



**ESRDC Notional Ship Data**

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Revision History

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**Document Use and Modification**

This document will be updated as additional information becomes available, and the revision history will be tabulated above. Please make changes in the Word version of this document using track changes. When sufficient recommendations for change are made, they will be incorporated and a new revision will be released.

This document will be stored on the ESRDC website in .pdf format, along with a Word format and an Excel spreadsheet containing the data.

Note that this is version 0.1; there are a few items that still need to be added to the document. These items are highlighted in yellow.

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# Introduction

The Electric Ship Research and Development Consortium (ESRDC) has created a notional ship for use as a test case in developing research to advance the state of the art in electric ship concepts. The notional ship is a nominal 100MW, 10,000 ton displacement surface combatant, using data compiled from open source documentation. This document provides data relative to the ship, for use by ESRDC researchers.

A model of the ship was created in the Smart Ship Systems Design (S3D) design environment, to include electrical, piping and mechanical schematics along with three-dimensional placement of equipment on a ship hull in a naval architecture view.

Please note that this ship was designed by ESRDC researchers and is not intended to meet or represent any current or future Navy designed vessel. It is merely a somewhat realistic representative example for testing electrical and thermal system concepts.

The systems delineated in this document are a single, baseline reference ship. It is intended that alternative designs can be tested against this design; these alternatives may make adjustments such as replacing single pieces or classes of equipment, rearranging equipment using different topology and connectivity, or replacing entire support systems with systems using a different paradigm entirely.

# Notes

## Nomenclature

Decks are numbered sequentially downwards with the main deck numbered 1 and the next deck numbered 2, etc. Decks above main deck are referred to as levels, with the deck above main deck called the “01 level”, increasing upwards.

Bulkheads are numbered from the bow of the ship, increasing aft.

Zones are numbered beginning at the bow of the ship, increasing aft. In this notional ship, zones are divided by watertight bulkheads and extend from baseline to the top of the ship. While this is an accepted practice, it is not the only method for dividing ships into zones; in some cases, zonal divisions may not be vertical planes, and there may be horizontal divisions as well. For example, the superstructure could be a separate zone.

The Ships Work Breakdown Structure (SWBS) is a Navy categorization system for organizing equipment. SWBS numbers are included for reference.



z

y

x

Zone 4

8

Bulkheads:

13

12

11

10

9

7

6

5

4

2

3

1

2nd Deck

4th Deck

3rd Deck

03 Level

02 Level

01 Level

Main Deck

Zone 1

Zone 2

Zone 3

Figure 1. Nomenclature (old hullform – need to update; decks and bhds are in the proper (new) locations

## Origin

The origin is located at the intersection of the forward perpendicular, the baseline, and the centerline. The forward perpendicular is located where the design waterline crosses the bow. The x-axis is positive pointing aft in the longitudinal direction; the y-axis is positive pointing to the starboard side of the ship, and the z-axis is positive pointing up.

## Margining

Mission systems, aggregated loads and propulsion loads do not include a margin as modeled in this ship design in S3D. Service system items such as cables, switchboards, disconnects, and converters are sized to carry 20% greater load than is connected. Generators and chillers were selected for 20% greater capacity than the connected load demands.

## Energy Storage

The only energy storage explicitly modeled in this baseline ship design is the energy storage modules (ESMs) associated with the railgun. In this instantiation, the railgun ESMs are available only to the railgun and not for any other purpose. Although the Integrated Power Node Centers (IPNCs) and Power Conversion Module 1As (PCM1As) are designed to contain energy storage, the current model does not include energy storage in these locations.

# Hullform Data

The notional ship is a destroyer-sized monohull with a 10,000 ton displacement.

## Hullform View



Figure 2. S3D view of hull. This is the old 10kt ship; need image of new hull (similar, but not exactly the same).

## Hullform Dimensions

|  |  |
| --- | --- |
| Length Overall | 163 m |
| Beam Overall | 20.9 m |
| Depth Overall (baseline to top of superstructure) | 23.6 m |
| Length Between Perpendiculars | 152.3 m |
| Beam at Waterline | 18.9 m |
| Draft | 6.6 m |
| Depth at Midship | 12.8 m |

## Bulkhead Locations and Deck Heights

Transverse watertight bulkheads in the hull are located at the indicated distance in meters measured aft of the forward perpendicular. Deck heights are given in meters above baseline

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Bulkhead Number | Location (m) |  | Deck Number | Height (m) |
| 1 | 8 |  | 03 Level | 23.6 |
| 2 | 19 |  | 02 Level | 20.6 |
| 3 | 30 |  | 01 Level | 16.7 |
| 4 | 38 |  | Main Deck | 12.7 |
| 5 | 52 |  | Second Deck | 10.1 |
| 6 | 60 |  | Third Deck | 7 |
| 7 | 76 |  | Fourth Deck | 4.3 |
| 8 | 85 |  | Inner Bottom | 1.2 |
| 9 | 101 |  | *Top of Hangar* | *14.0* |
| 10 | 109 |  |  |  |
| 11 | 116 |  |  |  |
| 12 | 129 |  |  |  |
| 13 | 140 |  |  |  |

# Propulsion Data

## Speed Data

The maximum speed is the highest speed attainable by the ship in calm water. The sustained speed is the maximum speed the ship can sustain for long periods of time in calm water. Battle speed is the maximum speed the ship can attain with all shipboard electrical systems operating at maximum power. Endurance speed is the design speed for long transits. The range is the distance a ship can travel, without refueling, at the endurance speed with a given nominal electrical load.

|  |  |
| --- | --- |
| Max Speed | 32.0 kt |
| Sustained Speed | 30.5 kt |
| Battle Speed | 27.3 kt |
| Endurance Speed | 18.0 kt |
| Range  | 2478 nm |

## Speed-Power Curve

The tables below display power in kW required to drive the ship at the given speed in knots. The power is the shaft power required at the output of the propulsion motor; thus, it already accounts for any changes in efficiency due to the propeller design and location and any losses in the transmission through the shaft and bearings.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Speed (knots)** | **Power (kW)** |  | **Speed (knots)** | **Power (kW)** |
| 5 | 138 |  | 19 | 8,157 |
| 6 | 241 |  | 20 | 9,698 |
| 7 | 372 |  | 21 | 11,359 |
| 8 | 534 |  | 22 | 12,894 |
| 9 | 794 |  | 23 | 14,151 |
| 10 | 1,121 |  | 24 | 15,482 |
| 11 | 1,502 |  | 25 | 17,004 |
| 12 | 1,918 |  | 26 | 20,755 |
| 13 | 2,359 |  | 27 | 24,780 |
| 14 | 2,851 |  | 28 | 29,074 |
| 15 | 3,432 |  | 29 | 35,362 |
| 16 | 4,434 |  | 30 | 42,840 |
| 17 | 5,543 |  | 31 | 50,811 |
| 18 | 6,760 |  |  |  |

## Propulsion Equipment

The two propulsion motors are Converteam 15-phase Advanced Induction Motors. For information on the motor drives, see the section on Power Generation and Distribution.

## Propulsion Equipment Data (Dimensions, Location)

|  |  |  |
| --- | --- | --- |
| Identification | Dimensions | Location |
| Name | **SWBS** | **Length (m)** | **Width (m)** | **Height (m)** | **Weight (kg)** | **Zone** | **X (m)** |  **Y (m)** | **Z (m)** |
| Propulsion Motor | 235 | 5.1 | 5.4 | 5.3 | 127,000 | 2 | 80.29 | 3.75 | 3.49 |
| Propulsion Motor | 235 | 5.1 | 5.4 | 5.3 | 127,000 | 3 | 104.8 | -3.75 | 3.52 |
| Motor Drive | 235 | 4.8 | 3.5 | 2.36 | 9,210 | 2 | 79.9 | -1.06 | 2.74 |
| Motor Drive | 235 | 4.8 | 3.5 | 2.36 | 9,210 | 3 | 105.02 | 0.58 | 2.11 |

## Propulsion Equipment Data (Power, Efficiency)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Name | Rated Mechanical Power (kW) | Rated Electrical Power (MW) | Efficiency (%) | Primary Rated Voltage (kV) | Primary Current Type  | Secondary Rated Voltage (kV) | Secondary Current Type  |
| Propulsion Motor | 36.5 | 37.5 | var | 6.9 | AC |  |  |
| Propulsion Motor | 36.5 | 37.5 | var | 6.9 | AC |  |  |
| Motor Drive |  | 37.5 | 98 | 12 | DC | 6.9 | AC |
| Motor Drive |  | 37.5 | 98 | 12 | DC | 6.9 | AC |

### Propulsion Motor Efficiency Curve

|  |  |
| --- | --- |
| Percent Full Load | Efficiency (%) |
| 0 | 10 |
| 20 | 80 |
| 35 | 92 |
| 60 | 96 |
| 100 | 95 |

# Mission Equipment Data

To place the design in the realm of future capabilities, we performed a survey of new weapon and sensor technologies in the world’s navies and selected several leading-edge technologies that would tax the power and cooling systems onboard the ship. Using publicly available information, a list of sensors, communications and weapons equipment along with the associated power and cooling system loads, efficiencies, weights and dimensions was compiled. Information on the sources of data and decisions made in sizing the equipment can be found in Appendix B of [Smart et al., 2017].

