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Cost Engineering an MVDC Power & Energy Design for Navy Surface Combatants

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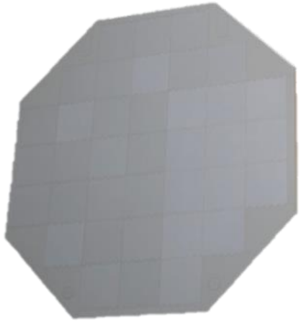
Background

- Combat systems and mission loads have significantly grown and consumed the power margin of traditional power generation and distribution designs
  - Roughly 400% growth in power demand due to new system loads

Laser Weapons systems
E.g., 300kW Laser

Radars/Sensors
E.g., SPY-6



- Additionally, the waveforms and behaviors of these loads act differently and present challenges to integration into the medium-voltage alternating current (MVAC) distribution system that ships have historically employed
- The Navy is exploring alternatives to address potential power system risks which include medium-voltage direct current (MVDC) and advanced energy storage capabilities

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The Big Question

What should be the Navy's primary distribution system of the future?

Medium-Voltage Alternating Current (MVAC)
Or
Medium-Voltage Direct Current (MVDC)

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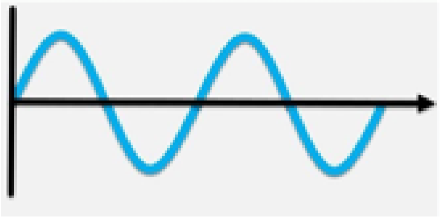
Definitions

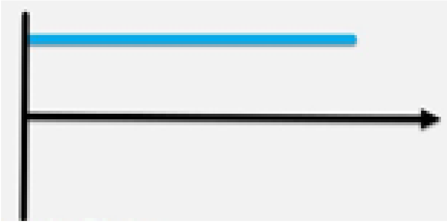
AC

- Current flow changes its direction periodically
- Voltage can reliably be increased/decreased using transformers
- Common uses include powering homes and businesses

