DDS 310-1
REV 1

DESIGN DATA SHEET

ELECTRIC POWER LOAD ANALYSIS (EPLA) FOR SURFACE SHIPS

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON NAVY YARD, DC 20376-5124

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This design data sheet (DDS) provides procedures for preparing an Electric Power Load Analysis (EPLA) for conventional-powered fossil fueled surface ships. However, this DDS may be used as a basis for preparing a load and power analysis for a ship powered by other means. The EPLA, also referred to as the Electric Plant Load Analysis or the System Load and Power Analysis, is used as an input for determining the power requirements for electrical generation, energy storage, and power conversion components and equipment and current requirements for electrical distribution equipment and components. The EPLA is also used to develop 24-hour average electrical load estimates for calculating fuel endurance and annual fuel consumption. The process of creating an EPLA is generally composed of two steps: First, identifying, compiling, estimating, and categorizing all of the electrical loads on a ship; and second, using an algorithm to combine the estimated loads to determine the design requirements for electrical system components and equipment.</td></tr>
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1. APPLICABLE DOCUMENTS

1.1 General. The documents listed in this section are specified in the main body of this document. This section does not include documents cited in the Appendices.

1.2 Government documents.

1.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-1399-300 - Interface Standard for Shipboard Systems, Section 300B, Electric Power, Alternating Current

MILITARY STANDARD (MS) DRAWINGS

MS 18299 - Shipboard Power Demand Factors 450 Volts

(Copies of these documents are available online at https://assist.dla.mil or http://assistdocs.com.)

1.2.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

NAVAL SEA SYSTEMS COMMAND (NAVSEA) PUBLICATIONS

S9040-AA-IDX-010/SWBS 5D - Expanded Ship Work Breakdown Structure for All Ships and Ship/Combat Systems (ESWBS)

T9300-AF-PRO-020 - NAVSEA Design Practice and Criteria Manual, Electrical Systems for Surface Ships, Chapter 300

(Copies of these documents are available from the Naval Logistics Library, 5450 Carlisle Pike, Mechanicsburg, PA 17055 or online at https://nll1.ahf.nmci.navy.mil.)

NAVAL SEA SYSTEMS COMMAND (NAVSEA) DESIGN DATA SHEETS (DDS)

DDS 200-1 - Calculation Of Surface Ship Endurance Fuel Requirements

(Copies of this document are available from Commander, Naval Sea Systems Command, ATTN: SEA 05S, 1333 Isaac Hull Avenue, SE, Stop 5160, Washington Navy Yard DC 20376-5160, or by email at commandstandards@navy.mil with the subject line “DDS request”.)

1.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

CODE OF FEDERAL REGULATIONS (CFR)

TITLE 46, PART 112 - Shipping: Emergency Lighting And Power Systems

(Copies of this document are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20401 or online at http://www.gpo.gov/fdsys/.)

1.4 Order of precedence. Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2. INTRODUCTION

2.1 Scope. This design data sheet (DDS) provides procedures for preparing an Electric Power Load Analysis (EPLA) for conventional-powered fossil fueled surface ships. However, this DDS may be used as a basis for preparing a load and power analysis for a ship powered by other means.

The EPLA, also referred to as the Electric Plant Load Analysis or the System Load and Power Analysis, is used as an input for determining the power requirements for electrical generation, energy storage, and power conversion components and equipment and current requirements for electrical distribution equipment and components. The EPLA is also used to develop 24-hour average electrical load estimates for calculating fuel endurance and annual fuel consumption. The process of creating an EPLA is generally composed of two steps: First, identifying, compiling, estimating, and categorizing all of the electrical loads on a ship; and second, using an algorithm to combine the estimated loads to determine the design requirements for electrical system components and equipment. Historically, the algorithm used to combine loads to determine the rating of generation has been based on load factors, while the algorithm used to combine loads for 450 volt bus feeders to load centers has been based on demand factors as prescribed in MS 18299. Previously, there has not been a standardized method for combining loads to size medium voltage to low voltage transformers, energy storage modules, or power conversion equipment for zonal architectures.

The EPLA provides an estimate of the load that a power system component must serve or an estimate of the average load. Different load amalgamation methods will result in different load estimates. Power system design methods should result in ratings selected for equipment that are likely neither excessively high, nor too low. Too high of a rating typically results in higher costs and higher system losses (due to lower system efficiencies when equipment is lightly loaded) and higher maintenance costs due to lightly loading of prime movers (such as diesels). Too low of a rating can result in higher maintenance costs, expensive post-delivery fixes to the power system, and shedding of loads under normal operation.

This DDS provides guidance for modeling and estimating loads, provides five methods for combining loads, provides a method for conducting Quality of Service (QOS) load analysis, and provides a method to compare actual measured trials electrical load data with the load analysis.

This DDS does not provide specific direction for determining the number or rating of power system equipment. It also does not provide guidance for developing the electric and propulsion plant concept of operation or for ensuring adequate fault current for fault detection and isolation. Electrical system design practices and criteria, such as design considerations to avoid lightly loading generators, are detailed in T9300-AF-PRO-020.