Some mission packages include the weapon or sensor and “support equipment.” Although the support equipment is represented as a single component, this component may in actuality be realized as several cabinets and functions. For the purposes of this notional vessel, we assume the mission packages to be “black boxes” that require power and cooling. Note that the weapon and support equipment may have separate efficiencies in order for the cooling system to remove heat produced in different locations.

The railgun system is comprised of the railgun, four energy storage components, four charging power supplies, and an electrical storage mechanism (ESM). The ESM stores incoming power from the bus during the railgun discharge cycle to maintain a constant load on the ship’s electrical distribution system of approximately 17 MW instead of inducing a reverse pulse during the discharge. There is also a relatively small ammunition handling equipment load. The S3D model of the rail gun mount is assigned an efficiency of 100% because this model does not address the cooling system for the railgun mount itself.

### Weapons Data (Dimensions, Location)

|  |  |  |
| --- | --- | --- |
| Identification | Dimensions | Location |
| Name | SWBS  | Length (m) | Width (m) | Height (m) | Weight (kg) | Zone | X (m) | Y (m) | Z (m) |
| Active Denial System | 711 | 0.6 | 2 | 2 | 1,000 | 2 | 80.5 | -5.6 | 19.83 |
| Active Denial System | 711 | 0.6 | 2 | 2 | 1,000 | 2 | 80.5 | 5.6 | 19.83 |
| Laser | 711 | 4 | 4 | 3 | 4,000 | 4 | 113.37 | 0 | 15.47 |
| Laser Support Equipment | 711 | 6 | 4 | 3 | 4,000 | 3 | 112.64 | 0 | 11.69 |
| Vertical Launch System | 721 | 6.8 | 5.08 | 7.7 | 56,000 | 1 | 24.84 | 0 | 8.85 |
| Vertical Launch System | 721 | 6.8 | 5.08 | 7.7 | 56,000 | 3 | 105.03 | 0 | 10.97 |
| Railgun | 711 | 3 | 10 | 3 | 78,000 | 2 | 44.03 | 0 | 14.32 |
| Railgun Capacitor Bank | 711 | 4 | 2 | 1 | 15,369 | 2 | 41.05 | 1.5 | 9.08 |
| Railgun Capacitor Bank | 711 | 4 | 2 | 1 | 15,369 | 2 | 41.05 | -1.5 | 7.62 |
| Railgun Capacitor Bank | 711 | 4 | 2 | 1 | 15,369 | 2 | 46.6 | 1.5 | 9.18 |
| Railgun Capacitor Bank | 711 | 4 | 2 | 1 | 15,369 | 2 | 46.6 | -1.5 | 7.62 |
| Railgun dc Charging Power Supply | 711 | 7 | 1.6 | 2.36 | 5,000 | 2 | 42.4 | 3.8 | 8.3 |
| Railgun dc Charging Power Supply | 711 | 7 | 1.6 | 2.36 | 5,000 | 2 | 42.4 | -3.8 | 8.3 |
| Railgun dc Charging Power Supply | 711 | 7 | 1.6 | 2.36 | 5,000 | 2 | 48.2 | 6 | 8.3 |
| Railgun dc Charging Power Supply | 711 | 7 | 1.6 | 2.36 | 5,000 | 2 | 48.2 | -6 | 8.3 |
| Railgun Energy Storage Module | 711 | 2.17 | 1.9 | 1.51 | 15,000 | 2 | 50.5 | -3.26 | 7.88 |
| Railgun Switchboard | 324 | 3.07 | 0.75 | 1.47 | 840 | 2 | 49.58 | 0 | 8.16 |
| Railgun Ammunition Handling | 711 | 6 | 2 | 2.36 | 13,560 | 2 | 44.85 | 0 | 11.37 |

### Weapons Data (Electrical Power, Efficiency)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name | Rated Electrical Power (MW) | Efficiency (%) | Primary Rated Voltage (kV) | Primary Current Type  | Secondary Rated Voltage (kV) | Secondary Current Type  |
| Active Denial System | 0.3 | 35 | 1 | DC |  |  |
| Active Denial System | 0.3 | 35 | 1 | DC |  |  |
| Laser | 0.3 | 100 | 1 | DC |  |  |
| Laser Support Equipment | 0.31 | 25 | 1 | DC |  |  |
| Vertical Launch System | 0.48 | 75 | 0.45 | AC |  |  |
| Vertical Launch System | 0.48 | 75 | 0.45 | AC |  |  |
| Railgun | 10 | 100 | 1 | DC |  |  |
| Railgun Capacitor Bank | 3.58 | 98 | 1 | DC | 1 | DC |
| Railgun Capacitor Bank | 3.58 | 98 | 1 | DC | 1 | DC |
| Railgun Capacitor Bank | 3.58 | 98 | 1 | DC | 1 | DC |
| Railgun Capacitor Bank | 3.58 | 98 | 1 | DC | 1 | DC |
| Railgun dc Charging Power Supply | 4.16 | 98 | 12 | DC | 1 | DC |
| Railgun dc Charging Power Supply | 4.16 | 98 | 12 | DC | 1 | DC |
| Railgun dc Charging Power Supply | 4.16 | 98 | 12 | DC | 1 | DC |
| Railgun dc Charging Power Supply | 4.16 | 98 | 12 | DC | 1 | DC |
| Railgun Energy Storage Module | 17 | 98 | 12 | DC | 12 | DC |
| Railgun Switchboard |  | 100 | 12 | DC |  |  |
| Railgun Ammunition Handling | 0.4 | 100 | 1 | DC |  |  |

### Sensor Data (Dimensions, Location)

|  |  |  |
| --- | --- | --- |
| Identification | Dimensions | Location |
| Name | SWBS | Length (m) | Width (m) | Height (m) | Weight (kg) | Zone | X (m) | Y (m) | Z (m) |
| Integrated Topside Array | 410 | 2 | 1 | 1 | 2,000 | 2 | 72 | -7.6 | 24.23 |
| Integrated Topside Array | 410 | 2 | 1 | 1 | 2,000 | 2 | 72 | 7.6 | 24.23 |
| Integrated Topside Support Equipment | 410 | 2.5 | 2.5 | 2.5 | 2,000 | 2 | 72 | -5.82 | 22 |
| Integrated Topside Support Equipment | 410 | 2.5 | 2.5 | 2.5 | 2,000 | 2 | 72 | 5.82 | 22 |
| Hull-mounted Sonar | 461 | 5 | 5 | 1.5 | 30,000 | 1 | 4 | 0 | 0 |
| Sonar Support Equipment | 461 | 10 | 2 | 5.3 | 15,000 | 1 | 14.19 | 0 | 3.85 |
| Towed-Array Sonar | 461 | 3 | 6 | 2 | 14,000 | 4 | 148.61 | 3.5 | 8.12 |
| S-band Radar Array | 456 | 4 | 1 | 4 | 10,000 | 2 | 55 | -5 | 18.75 |
| S-band Radar Array | 456 | 4 | 1 | 4 | 10,000 | 2 | 55 | 5 | 18.75 |
| S-band Radar Array | 456 | 4 | 1 | 4 | 10,000 | 3 | 100 | 0 | 18.75 |
| X-band Radar Array | 456 | 2.5 | 1 | 2.5 | 2,500 | 2 | 55.5 | -3.85 | 23 |
| X-band Radar Array | 456 | 2.5 | 1 | 2.5 | 2,500 | 2 | 55.5 | 3.85 | 23 |
| X-band Radar Array | 456 | 2.5 | 1 | 2.5 | 2,500 | 3 | 99.5 | 0 | 23 |
| Radar Support Equipment | 456 | 5 | 10 | 4 | 32,000 | 2 | 57.55 | 0 | 14.85 |
| Radar Support Equipment | 456 | 5 | 5 | 4 | 16,000 | 3 | 95.33 | 0 | 14.85 |

