidal Output

Mil-Std-1399 Sec 300B
User Voltage & Frequency Tolerance
Surge/Inrush Current Limits
Minimum Input Current Distortion
Maximum Input Capacitance to Ground

Mil-S-901
Shock Withstand
Mil-Std-167-1
Vibration Withstand
Mil-Std-1474D
Airborne Sound Limits
**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
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

- 3-Level 3-Phase NPC Bridge
- PFM
- PEM
- HKPS

450VAC
X 6 in parallel

DC-Fed

- 3-Level NPC H-Bridge Bridge
- PFM
- PEM
- HKPS

1500VDC
X 2

6 Phase Motor

12 Ph, 1.1kVAC
X 2

18 Phase Motor
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