This DDS is organized in a task oriented approach. Each method is described as a task and has a dedicated subsection of the General Requirements and Specific Requirements sections. Each subsection of the General Requirements section details the inputs and outputs of the applicable methods and is intended to assist the ship design management team in planning for the conduct of an EPLA. Each subsection of the Specific Requirements section provides details on the method to calculate the task outputs based on the inputs. The intended audience of the Specific Requirements subsections is the engineer assigned to accomplish the task.

The inter-relationship of the tasks described in this document is depicted in figure 1. In particular, note that the EPLA supports a number of ship design activities to include generator selection, energy storage selection, power conversion selection, feeder cable sizing, endurance fuel calculations, and annual fuel calculations. In many cases the data that must be generated and captured in the EPLA will be somewhat different for the different ship design activities. In particular, the load factors evaluated for calculating ship demand power will likely differ from the load factors for 24-hour average load calculations and could also differ from zonal load factors for the sizing of zonal power system elements.

For a number of cases, this DDS provides the power system engineer several options for calculating electrical load. The particular method to use will generally be specified in a tasking statement/statement of work, or left to the power system engineer to pick the most appropriate method. In deciding which method to use, the difference in cost associated with conducting the different types of analyses should be compared to the risk associated with errors in the load estimates.

This DDS is a significant revision from the previous version. The next revision is anticipated to update Appendix A to include more modern loads as well as provide guidance for assigning load factors for 24-hour average computations. A future revision may also include more detailed guidance for zonal load analysis, stochastic load modeling, and dynamic load modeling.

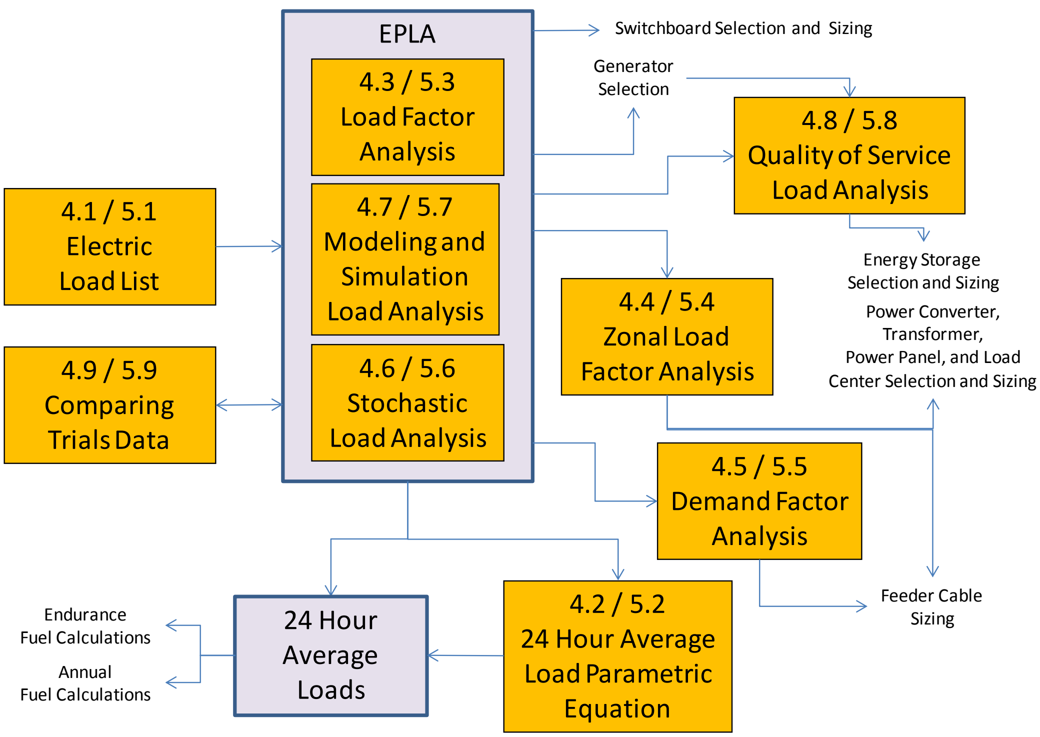

Figure 1. Inter-relationship of DDS 310-1 tasks.

3. DEFINITIONS

3.1 24-hour average ship service endurance electric load. The 24-Hour Average Endurance Ship Service Electric Load is the average anticipated ship service electrical load (including margin and service life allowance) expected over a 24-hour period for the ship service operating condition corresponding to a cruise with self defense capability for non-combatants or Condition III Wartime Cruising for combatants (as defined by the ship's requirements documents) for each ambient condition specified in the ambient condition profile. Propulsion related Ship Service Loads are calculated for the Average Endurance Power. Electric propulsion power is not included. The 24-hour average ship service endurance electric load is used for endurance fuel calculations in accordance with DDS 200-1.

3.2 24-hour average ship service mission electric load profile. The 24-Hour Average Mission Ship Service Electric Load Profile is the curve of the average anticipated ship service electrical load (including margin and service life allowance) expected over a 24-hour period for the ship service operating condition corresponding to the specified missions for each ambient condition specified in the ambient condition profile versus the speeds in the specified ship speed-time profile. Propulsion related Ship Service Loads are calculated for each speed in the specified ship speed-time profile. Electric propulsion power is not included. The 24-hour average ship service mission electric load profile is used for endurance fuel calculations in accordance with DDS 200-1.