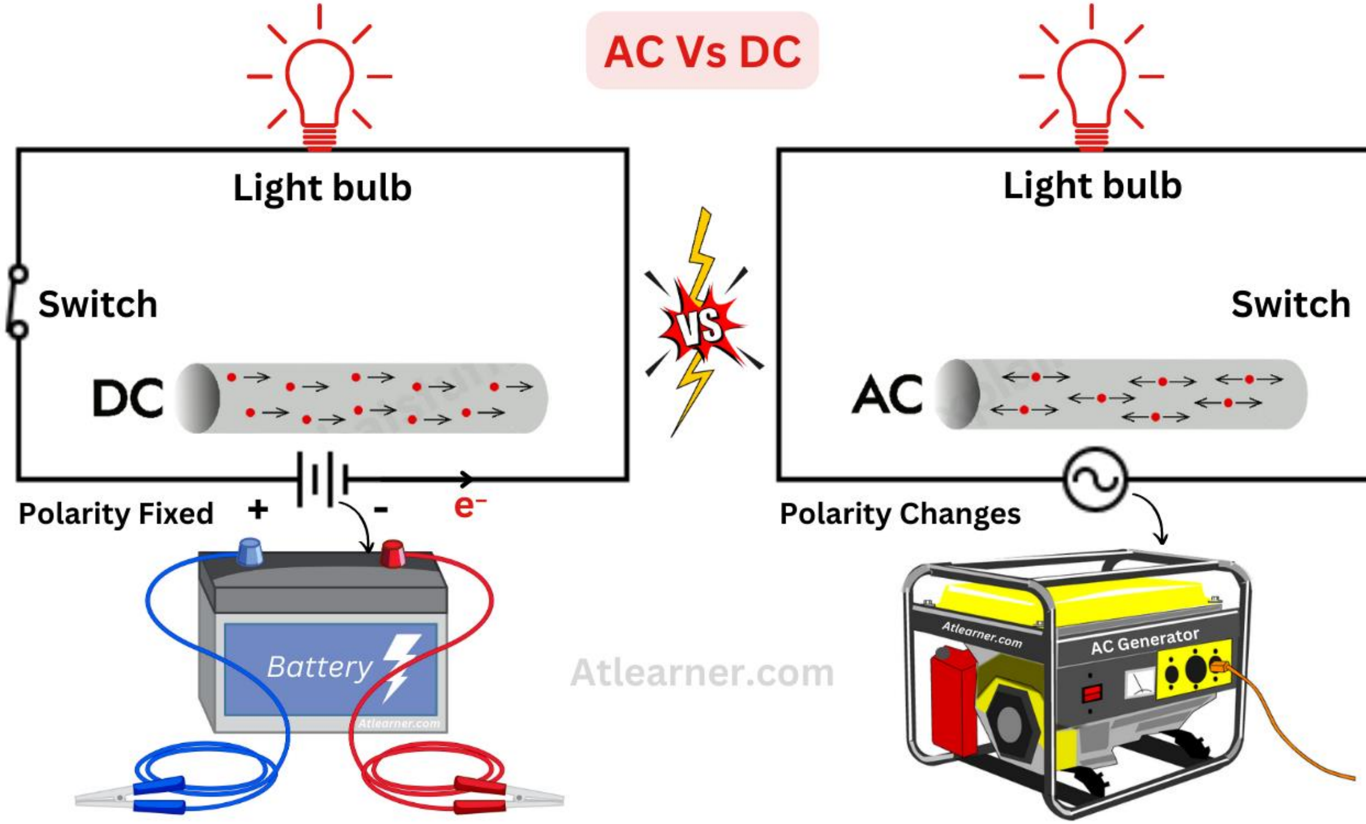


DC

- Current flows constantly in a single direction for a steady voltage
- Can be stored
- Common uses include rechargeables such as batteries, solar panels, and laptops



Definitions



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Surface Combatant Benefits

MVAC vs. MVDC

MVAC

- Deployed in multiple ship classes
- Navy and commercial investment = low risk
- Easily configurable

MVDC

- Provides power more efficiently
- Lower maintenance
- Reduced space and weight demands

IN THEORY

Purpose for Study

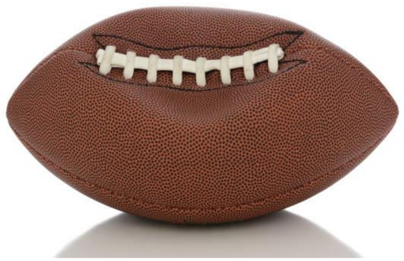
- NAVSEA05Z, Marine Engineering, is responsible for determining the Navy's future primary distribution system
- NAVSEA05Z requested Herren:
  - Perform Cost Comparison of MVDC and MVAC using an independent cost engineering approach
  - Perform Producibility Risk Assessment associated with MVDC
- This study was one of four discrete research efforts aimed to answer this question

Plan A

- Develop a Business Case Analysis (BCA)
  - Develop cost estimates for both MVDC and MVAC systems (two alternatives)
  - Assess quantifiable and non-quantifiable factors supporting each alternative
  - Compare the cost estimates to determine the best value for achieving operational requirements while achieving operational costs
- Producibility Risk Assessment
  - Evaluated MVDC Producibility Risks

Well, that didn't work…

- Developing a cost estimate for an MVDC system was not feasible due to the following issues:
  - Unable to use Parametric, Analogy, or Extrapolation from Actuals Methods
    - MVDC systems do not exist, therefore there is no historical data available
    - "MV" not well-defined nor agreed upon across the technical community
    - MVAC systems do exist, but they are not analogous
    - There are no other analogous power distribution systems
  - Unable to use Engineering Build-up Method
    - Initially provided two-months to complete study
    - MVDC engineering design or drawings not provided
- Developing a cost estimate for an MVAC system would also prove a challenge as it is difficult to extract power distribution costs from previous ship builds



~~Plan A~~
Plan B

- Cost Driver Comparison
  - Evaluated Cost and Level of Uncertainty of MVDC system based on:
    - Components
    - Commodities (Material Makeup)
    - Operations Costs
- Producibility Risk Assessment
  - Evaluated MVDC Producibility Risks

Approach

- Cost and Level of Uncertainty were determined subjectively based on
  - SME input from NAVSEA engineers
  - Industry literature (i.e., IEEE)
- MVDC Costs were assessed as:
  - More Expensive
  - Less Expensive
  - Or the Same Cost
- MVDC Level of Risk/Uncertainty was assessed as:
  - Low
  - Moderate
  - High