### Sensor Data (Electrical Power, Efficiency)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Name | Rated Electrical Power (MW) | High Energy Power (MW) | Medium Energy Power (MW) | Low Energy Power (MW) | Efficiency (%) | Primary Rated Voltage (kV) | Primary Current Type  |
| Integrated Topside Array | 1.5 | 1.5 | 0.38 | 0 | 33.33 | 1 | DC |
| Integrated Topside Array | 1.5 | 1.5 | 0.38 | 0 | 33.33 | 1 | DC |
| Integrated Topside Support Equipment | 1.5 |  |  |  | 75 | 1 | DC |
| Integrated Topside Support Equipment | 1.5 |  |  |  | 75 | 1 | DC |
| Hull-mounted Sonar | 0.3 |  |  |  | 100 | 1 | DC |
| Hull-mounted Sonar Support Equipment | 0.3 |  |  |  | 75 | 1 | DC |
| Towed-Array Sonar | 0.15 |  |  |  | 75 | 1 | DC |
| S-band Radar Array | 0.75 | 0.75 | 0.38 | 0.02 | 50 | 1 | DC |
| S-band Radar Array | 0.75 | 0.75 | 0.38 | 0.02 | 50 | 1 | DC |
| S-band Radar Array | 0.75 | 0.75 | 0.38 | 0.02 | 50 | 1 | DC |
| X-band Radar Array | 0.24 | 0.24 | 0.12 | 0.01 | 50 | 1 | DC |
| X-band Radar Array | 0.24 | 0.24 | 0.12 | 0.01 | 50 | 1 | DC |
| X-band Radar Array | 0.24 | 0.24 | 0.12 | 0.01 | 50 | 1 | DC |
| Radar Support Equipment | 2 |  |  |  | 60 | 1 | DC |
| Radar Support Equipment | 1 |  |  |  | 60 | 1 | DC |

## Aggregated Vital and Non-Vital Loads

Some electrical loads are individually modeled, such as the Railgun and the Radar; these loads are described in “mission loads” above. The remainder of all electrical loads were estimated and aggregated into a single dc vital load and a single ac non-vital load for each zone. Since these are representative aggregated loads and not actual loads with specific locations and sizes, they are not assigned a weight or dimensions and no cable or cooling piping is routed to them. They are assigned an electrical power and an efficiency to provide both and electrical and a heat load to the ship’s systems.

### Aggregated Vital and Non-Vital Load Data

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Name | SWBS | Zone | Rated Electrical Power (MW) | High Energy Power (MW) | Medium Energy Power (MW) | Low Energy Power (MW) | Efficiency (%) | Primary Rated Voltage (kV) | Primary Current Type  |
| Aggregated AC Non-vital Loads | 600 | 1 | 0.03 | 0.03 | 0.01 | 0 | 80 | 0.45 | AC |
| Aggregated AC Non-vital Loads | 600 | 2 | 0.04 | 0.04 | 0.02 | 0 | 80 | 0.45 | AC |
| Aggregated AC Non-vital Loads | 600 | 3 | 0.04 | 0.04 | 0.02 | 0 | 80 | 0.45 | AC |
| Aggregated AC Non-vital Loads | 600 | 4 | 0.03 | 0.03 | 0.01 | 0 | 80 | 0.45 | AC |
| Aggregated DC Vital Loads | 600 | 1 | 1.43 | 1.43 | 0.65 | 0.09 | 80 | 1 | DC |
| Aggregated DC Vital Loads | 600 | 2 | 1.61 | 1.61 | 0.96 | 0.27 | 80 | 1 | DC |
| Aggregated DC Vital Loads | 600 | 3 | 1.61 | 1.61 | 0.96 | 0.26 | 80 | 1 | DC |
| Aggregated DC Vital Loads | 600 | 4 | 1.51 | 1.51 | 0.77 | 0.18 | 80 | 1 | DC |

# Power Generation Module (PGM)

A power generation module (PGM) in this design is composed of an engine, a generator, a breaker and a rectifier.

The engines and generators were selected in order to meet the power requirements of the ship and to have generation capability in each zone. Thus, there is a Caterpillar C18 emergency diesel generator in zone 1, two LM2500+G4 gas turbine generators in zone 2, one LM2500+G4 and one LM500 gas turbine generator in zone 3, and one LM500 gas turbine generator in zone 4, for a total of 95MW of installed power.

The generators are dual-wound generators with a separate rectifier for each set of windings and thus can provide power to each bus separately.

The generation power of the generators is rated for 100oF; it is expected that the generator may produce significantly greater than 100% power for short periods of time, especially if the ambient temperature is low. Therefore, the rectifiers are rated for higher power than the generators with which they are associated.

An ac breaker is placed between the generator and rectifier.

### Power Generation Module Data (Dimensions, Location)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Name | SWBS | Height (m) | Width (m) | Length (m) | Weight (kg) | Zone |  X (m) |  Y (m) |  Z (m) |
| Emergency Diesel Generator (EDG) | 311 | 1.57 | 1.1 | 3.21 | 6,600 | 1 | 34.93 | 2.75 | 3.8 |
| LM2500+G4 Gas Turbine Generator | 311 | 4 | 3.81 | 14.3 | 97,045 | 2 | 67.7 | -2.5 | 3.19 |
| LM2500+G4 Gas Turbine Generator | 311 | 4 | 3.81 | 14.3 | 97,045 | 2 | 67.7 | 2.5 | 3.19 |
| LM2500+G4 Gas Turbine Generator | 311 | 4 | 3.81 | 14.3 | 97,045 | 3 | 93.13 | -3 | 3.19 |
| LM500 Gas Turbine Generator | 311 | 2.39 | 2.36 | 7.14 | 27,273 | 3 | 89.02 | 3 | 3.19 |
| LM500 Gas Turbine Generator | 311 | 2.39 | 2.36 | 7.14 | 27,273 | 4 | 133.8 | 6.51 | 8.15 |
| EDG Breaker | 311 | 0.4 | 0.4 | 0.4 | 25 | 1 | 31.99 | 2.63 | 5.16 |
| LM2500 Breaker | 311 | 0.8 | 0.8 | 0.8 | 250 | 2 | 75.4 | -4.5 | 5.02 |
| LM2500 Breaker | 311 | 0.8 | 0.8 | 0.8 | 250 | 3 | 75.4 | -4.5 | 3.8 |
| LM2500 Breaker | 311 | 0.8 | 0.8 | 0.8 | 250 | 2 | 75.4 | 4.5 | 5.02 |
| LM2500 Breaker | 311 | 0.8 | 0.8 | 0.8 | 250 | 3 | 75.4 | 4.5 | 3.8 |
| LM2500 Breaker | 311 | 0.8 | 0.8 | 0.8 | 250 | 2 | 100.8 | -4.5 | 5.02 |
| LM2500 Breaker | 311 | 0.8 | 0.8 | 0.8 | 250 | 2 | 100.8 | -4.5 | 3.8 |
| LM500 Breaker | 311 | 0.6 | 0.6 | 0.6 | 50 | 3 | 93 | 3.55 | 5.02 |
| LM500 Breaker | 311 | 0.6 | 0.6 | 0.6 | 50 | 4 | 93 | 3.55 | 3.8 |
| LM500 Breaker | 311 | 0.6 | 0.6 | 0.6 | 50 | 3 | 138 | 8 | 10.02 |
| LM500 Breaker | 311 | 0.6 | 0.6 | 0.6 | 50 | 4 | 138 | 8 | 8.8 |
| EDG Rectifier | 311 | 2.36 | 3.4 | 1.6 | 2,550 | 1 | 31.9 | 2.59 | 2.88 |
| LM2500 Rectifier | 311 | 2.36 | 1.6 | 5.5 | 5,730 | 2 | 64 | -6 | 2.85 |
| LM2500 Rectifier | 311 | 2.36 | 1.6 | 5.5 | 5,730 | 2 | 70.9 | -6 | 2.85 |
| LM2500 Rectifier | 311 | 2.36 | 1.6 | 5.5 | 5,730 | 2 | 64 | 6 | 2.85 |
| LM2500 Rectifier | 311 | 2.36 | 1.6 | 5.5 | 5,730 | 2 | 70.9 | 6 | 2.85 |
| LM2500 Rectifier | 311 | 2.36 | 1.6 | 5.5 | 5,730 | 3 | 96.31 | -6.5 | 2.85 |
| LM2500 Rectifier | 311 | 2.36 | 1.6 | 5.5 | 5,730 | 3 | 89.88 | -6.5 | 2.85 |
| LM500 Rectifier | 311 | 2.36 | 1.6 | 3.4 | 2,910 | 3 | 91.7 | 5.38 | 2.85 |
| LM500 Rectifier | 311 | 2.36 | 1.6 | 3.4 | 2,910 | 3 | 87.3 | 5.38 | 2.85 |
| LM500 Rectifier | 311 | 2.36 | 1.6 | 3.4 | 2,910 | 4 | 132 | 3.54 | 8.5 |
| LM500 Rectifier | 311 | 2.36 | 1.6 | 3.4 | 2,910 | 4 | 136.3 | 3.54 | 8.5 |