3.3 24-hour average ship service sustained electric load. The 24-Hour Average Sustained Ship Service Electric Load is the average anticipated ship service electrical load (including margin and service life allowance) expected over a 24-hour period for the ship service operating condition corresponding to a cruise with self defense capability for non-combatants or Condition III Wartime Cruising for combatants (as defined by the ship's requirements documents) for each ambient condition specified in the ambient condition profile. Propulsion related Ship Service Loads are calculated for the Average Sustained Power. (vice Average Endurance Power for the 24-hour average ship service endurance electric load) Electric propulsion power is not included. The 24-hour average ship service sustained electric load is used for endurance fuel calculations in accordance with DDS 200-1.

3.4 Ambient condition profile. The Ambient Condition Profile consists of a number of (dry bulb) temperature/relative humidity ambient conditions and an associated percentage of time the ship is spent operating in the particular ambient condition. The ambient condition profile is used for endurance fuel calculations as described in DDS 200-1. Note that the ambient conditions refer to the atmospheric environment external to the ship. Equipment inside the ship generally does not experience these conditions directly. Unless otherwise specified, the following default ambient condition profiles shall be used:

a. 25% of time at 10 °F with 95% relative humidity

b. 50% of time at 59 °F with 95% relative humidity

c. 25% of time at100 °F with 40% relative humidity

The intent of this default profile is to promote fuel efficiency across the expected range of temperatures the ship will experience. This profile should be modified if a ship is expected to operate in a range of ambient conditions that is significantly different.

3.5 Connected load: Identification plate or rated power of the load (kW). For equipment with a rated current instead of a rated power, the rated current shall be converted to rated power using an appropriate power factor. (Resistive loads usually have a power factor of about 1.0. Induction motor loads typically have a power factor between about 0.70 and 0.90 with higher values for larger and more modern motors. The nameplate on an induction motor may include the power factor at rated load.)

3.6 Demand factor. A factor applied to the connected load of a bus feeder to determine the required rating of that bus feeder. The demand factor is used to estimate the load based on historical operations.

3.7 Demand power. For a given operating condition and ambient condition, the amount of electrical power a particular power system component must be capable of supplying continuously.

3.8 Electric and propulsion plant concept of operations. Electric and propulsion plant concept of operations is used to determine which prime movers and power conversion equipment are online, and for determining how power is shared among the prime movers and power conversion equipment for given operational conditions and loads. For QOS calculations, it also includes reconfiguration time (t1) and generator start time (t2) as well as the minimum mission speed to determine the amount of propulsion power to be considered Long-Term Interrupt Load. The electric and propulsion plant concept of operations also includes the electric plant configuration or line up of switchgear for each operational condition.

3.9 Emergency ship control. Emergency ship control requirements are as defined by the customer and T9300-AF-PRO-020. Generally, emergency ship control includes, as a minimum, the following electrical loads:

a. Steering gear and associated auxiliaries.

b. Vital propulsion and propulsion auxiliaries. Vital propulsion and propulsion auxiliaries are:

(1) Required for cold starting the ship's propulsion plant.

(2) Necessary for propulsion machinery protection.

(3) Needed to achieve a minimum emergency propulsion capability (typically 7 knots) if propulsion cannot be otherwise restored in less than 2 minutes.

c. Machinery space class W and circle W ventilation.

d. Emergency lighting.

e. Emergency communications and radio communication systems.

f. Navigation Systems and Navigation Lights.

g. Fire pumps, fire containment equipment, magazine sprinkling, dewatering pumps, and associated damage control equipment.

h. Control systems, critical sensors, networks, and interior communications supporting emergency systems.

i. Auxiliaries to support the emergency generator and all equipment necessary to generate and distribute power to the other emergency loads, Auxiliaries required to directly support other emergency loads.

j. Personnel locator.

k. Flammable fluid isolation valves.

l. Exhaust ventilation for desmoking and damage control ventilation.

3.10 Energy storage module. An Energy Storage Module (ESM) stores energy provided by the electrical power system and uses that energy to provide power back to the electrical power system at a later time. An ESM can be based on a host of technologies to include batteries, flywheels, and ultra-capacitors. Energy storage can be provided for use in a specific zone and for use across the entire ship.

3.11 Load factor. For a given load, the ratio of the operating load to the connected load.

3.12 Long-term interrupt load. Loads that can tolerate service interruptions in excess of t2 are categorized as long-term interrupt loads. A load can tolerate a service interruption when the functional system the load supports can still meet its requirement without the load functioning for a period of time as a result of the service interruption.

3.13 Margin. A factor applied during design and construction to increase the load estimate to account for design and estimation uncertainty (the difference between the actual load at ship delivery and the load estimate at ship delivery). In earlier stages of design, margins are typically higher than in later stages of design. Any margin remaining at ship delivery is converted into service life allowance. T9300-AF-PRO-020 provides margin policy.

3.14 Maximum residual zonal power demand. For a zonal power system element, ship operating condition, and ambient condition, the maximum residual zonal power demand is the maximum of the residual zonal power demands of the loads powered by the zonal power system element.

3.15 Mutually exclusive loads. Loads that cannot be on at the same time through either an inter-lock or via an established procedure.

3.16 Operating load. For a given ambient condition and operating condition, the operating load represents a load's demand for power (kW). In 24-hour average load calculations, the operating load corresponds to the long-term average. For ship demand power calculations and zonal demand power calculations, the operating load may be somewhat greater than the average value to ensure equipment is sized properly to accommodate variance of the load around the average value for extended periods of time. Operating load does not include instantaneous power surges which are caused by starting large motors or short duration peak loads.