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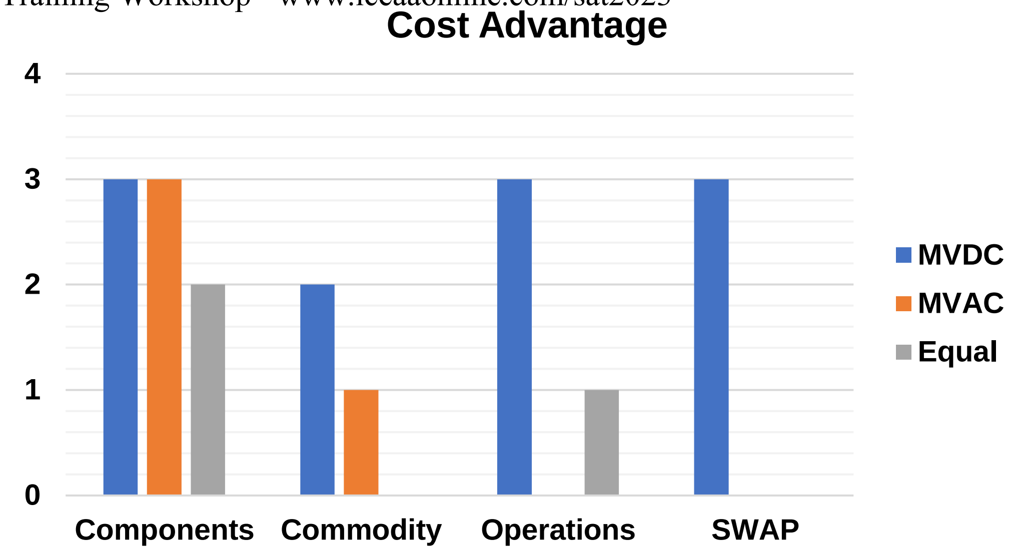
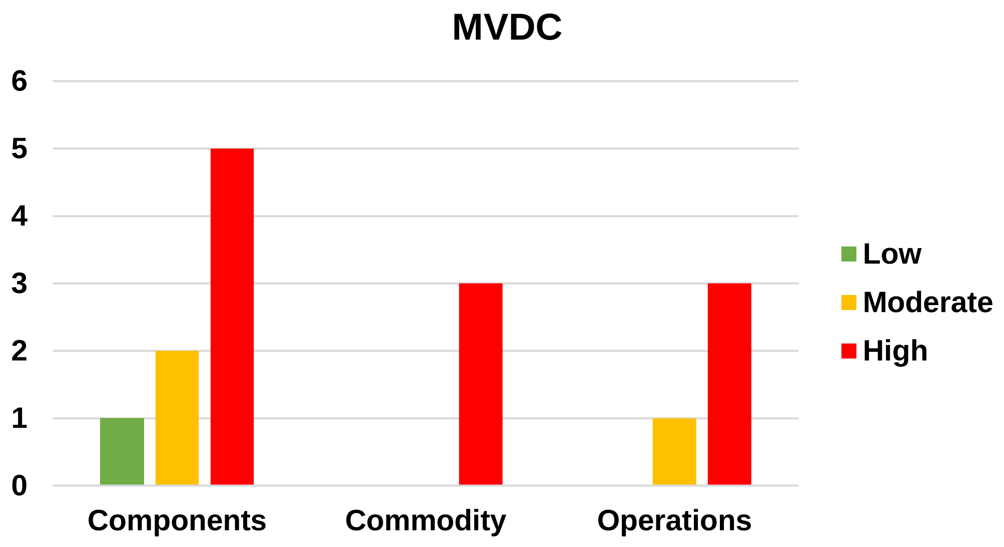
MVDC Cost Comparison

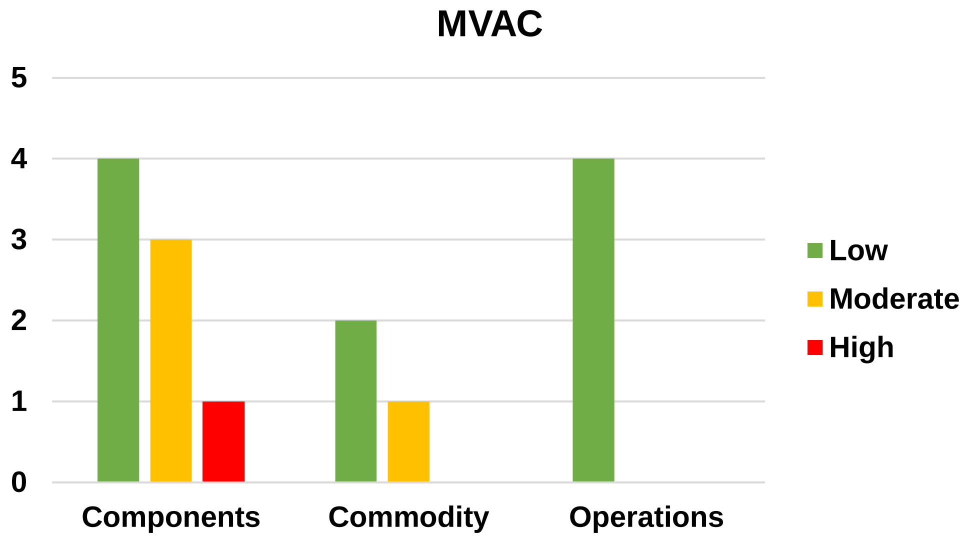
Description	Engineering Assessment	Cost
Major Components:		
Generator Set	Less Space/Weight	Lower
Power Conversion Modules	Design Dependent	Same
Propulsion Motor	More Magnets	Higher
Rectifiers/Inverters/Transformers	Design Dependent	Same
Energy Storage	Expect Less	Lower
Cables/Bus Pipe	Expect Less Weight/Raw Material	Lower
Circuit Protection	More Space/Weight	Higher
Controls	More Complex	Higher
Operations:		
Operating Costs (Manpower, sustaining support, and maintenance)	Expect Less	Lower
Fuel Cost	Expect Less	Lower
Thermal Efficiency	Expect More Efficient	Lower
Hardware Reliability (MTBF and MTBR)	Assumed Same	Same
Major Commodities:		
Copper	Assume Less	Lower
Silicon Steel	Assume Less	Lower
Silicon Carbide	Assume More	Higher
SWaP:		
Space	Expect Less	Lower
Weight	Expect Less	Lower
Power	Assumed Same	Same