### Power Generation Module Data (Electrical Power, Efficiency)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Name | Rated Electrical Power (MW) | Rated Continuous Current (kA) | Efficiency (%) | Primary Rated Voltage (kV) | Primary Current Type  | Secondary Rated Voltage (kV) | Secondary Current Type  |
| Emergency Diesel Generator (EDG) | 0.55 |  | var | 6.9 | AC |  |  |
| LM2500+G4 Gas Turbine Generator | 29 |  | var | 6.9 | AC |  |  |
| LM2500+G4 Gas Turbine Generator | 29 |  | var | 6.9 | AC |  |  |
| LM2500+G4 Gas Turbine Generator | 29 |  | var | 6.9 | AC |  |  |
| LM500 Gas Turbine Generator | 3.7 |  | var | 6.9 | AC |  |  |
| LM500 Gas Turbine Generator | 3.7 |  | var | 6.9 | AC |  |  |
| EDG Breaker |  | 0.1 |  | 6.9 | AC |  |  |
| LM2500 Breaker |  | 2.5 |  | 6.9 | AC |  |  |
| LM2500 Breaker |  | 2.5 |  | 6.9 | AC |  |  |
| LM2500 Breaker |  | 2.5 |  | 6.9 | AC |  |  |
| LM2500 Breaker |  | 2.5 |  | 6.9 | AC |  |  |
| LM2500 Breaker |  | 2.5 |  | 6.9 | AC |  |  |
| LM2500 Breaker |  | 2.5 |  | 6.9 | AC |  |  |
| LM500 Breaker |  | 0.5 |  | 6.9 | AC |  |  |
| LM500 Breaker |  | 0.5 |  | 6.9 | AC |  |  |
| LM500 Breaker |  | 0.5 |  | 6.9 | AC |  |  |
| LM500 Breaker |  | 0.5 |  | 6.9 | AC |  |  |
| EDG Rectifier | 0.66 |  | 98 | 6.9 | AC | 12 | DC |
| LM2500 Rectifier | 17.4 |  | 98 | 6.9 | AC | 12 | DC |
| LM2500 Rectifier | 17.4 |  | 98 | 6.9 | AC | 12 | DC |
| LM2500 Rectifier | 17.4 |  | 98 | 6.9 | AC | 12 | DC |
| LM2500 Rectifier | 17.4 |  | 98 | 6.9 | AC | 12 | DC |
| LM2500 Rectifier | 17.4 |  | 98 | 6.9 | AC | 12 | DC |
| LM2500 Rectifier | 17.4 |  | 98 | 6.9 | AC | 12 | DC |
| LM500 Rectifier | 2.24 |  | 98 | 6.9 | AC | 12 | DC |
| LM500 Rectifier | 2.24 |  | 98 | 6.9 | AC | 12 | DC |
| LM500 Rectifier | 2.24 |  | 98 | 6.9 | AC | 12 | DC |
| LM500 Rectifier | 2.24 |  | 98 | 6.9 | AC | 12 | DC |

### Specific Fuel Consumption

|  |  |  |
| --- | --- | --- |
| LM2500+G4 Specific Fuel Consumption | LM500 Specific Fuel Consumption | Diesel Specific Fuel Consumption |
| Power (MW) | **SFC (kg/Mj)** | **Power (MW)** | **SFC (kg/Mj)** | **Power (MW)** | **SFC (kg/Mj)** |
| 2 | 0.268 | 0.3 | 0.186 | 0.159 | 0.066 |
| 8 | 0.155 | 0.9 | 0.124 | 0.184 | 0.064 |
| 20 | 0.072 | 1.5 | 0.093 | 0.272 | 0.063 |
| 29 | 0.062 | 2.25 | 0.082 | 0.31 | 0.061 |
|  |  | 3.7 | 0.077 | 0.55 | 0.061 |

# Power Distribution Data

The electrical distribution system is modeled after the proposed MVDC architecture circulated by the U.S. Navy [Doerry 2016] as depicted in Figure 3. Main bus distribution voltage is 12 kV (+-6kV). The notional ship described herein uses four electrical zones instead of six and is modified to accommodate the equipment selected for this ship design, but uses the same paradigm for distribution, e.g. cross-zone connections between ac load centers in adjacent zones, dedicated converters for electrical loads greater than 1 MW, and a combination of bus nodes, power conversion modules (PCM 1As), integrated power node centers (IPNCs) and ac Load Centers (ACLCs) to provide the required power supply. The resultant power distribution system is depicted in Figure 4. Note that all loads are individually switched; although some ports on the Bus Nodes, ACLCs and IPNCs appear to have multiple loads connected to a single port, this is a rendering problem and does not indicate that the loads are switched as a group. Similarly, cables that appear coincident are actually separate.



Figure 3. Proposed Navy distribution system [Doerry 2016]

## Electrical View



Figure 4. Notional Ship Electrical Distribution System, from S3D Model (model simplified to make connections more clear).

## Power Conversion and Distribution Equipment

Bus nodes provide dc disconnect capability for each line. They are sized for the number of connections that are made.

The PCM1A (power conversion module 1A) converts power from bus voltage to an internal 1kVdc bus, then provides power at1kVdc to the IPNC via a disconnect, and power at 450Vac to the ACLC via a circuit breaker.

The ACLC (ac Load Center) is a traditional 450 Vac switchboard, with a connection to the next zone load center for casualty power operations.

The IPNC (integrated power node center) supplies power to loads with special power needs, such as dc, 400Hz ac, or variable speed motors, and supplies power to un-interruptible loads; thus, it contains energy storage for about one second.

In normal operations, the ACLC and IPNC are fed from the PCM1A in the same zone. If a casualty exists that prevents this, power is provided from the ACLC in the adjacent zone to the in-zone ACLC and then to the IPNC.

We assume that the flow of power throughout the distribution system is controlled by the power electronics. No-load dc disconnects are included to provide galvanic isolation where needed.

Sizing of all power conversion equipment in this model is adapted from [Soltau et al., 2014]. A summary table for sizing is shown below.

### Nominal Power Converter Sizing Chart

|  |  |
| --- | --- |
|  | dc/ac or ac/dc |
| Power Rating (MW) | Weight (kg) | Length (m) | Depth (m) | Height (m) |
| 1 | 2550 | 3.4 | 1.6 | 2.36 |
| 2 | 2730 | 3.4 | 1.6 | 2.36 |
| 3 | 2910 | 3.4 | 1.6 | 2.36 |
| 4 | 3090 | 3.4 | 1.6 | 2.36 |
| 6 | 3720 | 4 | 1.6 | 2.36 |
| 8 | 3780 | 4 | 1.6 | 2.36 |
| 10 | 3900 | 4 | 1.6 | 2.36 |
| 12 | 3960 | 4 | 1.6 | 2.36 |
| 14 | 5610 | 5.5 | 1.6 | 2.36 |
| 18 | 5730 | 5.5 | 1.6 | 2.36 |
| 22 | 6438 | 6.4 | 1.6 | 2.36 |
| 24 | 6618 | 6.4 | 1.6 | 2.36 |