3.17 Peak load. The maximum power a load will draw (not considering transients). The peak load should be less than or equal to a load's connected load.

3.18 Product model. A product model is the combination of 3D geometry and non-graphic attributes to define ship objects such as a piece of equipment, deck, bulkhead, etc. A product model can define systems views, behavioral properties, interim products, and ultimately the entire ship.

3.19 Quality of service (QOS). Quality of Service (QOS) is a metric of how reliably the power system provides power to the loads. It is calculated as a Mean-Time-Between-Service-Interruption (MTBSI). QOS is a reliability metric; as such, the calculation of QOS metrics does not take into account survivability events such as battle damage, collisions, fires, or flooding. QOS does take into account equipment failures and normal system operation transients. Loads can be categorized into the following three QOS categories:

a. Un-interruptible

b. Short-term interrupt

c. Long-term interrupt

3.20 Reserve power. Within a power system, the difference between the total amount of power generation capacity (including energy storage with a hold-up time greater than t2) available within time t1 measured in kW and the ship demand power. Reserve power is composed of the rolling reserve of online generators and the power rating of energy storage.

3.21 Residual zonal power demand. For a load, the difference between its peak load (kW) and zonal operating load (kW).

3.22 Service interruption. A service interruption is any interruption in service, or power quality degradation outside of acceptable parameters for a period of time, which result in the functional system the load supports not being capable of meeting its requirements. The duration of service interruption is measured relative to two system dependent times: reconfiguration time (t1) and generator start time (t2).

3.22.1 Reconfiguration time (t1). Reconfiguration time (t1) is defined as the maximum time to reconfigure the distribution system (typically an automatic switchgear function) without bringing on additional generation capacity. For systems employing conventional circuit breakers, t1 can be on the order of 1 to 2 seconds (as implied by the recovery time requirements in MIL-STD-1399-300). t1 should be specified in the electric and propulsion plant concept of operations.

3.22.2 Generator start time (t2). Generator start time (t2) is defined as the maximum time to bring the slowest standby power generation module online. t2 can be on the order of several minutes (see the power interruption paragraph in MIL-STD-1399-300). Unless otherwise specified in the electric and propulsion plant concept of operations, for gas turbine and diesel generator sets, the t2 time shall assume one failed start attempt followed by a successful start if the probability of a successful first start is less than 95 percent and shall assume a successful first start otherwise. The electric and propulsion plant concept of operations shall specify which power generation modules may serve as a standby power generation module, and the operating state of the standby power generation module and associated auxiliaries.

3.23 Service life allowance. Extra capacity incorporated into the power system to accommodate future growth in loads due to ship modernization and load deterioration. Service life allowance was formerly known as service life margin. T9300-AF-PRO-020 provides service life allowance policy.

3.24 Ship demand power. For a given operating condition and ambient condition, the amount of electrical power the ship's power system must be capable of supplying continuously. The ship demand power is used to select and establish the rating of generator sets and possibly energy storage modules. The ship demand power is obtained by applying margin and service life allowance to the total operating load.

3.25 Ship operating conditions.

3.25.1 Anchor. An anchor condition is a ship operating condition in which the ship supplies all electric power while the ship is at anchor.

3.25.2 Shore. A shore condition is a ship operating condition in which the ship receives all electric power from a shore facility or a tender.

3.25.3 Cruising. A cruising condition is a ship operating condition corresponding to:

a. Condition III Wartime Cruising as defined by the ship's requirements documents, for combatants.

b. Cruising at a specified cruising speed; has self defense capability (if provided), but is not at general quarters for non-combatants.

3.25.4 Functional. A functional condition is a ship operating condition in which the ship is performing its designed function. The following are examples of a functional condition:

a. Battle for destroyers and frigates.

b. Air operation for aircraft carriers.

c. Debarking operation for cargo and amphibious warfare ships.

d. Replenishment-at-sea of ships for combat support and store ships.

e. Tending operations for tenders and repair ships.

3.25.5 Emergency. An emergency condition is a ship operating condition in which the ship is on emergency generator with ship service generators down. The emergency generators, as a minimum, supply loads associated with the following:

3.25.5.1 Surface combatant. Emergency ship control and selected self defense weapons.

3.25.5.2 Aircraft carrier. Emergency ship control and the larger electrical load associate with selected weapons or limited air operations (recovery and strike down of aircraft).

3.25.5.3 Amphibious. Emergency ship control and limited unloading operations.

3.25.5.4 Auxiliary. As listed in the Code of Federal Regulations, Title 46, Part 112.

3.25.5.5 Mine warfare and patrol craft. Emergency ship control.

3.26 Short-term interrupt load. Loads that can tolerate service interruptions in excess of t1 but cannot tolerate service interruptions greater than t2 are categorized as short-term interrupt loads. A load can tolerate a service interruption when the functional system the load supports can still meet its requirement without the load functioning for a period of time as a result of the service interruption.

3.27 Standby power. Within a power system, the amount of power generation capacity (kW) that is not available for use within time t1, but can be made available for use within time t2.

