ELECTRICAL AND THERMAL SYSTEM
CONSIDERATIONS FOR MVDC
SUPERCONDUCTING DISTRIBUTION ON NAVY SHIPS

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Challenge

- Set appropriate metrics that are research targets for the adoption of superconducting power cables for ships
- For motors and generators the key metric is generally recognized
  - $\gg 1$ T air gap magnetic field
- Metrics for cables in general
  - Smaller
  - Lighter
  - Traditional reliability
    - But not a particular metric for superconducting cables vs. conventional
Generic Ship Power System
## S3D Cable Sizing

<table>
<thead>
<tr>
<th></th>
<th>S3D</th>
<th>New DC Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage of cable bundle, kV</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Rated current of cable bundle, kA</td>
<td>10</td>
<td>8.3</td>
</tr>
<tr>
<td>Total bus length, m</td>
<td>138</td>
<td>138</td>
</tr>
<tr>
<td>Number of cable bundle sections</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Average cable bundle length, m</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>OD of each cable, mm</td>
<td>57.9</td>
<td>57.9</td>
</tr>
<tr>
<td>Number of cables per bundle</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Resistance per unit length, mΩ/m</td>
<td>0.030</td>
<td>0.036</td>
</tr>
<tr>
<td>Weight per unit length, kg/m</td>
<td>50.8</td>
<td>42.3</td>
</tr>
<tr>
<td>Number of connections to dc bus</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

TABLE 1: Main DC Bus Data from S3D Baseline Design [19]
Potential Comparison

• Losses based on generalized mission profile
  • Analogous to vehicle drive cycles

<table>
<thead>
<tr>
<th>Mission Segment</th>
<th>Days</th>
<th>Electrical Power MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peacetime Cruise</td>
<td>90</td>
<td>23</td>
</tr>
<tr>
<td>Sprint to Station</td>
<td>1</td>
<td>43.5</td>
</tr>
<tr>
<td>On Station</td>
<td>7</td>
<td>23.7</td>
</tr>
</tbody>
</table>

• Room temperature: 6.2 kW
• Superconductors: 9.4 kW

But neither seem to be near the limits of the technology
Weight

- Weight is an area in which superconductivity appears to have a potential advantage
  - For a point design based on notional circuit
    - Conventional: 4,800 kg
    - Superconducting: 480 kg
- The advantage achieved by superconductors is due to maintaining a fixed temperature.
  - Analysis is needed to see how much the apparent benefit is reduced if copper or aluminum is cooled
Cable Reliability - I

• Reduce size and weight without reducing reliability
  • NAVAIR cable failure is largely due to vibration-induced abrasion.
    • Serious abrasion less likely in ships due to need for magnetic field cancelling leading to a metal shield
    • Vibration can still be an issue
  • Utility cable failure largely at splices and terminations
    • Short ship runs mean that splices can be avoided
    • Terminations are numerous and potentially problematic
Cable Reliability - II

• Insulation thickness is driven by mechanical not electrical limits.
  • Electrically, a thin varnish coating would likely be good enough
    • But risk would be unacceptable due to mechanical strength
      • Polymers, ceramics, or superconductors
• Lack of relevant engineering data on reliability is an impediment
  • Sparse for conventional cable
  • Nearly non-existent for superconducting cable
External Factors

• Without major breakthroughs, superconductivity is unlikely to be brought on ships by other than a cable application.
  • Motors and generators
    • Limited achievable benefit
  • Storage
    • SMES works
      • But smaller, lighter options are available
Conclusions

- Process developed to compare superconducting and advanced cables.
- Challenges in dc ship power system
  - Multiple taps
  - Lack of reliability data
- Conventional cable technology does not have the common courtesy to stop getting better
- So, primary emphasis on data for improved conventional cables