### Power Conversion and Distribution Equipment Data (Dimensions, Location)

|  |  |  |
| --- | --- | --- |
| Identification | Dimensions | Location |
| Name | **SWBS** | **Height (m)** | **Width (m)** | **Length (m)** | **Weight (kg)** | **Zone** | **X (m)** | **Y (m)** | **Z (m)** |
| Bus Node | 324 | 0.8 | 0.8 | 1.2 | 100 | 1 | 17.47 | -1.7 | 4.99 |
| Bus Node | 324 | 1.6 | 0.8 | 2.36 | 800 | 2 | 67.31 | -8.68 | 5.87 |
| Bus Node | 324 | 1.6 | 0.8 | 2.36 | 800 | 3 | 104.09 | -7 | 3.8 |
| Bus Node | 324 | 0.8 | 0.8 | 1.8 | 300 | 4 | 133.62 | -3.5 | 6.28 |
| Bus Node | 324 | 0.8 | 0.8 | 1.8 | 300 | 1 | 32.8 | 7.05 | 8.11 |
| Bus Node | 324 | 1.6 | 0.8 | 2.36 | 800 | 2 | 46.37 | 8.5 | 9.25 |
| Bus Node | 324 | 1.6 | 0.8 | 2.36 | 800 | 3 | 89.55 | 8.65 | 9.25 |
| Bus Node | 324 | 0.8 | 0.8 | 1.2 | 200 | 4 | 131.57 | 0.12 | 8.51 |
| Power Conversion Module 1A | 314 | 4 | 1.6 | 2.36 | 3,960 | 1 | 33.85 | 4.44 | 8.22 |
| Power Conversion Module 1A | 314 | 4 | 1.6 | 2.36 | 3,960 | 2 | 64.8 | -6.75 | 5.24 |
| Power Conversion Module 1A | 314 | 4 | 1.6 | 2.36 | 3,960 | 3 | 89.53 | 7.13 | 8.22 |
| Power Conversion Module 1A | 314 | 4 | 1.6 | 2.36 | 3,960 | 4 | 134.46 | 3.41 | 6.02 |
| ac Load Center | 324 | 2 | 1.6 | 2.36 | 1,500 | 1 | 35.77 | 2.31 | 8.22 |
| ac Load Center | 324 | 2 | 1.6 | 2.36 | 1,500 | 2 | 71.02 | -6.43 | 5.17 |
| ac Load Center | 324 | 2 | 1.6 | 2.36 | 1,500 | 3 | 91.41 | 4.97 | 8.22 |
| ac Load Center | 324 | 2 | 1.6 | 2.36 | 1,500 | 4 | 136.55 | 1.18 | 6.14 |
| Integrated Power Node Center (IPNC) | 314 | 4 | 1.6 | 2.36 | 5,000 | 1 | 31.94 | 2.2 | 8.22 |
| Integrated Power Node Center (IPNC) | 314 | 4 | 1.6 | 2.36 | 5,000 | 2 | 62.88 | -5.25 | 1.9 |
| Integrated Power Node Center (IPNC) | 314 | 4 | 1.6 | 2.36 | 5,000 | 3 | 87.57 | 4.92 | 8.22 |
| Integrated Power Node Center (IPNC) | 314 | 4 | 1.6 | 2.36 | 5,000 | 4 | 132.42 | 1.13 | 6.01 |
| Radar dc/dc Converter | 314 | 4 | 1.6 | 2.36 | 5,000 | 3 | 95.33 | 0 | 11.52 |
| Radar dc/dc Converter | 314 | 1.6 | 7 | 2.36 | 5,000 | 2 | 61.53 | 0 | 14 |
| Integrated Topside dc/dc Converter | 314 | 4 | 1.6 | 2.36 | 5,000 | 2 | 72 | -5.82 | 18.5 |
| Integrated Topside dc/dc Converter | 314 | 4 | 1.6 | 2.36 | 5,000 | 2 | 72 | 5.82 | 18.5 |

Although the S3D models for converters allow efficiency to vary with load, the notional baseline converters were modeled with a constant 98% efficiency. Switches and switchboards are ideal (no losses).

### Power Conversion and Distribution Equipment Data (Electrical Power)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Name | Rated Electrical Power (MW) | Rated Continuous Current (kA) | Efficiency (%) | Primary Rated Voltage (kV) | Primary Current Type  | Secondary Rated Voltage (kV) | Secondary Current Type  |
| Bus Node |  | 0.1 | 100 | 12 | DC |  |  |
| Bus Node |  | 5 | 100 | 12 | DC |  |  |
| Bus Node |  | 5 | 100 | 12 | DC |  |  |
| Bus Node |  | 1 | 100 | 12 | DC |  |  |
| Bus Node |  | 1 | 100 | 12 | DC |  |  |
| Bus Node |  | 5 | 100 | 12 | DC |  |  |
| Bus Node |  | 5 | 100 | 12 | DC |  |  |
| Bus Node |  | 0.5 | 100 | 12 | DC |  |  |
| Power Conversion Module 1A | 10.64 |  | 98 | 12 | DC | var | var |
| Power Conversion Module 1A | 10.64 |  | 98 | 12 | DC | var | var |
| Power Conversion Module 1A | 9.17 |  | 98 | 12 | DC | var | var |
| Power Conversion Module 1A | 9.17 |  | 98 | 12 | DC | var | var |
| ac Load Center | 7.82 |  | 100 | 0.45 | AC | 0.45 | AC |
| ac Load Center | 7.45 |  | 100 | 0.45 | AC | 0.45 | AC |
| ac Load Center | 5.14 |  | 100 | 0.45 | AC | 0.45 | AC |
| ac Load Center | 7.14 |  | 100 | 0.45 | AC | 0.45 | AC |
| Integrated Power Node Center (IPNC) | 2.77 |  | 98 | var | var | var | var |
| Integrated Power Node Center (IPNC) | 3.13 |  | 98 | var | var | var | var |
| Integrated Power Node Center (IPNC) | 3.95 |  | 98 | var | var | var | var |
| Integrated Power Node Center (IPNC) | 1.99 |  | 98 | var | var | var | var |
| Radar dc/dc Converter | 1.65 |  | 98 | 12 | DC | 1 | DC |
| Radar dc/dc Converter | 3.3 |  | 98 | 12 | DC | 1 | DC |
| Integrated Topside dc/dc Converter | 2 |  | 98 | 12 | DC | 1 | DC |
| Integrated Topside dc/dc Converter | 2 |  | 98 | 12 | DC | 1 | DC |

## Cable Data

The cables in this model are based on Caledonian Medium Voltage Cables for Marine Applications [Caledonian 2016].