3.28 Total operating load. For a given operating condition and ambient condition, the total operating load is the sum of all the operating loads powered by a zonal power system element, or for the total ship. Margin and service life allowance are not applied to the total operating load.

3.29 Un-interruptible load. Loads that cannot tolerate service interruptions in excess of t1 are categorized as un-interruptable loads. A load can tolerate a service interruption when the functional system the load supports can still meet its requirement without the load functioning for a period of time as a result of the service interruption.

3.30 Zonal load factor. The load factor of a load adjusted (if necessary) to account for load variability for the purpose of determining the required rating of zonal power systems elements.

3.31 Zonal operating load. The product of a load's zonal load factor and connected load.

3.32 Zonal power system element. A zonal power system element is one of the following: zonal power conversion equipment, load center, bus feeders, zonal transformers, or zonal energy storage. Small distribution transformers are not considered zonal power system elements.

4. GENERAL REQUIREMENTS

4.1 Electric load list. The first step in performing a load analysis is creating an electric load list of all the loads on a ship. This list is derived from the inputs specified in 4.1.1. Equipment items are categorized according to the three-digit SWBS and their connected load is estimated and tabulated. As the ship's electrical plant one line diagram and the general/machinery arrangements are developed, the electric load list also groups the loads according to their connectivity to load centers/switchboards. Details for determining and estimating load are provided in 5.1.

4.1.1 Inputs.

1. Master equipment list
2. Combat systems description and one line diagram
3. Electrical plant description and one line diagram
4. Distributed system descriptions and one line diagrams
5. General/machinery arrangements

6. Product model (if it exists)
7. Discussions with system designers (if possible)
8. EPLAs of similar ships (if available)

4.1.2 Outputs.

1. Electric load list (including associated load data)

4.2 24-hour average load parametric equation. The 24-hour average load parametric equation is used during the earliest stages of ship design when loads are generally only estimated to determine the rating of generators. In later stages of design, other load estimation methods should be used. The specific calculations for the 24-hour average load parametric equation are provided in 5.2.

4.2.1 Inputs.

1. EPLA for generator sizing for the 100 °F operating conditions

4.2.2 Outputs.

1. 24-hour average ship service endurance electric load
2. 24-hour average ship service mission electric load profile
3. 24-hour average ship service sustained electric load

4.3 Load factor analysis. Load factor analysis is used to calculate the ship demand power and the 24-hour average load. It generally assumes a large number of loads, each of which is a relatively small fraction of the rating of a prime mover. The operating load for most loads is estimated by multiplying a load factor by the load's connected load. The load factor is either calculated or obtained from Appendix A. The details for load factor analysis are provided in 5.3.

4.3.1 Inputs.

1. Electric load list (see 5.1.1) with estimated connected loads and connectivity to load centers and switchboards
2. Ship operating conditions
3. Information on each electric load sufficient to estimate load factors (including load factor information from similar ships, impact of the ship concept of operations on the load, and results from discussions with systems designers)
4. Margin policy
5. Service life allowance policy
6. Power generation and energy storage overload capacity and overload time capability (to the extent known)
7. Ambient condition profile
8. Electric and propulsion plant concept of operation

4.3.2 Outputs.

1. EPLA including identification of all loads with corresponding estimated connected load, load factors, and operating load for each combination of ambient condition and ship operating condition. Also includes a summary report providing the operating load sum at the 1-digit SWBS level and the total ship level for each combination of ambient condition and ship operating condition. Other sums of operating load (at a minimum, casualty conditions where loads are shed and loads shift sources from primary to alternate) shall also be provided as described in the electric and propulsion plant concept of operations.

4.4 Zonal load factor analysis. Zonal load factor analysis is used to calculate the zonal demand power for zonal power system elements. Zonal load factors (in comparison to load factor analysis at the total ship level) account for the increased variability in total operating load due to intermittent loads. Zonal load factor analysis is an extension of the load factor analysis method to zonal power system elements. The details for zonal load factor analysis are provided in 5.4.

4.4.1 Inputs.

1. Electric load list (see 5.1.1) with estimated connected loads and connectivity to load centers and switchboards
2. Ship operating conditions
3. Information on each electric load sufficient to estimate zonal load factors (including load factor and zonal load factor information from similar ships, impact of the ship concept of operations on the load, and results from discussions with systems designers)
4. Margin policy
5. Service life allowance policy
6. Electric plant description and one line diagram
7. Electric and propulsion plant concept of operation
8. Ambient condition profile

4.4.2 Outputs.

1. EPLA report for zonal power system element including identification of all loads with corresponding estimated connected load, zonal load factors, and zonal operating load for each combination of ambient condition and operating condition. A summary report includes the zonal operating load sum for each combination of ambient condition and operating condition.

4.5 Demand factor analysis. Demand factor analysis is used to determine the circuit load current for selecting cable for bus feeders to load centers, for selecting the circuit breakers protecting the bus feeder, and for determining the load center bus rating. Demand factor analysis is based on a graph in MS 18299. The details for demand factor analysis are provided in 5.5.

Demand factor analysis is a legacy method and consideration should be given to using zonal load factor analysis or stochastic load analysis instead.

4.5.1 Inputs.

1. Electric load list (see 5.1.1) with estimated connected loads and connectivity to load centers

4.5.2 Outputs.

1. A list of the load center bus feeders indicating the circuit load current for selecting cable for the bus feeder, for selecting the circuit breaker protecting the bus feeder, and for determining the load center bus rating.