Level of Uncertainty	Low	Moderate	High

MVDC Cost Comparison Summary







MVDC system traits have greater expected cost uncertainty than MVAC

MVDC System Producibility Risk Assessment

Manufacturing Risk Category	Risk	Rationale
Technology & Industrial Base	High	Unknown if significant investments are required due to lack of data for the requirements, design, and technology at the component and system level
Design	High	MVDC is not mature
Cost & Funding	High	Cost data does not exist; cost targets are not established
Materials	Moderate	Basic raw materials, components, subassemblies are known; accurate quantities are not known
Process Capability & Control	Low	Industry past performance to respond to new/unique Navy technology and design
Quality Management	Low	Industry past performance
Manufacturing Workforce (Engineering & Production)	Moderate	Skills, certs, requirements known; availability and capacity unknown
Facilities	High	Requirements for capabilities and capacities unknown
Manufacturing Management	Low	Industry past performance to respond to new/unique Navy technology and design

Level of Uncertainty	Low	Moderate	High

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Summary

- Cost Comparison results suggest that MVDC could be cheaper than MVAC, however, there is an overall high level of uncertainty in the MVDC costs due to reliance on subjective assessment (e.g. SME input) and lack of historical data
- Producibility Risk Assessment results show a high level of risk in the MVDC manufacturing capabilities, which has significant impact on investment decisions
- Navy would bear the entire cost of development and capital investment to build these components.

Navy would undertake significant risk and uncertainty in the pursuit of MVDC

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Navy's Decision

- Not proceeding with MVDC due to the combined results from all four discrete studies
- Industry investment can be leveraged once technology reaches adequate readiness level

Recommendations for Follow-On MVDC Cost Engineering Analysis

- Conduct a Complete BCA
  - Assume a 12kV as "Medium Voltage"
  - Engineering Build-up Approach
- Qualitative Benefits Ranking
  - Major Components
  - Operations
  - Commodities
- No Commercial Demand – Navy Assumes All Risk
  - Research and Development
  - Producibility

Author Biographies

Richard Shea (CCEA®) joined Herren Associates in 2016 as an Associate supporting NAVSEA 05C. Mr. Shea has years of experience supporting various Department of Defense (DoD) Organizations from the DoD Health Affairs, Defense Health Agency (DHA), Department of Veterans Affairs, US Marine Corps, US Army, and now the US Navy. Mr. Shea is experienced in building life cycle cost estimates, business case analysis, and independent cost estimates supporting DoD systems and services.

Victor Sorrentino retired from the United States Navy in 2018 after serving more than 21 years as a Surface Warfare Officer. Notable tours include Chief of Staff, Standing NATO Maritime Group TWO and Deputy Director, Operational Energy Office on the Secretary of the Navy Staff. Today, Mr. Sorrentino is the Director of Energy Programs at Herren Associates where he has continued to support the US Navy's executive decision-making process for energy innovation and investment.

Ann Hawpe is a co-founding member of Herren's Program Analysis and Cost Engineering practice. She established and managed the firm's business with the Navy, USMC, and USCG for almost 20 years and leads a team of 30 cost estimators. Ms. Hawpe identifies trends in cost estimating and delivers advanced training throughout the cost community. She holds a BS in Industrial and Systems engineering from Virginia Tech and a MS in Systems Engineering from GW University.

Henry Jones graduated from Old Dominion University with a B.S. in Mechanical Engineering with a focus in Mechanical Systems and Design. He began his career as a valve engineer specializing on Nimitz-class aircraft carriers and moved onto roles as a marine engineer designing auxiliary systems and as direct support to Navy Ship Design Managers. Currently, he is the Lead Model-Based Systems Engineer at Herren Associates where he interfaces extensively with Navy power and energy systems.

Backup