### Cable Data (Location, Dimensions)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | SWBS  | Zone | Length (m) | Connecting Equipment |
| z1\_CAB\_ACLC\_to\_IPNC | 321 | 1 | 3.94 | z1\_ACLC | z1\_IPNC |
| z1\_CAB\_Chiller | 321 | 1 | 9.14 | z1\_ACLC | z1\_CHILLER |
| z1\_CAB\_Chiller\_CHWPump | 321 | 1 | 12.4 | z1\_ACLC | z1\_CHILLER\_P\_CHW\_PUMP |
| z1\_CAB\_Chiller\_SWPump | 321 | 1 | 9.39 | z1\_ACLC | z1\_CHILLER\_P\_SW\_PUMP |
| z1\_CAB\_DC\_InZone\_S | 321 | 1 | 3.77 | z1\_BUS\_S | z1\_PCM1A\_S |
| z1\_CAB\_EDG\_AC | 321 | 1 | 4.42 | z1\_EDG | z1\_BRK\_EDG |
| z1\_CAB\_EDG\_DC\_P | 321 | 1 | 19.72 | z1\_EDG\_RECT | z1\_BUS\_P |
| z1\_CAB\_EDG\_DC\_S | 321 | 1 | 9.46 | z1\_EDG\_RECT | z1\_BUS\_S |
| z1\_CAB\_PCM1A\_to\_ACLC | 321 | 1 | 2.6 | z1\_PCM1A\_S | z1\_ACLC |
| z1\_CAB\_PCM1A\_to\_IPNC | 321 | 1 | 3.1 | z1\_PCM1A\_S | z1\_IPNC |
| z1\_CAB\_SONAR | 321 | 1 | 22.97 | z1\_IPNC | z1\_SONAR\_SUPPORT\_EQ |
| z1\_CAB\_VLS | 321 | 1 | 9.19 | z1\_IPNC | z1\_VLS |
| z1\_z2\_CAB\_ACLC\_DaisyChain | 321 | 1 / 2 | 44.15 | z1\_ACLC | z2\_ACLC |
| z1\_z2\_CAB\_P | 321 | 1 / 2 | 57.13 | z1\_BUS\_P | z2\_BUS\_P |
| z1\_z2\_CAB\_S | 321 | 1 / 2 | 15.11 | z1\_BUS\_S | z2\_BUS\_S |
| z2\_CAB\_ACLC\_to\_IPNC | 321 | 2 | 12.6 | z2\_ACLC | z2\_IPNC |
| z2\_CAB\_ADS\_P | 321 | 2 | 35.89 | z2\_IPNC | z2\_ADS\_P |
| z2\_CAB\_ADS\_S | 321 | 2 | 45.12 | z2\_ACLC | z2\_ADS\_S |
| z2\_CAB\_Chiller\_P | 321 | 2 | 17.93 | z2\_ACLC | z2\_CHILLER\_P |
| z2\_CAB\_Chiller\_S | 321 | 2 | 26.08 | z2\_ACLC | z2\_CHILLER\_S |
| z2\_CAB\_ChillerPCHWPump | 321 | 2 | 22.96 | z2\_ACLC | z2\_CHILLER\_P\_CHW\_PUMP |
| z2\_CAB\_ChillerPSWPump | 321 | 2 | 20.08 | z2\_ACLC | z2\_CHILLER\_P\_SW\_PUMP |
| z2\_CAB\_ChillerSCHWPump | 321 | 2 | 24.79 | z2\_ACLC | z2\_CHILLER\_S\_CHW\_PUMP |
| z2\_CAB\_ChillerSSWPump | 321 | 2 | 22.01 | z2\_ACLC | z2\_CHILLER\_S\_SW\_PUMP |
| z2\_CAB\_DC\_InZone\_P | 321 | 2 | 4.02 | z2\_BUS\_P | z2\_PCM1A\_P |
| z2\_CAB\_InTopP\_P | 321 | 2 | 19.43 | z2\_BUS\_P | z2\_InTop\_Eqpt\_P |
| z2\_CAB\_InTopP\_S | 321 | 2 | 36.37 | z2\_BUS\_S | z2\_InTop\_Eqpt\_P |
| z2\_CAB\_InTopS\_P | 321 | 2 | 31.07 | z2\_BUS\_P | z2\_InTop\_Eqpt\_S |
| z2\_CAB\_InTopS\_S | 321 | 2 | 48.01 | z2\_BUS\_S | z2\_InTop\_Eqpt\_S |
| z2\_CAB\_LM2500P\_AC\_P1 | 321 | 2 | 9.44 | z2\_LM2500\_P | z2\_BRK\_LM2500\_P1 |
| z2\_CAB\_LM2500P\_AC\_P2 | 321 |  | 9.26 | z2\_LM2500\_P | z2\_BRK\_LM2500\_P2 |
| z2\_CAB\_LM2500P\_DC\_P | 321 | 2 | 3.72 | z2\_LM2500\_RECT\_P | z2\_BUS\_P |
| z2\_CAB\_LM2500P\_DC\_S | 321 | 2 | 42.68 | z2\_LM2500\_RECT\_P | z2\_BUS\_S |
| z2\_CAB\_LM2500S\_AC\_S1 | 321 | 2 | 9.44 | z2\_LM2500\_S | z2\_BRK\_LM2500\_S1 |
| z2\_CAB\_LM2500S\_AC\_S2 | 321 |  | 9.26 | z2\_LM2500\_S | z2\_BRK\_LM2500\_S2 |
| z2\_CAB\_LM2500S\_DC\_P | 321 | 2 | 17.65 | z2\_LM2500\_RECT\_S | z2\_BUS\_P |
| z2\_CAB\_LM2500S\_DC\_S | 321 | 2 | 27.21 | z2\_LM2500\_RECT\_S | z2\_BUS\_S |
| z2\_CAB\_PCM1A\_to\_ACLC | 321 | 2 | 6.6 | z2\_PCM1A\_P | z2\_ACLC |
| z2\_CAB\_PCM1A\_to\_IPNC | 321 | 2 | 4.66 | z2\_PCM1A\_P | z2\_ACLC |
| z2\_CAB\_PMM\_P | 321 | 2 | 20.38 | z2\_BUS\_P | z2\_PMM\_Drive\_S |
| z2\_CAB\_PMM\_S | 321 | 2 | 47.08 | z2\_BUS\_S | z2\_PMM\_Drive\_S |
| z2\_CAB\_Radar\_P | 321 | 2 | 21.75 | z2\_BUS\_P | z2\_DCDC\_Radar |
| z2\_CAB\_Radar\_S | 321 | 2 | 27.14 | z2\_BUS\_S | z2\_DCDC\_Radar |
| z2\_CAB\_railgun\_ammo\_handling | 321 | 2 | 31.4 | z2\_IPNC | z2\_Railgun\_Ammo\_Handling |
| z2\_CAB\_Railgun\_P | 321 | 2 | 27.04 | z2\_BUS\_P | z2\_SWT\_Railgun |
| z2\_CAB\_Railgun\_S | 321 | 2 | 11.75 | z2\_BUS\_S | z2\_SWT\_Railgun |
| z2\_z3\_CAB\_P | 321 | 2 / 3 | 38 | z2\_BUS\_P | z3\_BUS\_P |
| z2\_z3\_CAB\_S | 321 | 2 / 3 | 43.33 | z2\_BUS\_S | z3\_BUS\_S |
| z3\_CAB\_ACLC\_to\_IPNC | 321 | 3 | 3.89 | z3\_ACLC | z3\_IPNC |
| z3\_CAB\_Chiller | 321 | 3 | 17.82 | z3\_ACLC | z3\_CHILLER\_S |
| z3\_CAB\_Chiller\_CHWPump | 321 | 3 | 20.2 | z3\_ACLC | z3\_CHILLER\_S\_CHW\_PUMP |
| z3\_CAB\_Chiller\_SWPump | 321 | 3 | 17.46 | z3\_ACLC | z3\_CHILLER\_S\_SW\_PUMP |
| z3\_CAB\_DC\_InZone\_S | 321 | 3 | 2.57 | z3\_BUS\_S | z3\_PCM1A\_S |
| z3\_CAB\_LM2500\_AC\_S1 | 321 | 3 | 8.91 | z3\_LM2500\_P | z3\_BRK\_LM2500\_P1 |
| z3\_CAB\_LM2500\_AC\_S2 | 321 |  | 8.73 | z3\_LM2500\_P | z3\_BRK\_LM2500\_P2 |
| z3\_CAB\_LM2500\_DC\_P | 321 | 3 | 13.3 | z3\_LM2500\_RECT\_P | z3\_BUS\_P |
| z3\_CAB\_LM2500\_DC\_S | 321 | 3 | 24.95 | z3\_LM2500\_RECT\_P | z3\_BUS\_S |
| z3\_CAB\_LM500P\_AC\_P1 | 321 | 3 | 5.78 | z3\_LM500\_S | z3\_BRK\_LM500\_S1 |
| z3\_CAB\_LM500P\_AC\_P2 | 321 |  | 5.32 | z3\_LM500\_S | z3\_BRK\_LM500\_S2 |
| z3\_CAB\_LM500P\_DC\_P | 321 | 3 | 29.63 | z3\_LM500\_RECT\_S | z3\_BUS\_P |
| z3\_CAB\_LM500P\_DC\_S | 321 | 3 | 7.54 | z3\_LM500\_RECT\_S | z3\_BUS\_S |
| z3\_CAB\_PCM1A\_to\_ACLC | 321 | 3 | 2.78 | z3\_PCM1A\_S | z3\_ACLC |
| z3\_CAB\_PCM1A\_to\_IPNC | 321 | 3 | 2.91 | z3\_PCM1A\_S | z3\_IPNC |
| z3\_CAB\_PMM\_P | 321 | 3 | 9.28 | z3\_PMM\_Drive\_P | z3\_BUS\_P |
| z3\_CAB\_PMM\_S | 321 | 3 | 28.86 | z3\_PMM\_Drive\_P | z3\_BUS\_S |
| z3\_CAB\_Radar\_P | 321 | 3 | 22.32 | z3\_RADAR\_Support\_Eq | z3\_BUS\_P |
| z3\_CAB\_Radar\_S | 321 | 3 | 15.54 | z3\_RADAR\_Support\_Eq | z3\_BUS\_S |
| z3\_CAB\_VLS | 321 | 3 | 23.65 | z3\_IPNC | z3\_VLS |
| z3\_z4\_CAB\_ACLC\_DaisyChain | 321 | 3 / 4 | 48.48 | z3\_ACLC | z4\_ACLC |
| z3\_z4\_CAB\_P | 321 | 3 / 4 | 34.16 | z3\_BUS\_P | z4\_BUS\_P |
| z3\_z4\_CAB\_S | 321 | 3 / 4 | 50.65 | z3\_BUS\_S | z4\_BUS\_S |
| z4\_CAB\_ACLC\_to\_IPNC | 321 | 4 | 4.31 | z4\_ACLC | z4\_IPNC |
| z4\_CAB\_Chiller | 321 | 4 | 7.06 | z4\_ACLC | z4\_CHILLER\_P |
| z4\_CAB\_Chiller\_CHWPump | 321 | 4 | 3.93 | z4\_ACLC | z4\_CHILLER\_S\_CHW\_PUMP |
| z4\_CAB\_Chiller\_SWPump | 321 | 4 | 3.03 | z4\_ACLC | z4\_CHILLER\_S\_SW\_PUMP |
| z4\_CAB\_DC\_InZone\_P | 321 | 4 | 8.01 | z4\_BUS\_P | z4\_PCM1A\_P |
| z4\_CAB\_Laser\_P | 321 | 3 | 26.59 | z3\_IPNC | z3\_laser\_support\_eq |
| z4\_CAB\_LM500\_AC\_S1 | 321 | 4 | 6.03 | z4\_LM500\_S | z4\_BRK\_LM500\_S1 |
| z4\_CAB\_LM500\_AC\_S2 | 321 |  | 5.58 | z4\_LM500\_S | z4\_BRK\_LM500\_S2 |
| z4\_CAB\_LM500S\_DC\_P | 321 | 4 | 4.89 | z4\_LM500\_RECT\_S | z4\_BUS\_P |
| z4\_CAB\_LM500S\_DC\_S | 321 | 4 | 2.38 | z4\_LM500\_RECT\_S | z4\_BUS\_S |
| z4\_CAB\_MFTA\_P | 321 | 4 | 19.5 | z4\_MFTA\_and\_Eq | z4\_IPNC |
| z4\_CAB\_PCM1A\_to\_ACLC | 321 | 4 | 3.01 | z4\_PCM1A\_P | z4\_ACLC |
| z4\_CAB\_PCM1A\_to\_IPNC | 321 | 4 | 3.27 | z4\_PCM1A\_P | z4\_IPNC |