4.6 Stochastic load analysis. Stochastic load analysis can be used as an alternative to load factor analysis, zonal load factor analysis, demand factor analysis, and modeling and simulation load analysis. Stochastic analysis models loads as a Probability Density Function (PDF). These PDFs are summed (typically using Monte Carlo methods) for power system equipment to produce an expected value and standard deviation of the load for each combination of ship operating condition and ambient condition. The details for stochastic load analysis are provided in 5.6.

4.6.1 Inputs.

1. Electric load list (see 5.1.1) with connectivity to load centers and switchboards
2. Ship operating conditions

3. Information on each electric load sufficient to estimate PDFs for electric load (including load factor and stochastic load information from similar ships, impact of the ship concept of operations on the load, and results from discussions with systems designers)

4. Margin policy

5. Service life allowance policy

6. Power system one line diagram

7. Electric and propulsion plant concept of operation

8. Ambient condition profile

4.6.2 Outputs.

1. EPLA including identification of all loads with corresponding estimated connected load, operating load PDF, mean value, and standard deviation. Also includes the total operating load and demand load PDF, mean value, and standard deviation for zonal power system elements and for the total ship.

4.7 Modeling and simulation load analysis. Modeling and simulation load analysis is part of a broader simulation based design (SBD) methodology. In simulation based design, a dynamic model of the ship or a portion of the ship is developed and exercised through a number of operating conditions/temperature conditions typically referred to as use cases. The dynamic model simultaneously models the relevant dynamic performance of the applicable systems on the ship to capture interdependencies that may not be captured in the other load analysis methods. This method typically requires the greatest amount of engineering work, but through the characterization of the interdependencies, may result in a less expensive system design. Because of the anticipated expense of conducting modeling and simulation load analysis, this method should generally be reserved for cases where interdependencies are anticipated to have an impact on system design and other methods will not address these interdependencies adequately. The details for modeling and simulation load analysis are provided in 5.7.

4.7.1 Inputs.

1. Electric load list (see 5.1.1) with connectivity to load centers and switchboards

2. Ship operating conditions

3. Dynamic models of equipment and systems onboard the ship

4. Margin policy

5. Service life allowance policy

6. Power system one line diagram

7. Electric and propulsion plant concept of operation

8. Ambient condition profile

4.7.2 Outputs.

1. EPLA including identification of all loads with corresponding estimated connected load, operating load PDF, mean value, and standard deviation. Also includes the total operating load and demand load PDF, mean value, and standard deviation for zonal power system elements and for the total ship.

4.8 Quality of service (QOS) load analysis. Quality of service (QOS) load analysis is a key factor for determining the amount of standby power and reserve power that the system as a whole and each zone independently must have available in each operating condition to enable power continuity to loads in the event of a single failure in the power system (tripping of a protective device, failure of power systems equipment, or failure of the control system). The reserve power can take the form of rolling reserve (kW) of online generator sets, or in the power (kW) and capacity (kWh) of energy storage modules. The standby power is the power rating of the designated offline standby generator for each operational condition (as described in the electric and propulsion plant concept of operations). For un-interruptible loads, QOS places constraints on where in the system the reserve power is located; the power for un-interruptible loads cannot be impacted by switching and fault clearing transients within the power distribution system. The details for QOS analysis are provided in 5.8.

While QOS load analysis does not directly calculate QOS as a Mean Time Between Service Interruption, it collects and presents summary load breakdowns into the QOS categories so that system designers can produce ship designs that meet the QOS objectives.

If a study trades off different combinations of generator sets with different start/restart times and different fault protection technologies, then the values of t1 and t2 can vary. If t1 and t2 vary, then QOS load analysis must be conducted for the different values of t1 and t2.

4.8.1 Inputs.

1. EPLA
2. Electric and propulsion plant concept of operation, including specified values for t1 and t2
3. Information about each load in the EPLA sufficient to categorize it into one of the three QOS categories: un-interruptible, short-term interruptible, and long-term interruptible

4.8.2 Outputs.

1. Breakdown of loads at the total ship level and for each zone of the amount of load required in each QOS category

4.9 Comparing trials data with load analysis. Prior to the delivery of a ship to the Navy, a new ship typically undergoes one or two sea trials to demonstrate the ship meets the contractual requirements and is ready for delivery. The ship's electric plant is typically instrumented to determine the electric load under different operating conditions. The sea trial conditions; however, rarely match the specific conditions in the EPLA and; therefore, are not necessarily directly comparable to the EPLA. To validate the EPLA following sea trials, the load analysis must be revised to reflect the sea trials conditions. The details for comparing trials data with load analysis are provided in 5.9.

4.9.1 Inputs.

1. Completed EPLA
2. Sea trials machinery plant line-ups
3. Sea trials electric load data with associated equipment line-ups for electric plant, machinery plant, and mission systems correlated on a time basis for tracking load with online equipment
4. Ambient temperature and sea-state conditions

4.9.2 Outputs.

1. Adjusted EPLA including identification of all loads with corresponding estimated connected load, and operating load for each combination of temperature and operating condition. Also includes the demand load for zonal power system elements and for the total ship for each combination of ambient condition and ship operating condition.

5. SPECIFIC REQUIREMENTS

5.1 Electric load list. The first step in performing a load analysis is creating an electric load list of all the loads on a ship. The list of loads is created by examining design artifacts such as master equipment lists, combat systems description and one line diagrams, electric plant one line diagram, distributed system one line diagram, general arrangement drawings, machinery arrangement drawings, and product models. In some cases, the ship design may not be mature enough to capture all of the loads. The electric list must still presume they exist and an estimate must be made with respect to connected load and connectivity to the power system. Equipment items are categorized according to the three-digit SWBS as defined in S9040-AA-IDX-010/SWBS 5D. The connected load is estimated and tabulated. As the ship's electrical plant one line diagram and the general/machinery arrangements are developed, the electric load list incorporates the connectivity to load centers/switchboards. The electric load list will evolve as the ship design evolves.

5.1.1 Collecting load data. Data on each load is collected to properly model the load for subsequent analysis. This data includes the following:

a. Nomenclature

b. SWBS (3-digit)

c. Location on the ship (zone and/or compartment) (needed for zonal equipment and distribution system sizing)

d. Point(s) of connection to the power system (load center, switchboard). If more than one point of connection, indicate the primary and alternate connection (if applicable). (needed for zonal equipment and distribution system sizing)

e. Identification Plate (nameplate) rating (include units)

f. Connected load (kW)

g. Peak load (kW)

h. Power type (voltage, number of phases, frequency)

i. Cyclic and intermittent behavior

j. Power requirements during different operating modes

k. Use during different ship operating conditions

l. Temperature dependence

m. Tolerance to power interruptions (for QOS analysis)

n. Correlation with other loads (such as mutually exclusive loads)

o. Load shed priority

p. Reference to the source of data to enable traceability

5.1.2 Combining loads. Multiple loads can be combined into a single entry on the electric load list under the following conditions:

a. When two or more associated power consuming devices are known to operate with some relation to each other and are provided power from a common distribution node. The relationship of the loads to one another may or may not be clearly established. For example, in considering the group of motors associated with the operation of a gun mount, a clearly established relationship exists between the ramming motors and the elevating motors, since the rammers operate under load only when the barrels are horizontal, while the elevating motors are idling at no load. In this case, the gun mount can be considered a single load.

b. Where there is a group of low power consuming equipment within the same space, the equipment are provided power from a common distribution node, and the equipment would be assigned approximately the same load factor. An example of this is a group of electronic equipment. The composition of the group of loads must be clearly identified in the electric load list.

5.2 24-hour average load parametric equation. During the earliest stages of design, loads may only be estimated at the 10 °F and 100 °F conditions to determine the maximum margined electric load for generator sizing. If the 59 °F condition is not calculated, or if load factors are not estimated for the 24-hour average, the 24-hour average electric load for all but aircraft carriers and large deck amphibious assault ships can be estimated using equation 1. For aircraft carriers and large deck amphibious assault ships, the 24-hour average electric load can be estimated using equation 2. The EPLA used for this estimation should be that used for calculating the ship demand power. In lieu of more detailed results provided by Load Factor Analysis, Modeling and Simulation Load Analysis, or Stochastic Load Analysis, the single value produced by the 24-hour average load parametric equation is used in all endurance fuel calculations described in DDS 200-1.

$$P_{24\text{-hour-ave}} = P_{prop\_steering} + 0.75(P_{cruise} - P_{prop\_steering}) \quad [1]$$

where:

$P_{24\text{-hour-ave}}$ = 24-hour average load

$P_{prop\_steering}$ = Propulsion plant and steering system loads (not including electric propulsion loads)

P_{cruise} = Load for the cruising ship operating condition with margins and service life for the 100 °F ambient condition

$$P_{24\text{-hour-ave}} = P_{prop\_steering} + 0.60(P_{cruise} - P_{prop\_steering}) \quad [2]$$

5.3 Load factor analysis. Load factor analysis can be used to calculate the ship demand power and the 24-hour average load used in fuel calculations and zonal load factor analysis. Load factor analysis is used to determine the total operating load of all the electric power consuming devices under the various combinations of temperature and operating conditions of the ship such as anchor, shore, cruising, functional, and emergency. Other operating conditions may also be included to emphasize minimum and maximum power requirements. Minimum power requirements are needed to avoid reduced reliability and maintenance costs associated with operating prime movers lightly loaded for extensive periods of time.

For each load in the electric load list, a load factor is assigned for each combination of temperature/relative humidity ambient condition in the ambient condition profile and operating condition. For a given temperature/relative humidity and operating condition, the operating load for each load is the product of the load factor and the connected load. All of the operating loads for the loads in the electric load list are summed to determine the total operating load for the given temperature/relative humidity and operating condition. As described in T9300-AF-PRO-020, margin policy and service life allowance policy increase this total load as part of the process to determine the ship demand power and 24-hour average loads. The load factor analysis shall document a reference, such as this DDS or a technical report, detailing the source or calculations for each load factor value.

For example, assume the load factors for a potable water pump are 0.3, 0.2, 0.3, 0.3, and 0 for all temperatures in the anchor, shore, cruising, functional, and emergency conditions, respectively. If the connected load for the pump is 19.1 kW, its operating load for all temperatures in each condition is 5.7 kW for the anchor condition; 3.8 kW for the shore condition; 5.7 kW for the cruising condition; 5.7 kW for the functional condition; and 0 kW for the emergency condition. Figure 2 shows another example of the application of load factors.