### Cable Data (Electrical Power, Weight)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Name | Rated Voltage (kV) | Current Type  | Number of Cables in Bundle  | Rated Continuous Current per Cable (A) | Total Rated Continuous Current (A) | Weight Per Unit Length (kg/m) | Weight (kg) |
| z1\_CAB\_ACLC\_to\_IPNC | 0.45 | AC | 5 | 780 | 3900 | 33.05 | 390.45 |
| z1\_CAB\_Chiller | 0.45 | AC | 2 | 890 | 1780 | 16.34 | 448.21 |
| z1\_CAB\_Chiller\_CHWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 37.94 |
| z1\_CAB\_Chiller\_SWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 28.74 |
| z1\_CAB\_DC\_InZone\_S | 12 | DC | 2 | 522 | 1044 | 7.45 | 56.11 |
| z1\_CAB\_EDG\_AC | 6.9 | AC | 1 | 127 | 127 | 1.02 | 13.53 |
| z1\_CAB\_EDG\_DC\_P | 12 | DC | 1 | 127 | 127 | 1.02 | 40.22 |
| z1\_CAB\_EDG\_DC\_S | 12 | DC | 1 | 127 | 127 | 1.02 | 19.29 |
| z1\_CAB\_PCM1A\_to\_ACLC | 0.45 | AC | 12 | 890 | 10680 | 98.04 | 766.03 |
| z1\_CAB\_PCM1A\_to\_IPNC | 1 | DC | 4 | 780 | 3120 | 26.44 | 164.04 |
| z1\_CAB\_SONAR | 1 | DC | 1 | 522 | 522 | 3.72 | 171.14 |
| z1\_CAB\_VLS | 0.45 | AC | 1 | 780 | 780 | 6.61 | 182.25 |
| z1\_z2\_CAB\_ACLC\_DaisyChain | 0.45 | AC | 10 | 890 | 8900 | 81.7 | 10822 |
| z1\_z2\_CAB\_P | 12 | DC | 1 | 127 | 127 | 1.02 | 116.55 |
| z1\_z2\_CAB\_S | 12 | DC | 2 | 522 | 1044 | 7.45 | 225.16 |
| z2\_CAB\_ACLC\_to\_IPNC | 0.45 | AC | 5 | 890 | 4450 | 40.85 | 1544.58 |
| z2\_CAB\_ADS\_P | 1 | DC | 1 | 389 | 389 | 2.55 | 183.04 |
| z2\_CAB\_ADS\_S | 1 | DC | 1 | 389 | 389 | 2.55 | 230.13 |
| z2\_CAB\_Chiller\_P | 0.45 | AC | 2 | 890 | 1780 | 16.34 | 879.09 |
| z2\_CAB\_Chiller\_S | 0.45 | AC | 2 | 890 | 1780 | 16.34 | 1278.6 |
| z2\_CAB\_ChillerPCHWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 70.26 |
| z2\_CAB\_ChillerPSWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 61.44 |
| z2\_CAB\_ChillerSCHWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 75.86 |
| z2\_CAB\_ChillerSSWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 67.35 |
| z2\_CAB\_DC\_InZone\_P | 12 | DC | 2 | 522 | 1044 | 7.45 | 59.93 |
| z2\_CAB\_InTopP\_P | 12 | DC | 1 | 242 | 242 | 1.6 | 61.98 |
| z2\_CAB\_InTopP\_S | 12 | DC | 1 | 242 | 242 | 1.6 | 116.02 |
| z2\_CAB\_InTopS\_P | 12 | DC | 1 | 242 | 242 | 1.6 | 99.11 |
| z2\_CAB\_InTopS\_S | 12 | DC | 1 | 242 | 242 | 1.6 | 153.15 |
| z2\_CAB\_LM2500P\_AC\_P1 | 6.9 | AC | 2 | 780 | 1560 | 13.22 | 374.21 |
| z2\_CAB\_LM2500P\_AC\_P2 | 6.9 | AC | 2 | 780 | 1560 | 13.22 | 367.32 |
| z2\_CAB\_LM2500P\_DC\_P | 12 | DC | 4 | 780 | 3120 | 26.44 | 196.75 |
| z2\_CAB\_LM2500P\_DC\_S | 12 | DC | 4 | 780 | 3120 | 26.44 | 2257.05 |
| z2\_CAB\_LM2500S\_AC\_S1 | 6.9 | AC | 2 | 780 | 1560 | 13.22 | 374.21 |
| z2\_CAB\_LM2500S\_AC\_S2 | 6.9 | AC | 2 | 780 | 1560 | 13.22 | 367.37 |
| z2\_CAB\_LM2500S\_DC\_P | 12 | DC | 4 | 780 | 3120 | 26.44 | 933.34 |
| z2\_CAB\_LM2500S\_DC\_S | 12 | DC | 4 | 780 | 3120 | 26.44 | 1438.68 |
| z2\_CAB\_PCM1A\_to\_ACLC | 0.45 | AC | 11 | 890 | 9790 | 89.87 | 1780.72 |
| z2\_CAB\_PCM1A\_to\_IPNC | 1 | DC | 4 | 890 | 3560 | 32.68 | 304.76 |
| z2\_CAB\_PMM\_P | 12 | DC | 5 | 780 | 3900 | 33.05 | 1346.83 |
| z2\_CAB\_PMM\_S | 12 | DC | 5 | 780 | 3900 | 33.05 | 3111.7 |
| z2\_CAB\_Radar\_P | 12 | DC | 1 | 339 | 339 | 2.24 | 97.23 |
| z2\_CAB\_Radar\_S | 12 | DC | 1 | 339 | 339 | 2.24 | 121.3 |
| z2\_CAB\_railgun\_ammo\_handling | 1 | DC | 1 | 522 | 522 | 3.72 | 233.93 |
| z2\_CAB\_Railgun\_P | 12 | DC | 2 | 890 | 1780 | 16.34 | 883.78 |
| z2\_CAB\_Railgun\_S | 12 | DC | 2 | 890 | 1780 | 16.34 | 384.04 |
| z2\_z3\_CAB\_P | 12 | DC | 6 | 890 | 5340 | 49.02 | 3725.49 |
| z2\_z3\_CAB\_S | 12 | DC | 6 | 890 | 5340 | 49.02 | 4248.27 |
| z3\_CAB\_ACLC\_to\_IPNC | 0.45 | AC | 6 | 890 | 5340 | 49.02 | 572.06 |
| z3\_CAB\_Chiller | 0.45 | AC | 2 | 890 | 1780 | 16.34 | 873.43 |
| z3\_CAB\_Chiller\_CHWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 61.81 |
| z3\_CAB\_Chiller\_SWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 53.43 |
| z3\_CAB\_DC\_InZone\_S | 12 | DC | 1 | 780 | 780 | 6.61 | 33.98 |
| z3\_CAB\_LM2500\_AC\_S1 | 6.9 | AC | 2 | 780 | 1560 | 13.22 | 353.19 |
| z3\_CAB\_LM2500\_AC\_S2 | 6.9 | AC | 2 | 780 | 1560 | 13.22 | 346.3 |
| z3\_CAB\_LM2500\_DC\_P | 12 | DC | 4 | 780 | 3120 | 26.44 | 703.34 |
| z3\_CAB\_LM2500\_DC\_S | 12 | DC | 4 | 780 | 3120 | 26.44 | 1319.27 |
| z3\_CAB\_LM500P\_AC\_P1 | 6.9 | AC | 1 | 196 | 196 | 1.32 | 22.89 |
| z3\_CAB\_LM500P\_AC\_P2 | 6.9 | AC | 1 | 196 | 196 | 1.32 | 21.08 |
| z3\_CAB\_LM500P\_DC\_P | 12 | DC | 1 | 389 | 389 | 2.55 | 151.13 |
| z3\_CAB\_LM500P\_DC\_S | 12 | DC | 1 | 389 | 389 | 2.55 | 38.45 |
| z3\_CAB\_PCM1A\_to\_ACLC | 0.45 | AC | 8 | 890 | 7120 | 65.36 | 544.19 |
| z3\_CAB\_PCM1A\_to\_IPNC | 1 | DC | 5 | 890 | 4450 | 40.85 | 237.37 |
| z3\_CAB\_PMM\_P | 12 | DC | 5 | 780 | 3900 | 33.05 | 613.68 |
| z3\_CAB\_PMM\_S | 12 | DC | 5 | 780 | 3900 | 33.05 | 1907.51 |
| z3\_CAB\_Radar\_P | 12 | DC | 1 | 196 | 196 | 1.32 | 58.92 |
| z3\_CAB\_Radar\_S | 12 | DC | 1 | 196 | 196 | 1.32 | 41.02 |
| z3\_CAB\_VLS | 0.45 | AC | 1 | 780 | 780 | 6.61 | 469.04 |
| z3\_z4\_CAB\_ACLC\_DaisyChain | 0.45 | AC | 7 | 890 | 6230 | 57.19 | 8317.82 |
| z3\_z4\_CAB\_P | 12 | DC | 1 | 780 | 780 | 6.61 | 451.55 |
| z3\_z4\_CAB\_S | 12 | DC | 1 | 389 | 389 | 2.55 | 258.31 |
| z4\_CAB\_ACLC\_to\_IPNC | 0.45 | AC | 3 | 890 | 2670 | 24.51 | 316.77 |
| z4\_CAB\_Chiller | 0.45 | AC | 2 | 890 | 1780 | 16.34 | 346.03 |
| z4\_CAB\_Chiller\_CHWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 12.04 |
| z4\_CAB\_Chiller\_SWPump | 0.45 | AC | 1 | 127 | 127 | 1.02 | 9.27 |
| z4\_CAB\_DC\_InZone\_P | 12 | DC | 1 | 780 | 780 | 6.61 | 105.94 |
| z4\_CAB\_Laser\_P | 1 | DC | 2 | 780 | 1560 | 13.22 | 703.11 |
| z4\_CAB\_LM500\_AC\_S1 | 6.9 | AC | 1 | 196 | 196 | 1.32 | 23.88 |
| z4\_CAB\_LM500\_AC\_S2 | 6.9 | AC | 1 | 196 | 196 | 1.32 | 22.08 |
| z4\_CAB\_LM500S\_DC\_P | 12 | DC | 1 | 389 | 389 | 2.55 | 24.93 |
| z4\_CAB\_LM500S\_DC\_S | 12 | DC | 1 | 389 | 389 | 2.55 | 12.13 |
| z4\_CAB\_MFTA\_P | 1 | DC | 1 | 196 | 196 | 1.32 | 51.47 |
| z4\_CAB\_PCM1A\_to\_ACLC | 0.45 | AC | 11 | 890 | 9790 | 89.87 | 811.07 |
| z4\_CAB\_PCM1A\_to\_IPNC | 1 | DC | 3 | 690 | 2070 | 16.26 | 106.38 |

# Thermal System Data

## Thermal view

Diagram to be added

## Cooling Equipment Data (Dimensions, Location)

|  |  |  |
| --- | --- | --- |
| Identification | Dimensions | Location |
| Name | SWBS | Length (m) | Width (m) | Height (m) | Weight (kg) | Zone | X (m) | Y (m) | Z (m) |
| Chiller | 514 | 2.9 | 2.3 | 5.7 | 38500 | 1 | 34.18 | -2.78 | 3.66 |
| Chiller | 514 | 2.9 | 2.3 | 5.7 | 38500 | 2 | 56.16 | -3.97 | 2.46 |
| Chiller | 514 | 2.9 | 2.3 | 5.7 | 38500 | 2 | 133.81 | -4.11 | 6.22 |
| Chiller | 514 | 2.9 | 2.3 | 5.7 | 38500 | 3 | 56.17 | 4.19 | 2.46 |
| Chiller | 514 | 2.9 | 2.3 | 5.7 | 38500 | 4 | 105.19 | 3.73 | 5.42 |
| Seawater Pump | 514 | 1 | 1 | 2 | 1000 | 1 | 36.91 | -0.68 | 1.81 |
| Seawater Pump | 514 | 1 | 1 | 2 | 1000 | 2 | 58.37 | -1.22 | 1.81 |
| Seawater Pump | 514 | 1 | 1 | 2 | 1000 | 2 | 58.49 | 0.83 | 1.81 |
| Seawater Pump | 514 | 1 | 1 | 2 | 1000 | 3 | 104.16 | 6 | 3.4 |
| Seawater Pump | 514 | 1 | 1 | 2 | 1000 | 4 | 136.5 | -1.13 | 4.9 |
| Chilled Water Pump | 514 | 1 | 1 | 2 | 1000 | 1 | 31.61 | -0.66 | 1.81 |
| Chilled Water Pump | 514 | 1 | 1 | 2 | 1000 | 2 | 55.76 | -0.95 | 1.81 |
| Chilled Water Pump | 514 | 1 | 1 | 2 | 1000 | 2 | 55.85 | 0.97 | 1.81 |
| Chilled Water Pump | 514 | 1 | 1 | 2 | 1000 | 3 | 106.9 | 6 | 3.4 |
| Chilled Water Pump | 514 | 1 | 1 | 2 | 1000 | 4 | 134.99 | -1.09 | 4.9 |

## Cooling Equipment Data (Electrical Power, Efficiency)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Name | Rated Electrical Power (MW) | Efficiency (%) | Rated Voltage (kV) | Current Type  | Coefficient of Performance |
| Chiller | 3.87 | 1.1 |  | 0.45 | AC |
| Chiller | 3.87 | 1.1 |  | 0.45 | AC |
| Chiller | 3.87 | 1.1 |  | 0.45 | AC |
| Chiller | 3.87 | 1.1 |  | 0.45 | AC |
| Chiller | 3.87 | 1.1 |  | 0.45 | AC |
| Seawater Pump |  | 0.08 | 80 | 0.45 | AC |
| Seawater Pump |  | 0.08 | 80 | 0.45 | AC |
| Seawater Pump |  | 0.08 | 80 | 0.45 | AC |
| Seawater Pump |  | 0.08 | 80 | 0.45 | AC |
| Seawater Pump |  | 0.08 | 80 | 0.45 | AC |
| Chilled Water Pump |  | 0.08 | 80 | 0.45 | AC |
| Chilled Water Pump |  | 0.08 | 80 | 0.45 | AC |
| Chilled Water Pump |  | 0.08 | 80 | 0.45 | AC |
| Chilled Water Pump |  | 0.08 | 80 | 0.45 | AC |
| Chilled Water Pump |  | 0.08 | 80 | 0.45 | AC |

# Mission Definition

## Static Mission Conditions

Four static mission conditions are defined as follows. These missions are intended for quasi-static system analysis for such evaluations as annual fuel usage.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Equipment | Peacetime Cruise | Sprint to Station | Battle | Anchor |
| Active Denial System | off | off | high | low |
| Laser | off | medium | high | off |
| Railgun | off | off | high | off |
| Vertical Launch System | off | off | high | off |
| Integrated Topside | medium | medium | high | medium |
| Radar | medium | high | high | low |
| Sonar | off | off | on | off |
| Towed-Array Sonar | off | off | off | off |
| Aggregated AC Non-vital Loads | high | medium | medium | high |
| Aggregated DC Vital Loads | medium | high | high | medium |
| Ship Speed | 15 kts | 31 kts | 8 kts | 0 kts |

## Dynamic Mission Scenario

An example dynamic mission scenario. This scenario is intended for dynamic system evaluations.

|  |  |
| --- | --- |
| Equipment | Initial state |
| Active Denial System | standby |
| Laser | standby |
| Railgun | standby |
| Vertical Launch System | standby |
| Integrated Topside | high |
| Radar | high |
| Sonar | on |
| Towed-Array Sonar | off |
| Aggregated AC Non-vital Loads | medium |
| Aggregated DC Vital Loads | high |
| Ship Speed | 8 kts |

Beginning in the initial state indicated above, flow through the following sequence:

* Charge railgun (5 seconds)
* Fire railgun (1 second)
* Charge railgun (5 seconds)
* Fire railgun (1 second)
* Increase speed to 25 kts
* Fire laser (15 seconds)

## Fault Scenarios

(expand description)

These fault scenarios are intended for dynamic system testing. Since S3D is currently a quasi-static analysis tool, fault testing is not applicable in that environment beyond manually opening the appropriate breakers or disconnects and determining whether power is available from a different source.

Example fault scenario 1: Beginning in the Sprint to Station condition described above, a fault develops in the cable leading from the zone 2 port bus node to the zone 2 dc/dc converter for the radar. This fault requires isolation of the cable from the bus node and the converter, and requires re-alignment of power to the radar from the starboard bus.

Example fault scenario 2: Beginning in the Sprint to Station condition described above, a fault develops in the zone 3 starboard bus node, requiring isolation of all connections to the bus node. This will require re-routing of power into zone three from the port bus; since the PCM1A in Zone 3 is connected to the starboard bus, power must be fed to in-zone loads via the ACLC in Zone 4. Additionally, the generators must deliver power to the starboard bus only and the radars and propulsion motor in zone 3 must receive power from the starboard bus.

# References

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Figure 5. Example Fault Scenario 1



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Figure 6. Example Fault Scenario 2