Intermittent or cyclic loads should generally have different load factors for ship demand power calculations and for 24-hour average calculations. To ensure the generator has sufficient capacity to serve both the long-term average and the short-term deviation of the load around the average, the load factor for ship demand power calculations should account for a portion of the peak load of intermediate and cyclic loads. For 24-hour average calculations, the load factor should only account for the long-term average. In general, the 24-hour average load factor should be less than or equal to the ship demand power load factor. If the differences are small in aggregate, the 24-hour average load factor and ship demand power load factor may be equated.

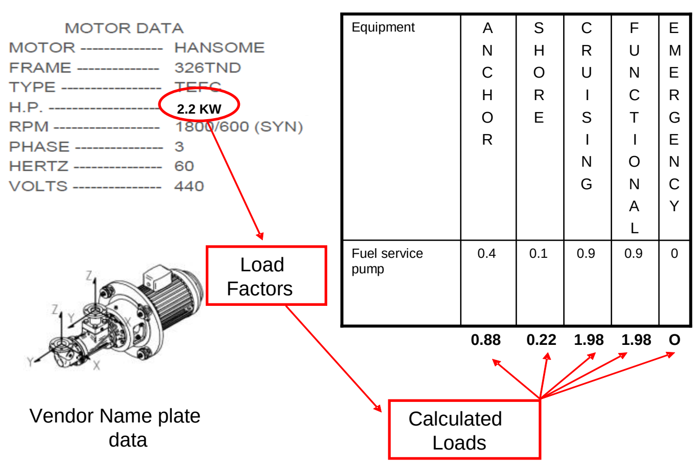

Figure 2. Load factor example.

5.3.1 Assigning load factors.

5.3.1.1 Load factor assignment considerations. In assigning load factors, the following shall be considered:

a. Zero load factors are assigned to seldom used equipment.

b. For ship demand power calculations, a load factor of 0.9 is typically used in cases where a motor operates at full load for an extended period of time during a specific ship condition. For 24-hour average load calculations, the load factor should reflect the long-term average load.

c. All standby units shall be listed and assigned zero load factors except when the standby unit is actually kept running or is based on percent of power used while idling.

d. Some ships are required to provide power to other ships, vehicles, and non-organic systems. Load analysis shall take into consideration the supply of power to these users of shipboard power.

e. If a load factor for 24-hour average calculations is known, the load factor for ship demand power can be approximated by applying the curve shown in figure 3 and equation 3.

f. For mutually exclusive loads, the load with the higher operating load value shall be assigned the appropriate load factor and the load with the lower operating load value shall be assigned a load factor of 0.

Appendix A lists typical load factors for calculating ship demand power. The compilation of the factors listed in Appendix A is the result of past experience with similar loads, but should not be considered the only option. Modification of these load factors should be incorporated when special circumstances or additional data exist to support the use of different load factors.

5.3.1.2 Load analysis when load data exists. For some pieces of equipment and groups of equipment, extensive investigations and tests have been conducted to determine operating load values during various ship operating conditions. Where such known and established operating load values are available, they should be used in lieu of the load factors from Appendix A. For these loads, the load factor for 24-hour average load calculations is selected such that the connected load multiplied by the load factor is equal to the actual long-term operating load. Where data is available, conditions having a general bearing on the selection of load factors and typical methods used in their selection include:

a. Motors: In selecting the size of a motor necessary to drive an auxiliary at its rated output, a larger motor than actually required is normally chosen because:

(1) In the design of the driven auxiliary, some margin in excess of calculated kW is allowed. Accordingly, the driving motor does not normally consume its rated kW when operating the driven auxiliary at its maximum load condition.

(2) The choice of available standard motor frame size may dictate selection of a larger than necessary motor.

b. Load factor for an individual load: If particular equipment operates continuously at a steady load during a given ship operational condition, the load factor for that equipment (for either ship demand power or 24-hour average calculations) may be taken as the ratio of the estimated operating load to the connected load of the equipment. If the load is intermittent or cyclic, such as an air compressor motor, the factor shall be selected based on:

(1) For 24-hour average calculations used in endurance and annual fuel calculations, the load factor should be set equal to the ratio of the long-term average load to the connected load of the equipment.

(2) For ship demand power calculations the load factor can be approximated by applying the curve shown in figure 3 and equation 3.

5.3.2 Special loads. For certain loads, calculating and tabulating actual kW load instead of using load factors is warranted. Examples include:

a. Electric load for dedicated power conversion equipment: A detailed analysis of electric loads that are fed through dedicated power conversion equipment that are not considered part of the power distribution system shall be performed. Taking into consideration the efficiency of the conversion equipment, the kW load shall be listed in the power analysis in lieu of load factors. The load analysis shall note the sum of the electric loads served and the power conversion efficiency at that operating point.

b Electric load for distribution system inefficiencies: Non-negligible distribution system losses (kW) (including losses from non-dedicated power conversion equipment that are part of the distribution system) shall be tabulated and incorporated into power analysis in lieu of load factors. The manner of incorporating these losses into the power analysis should be aligned with the methods used to estimate the losses.

5.3.3 <u>24-hour average load calculations</u>. DDS 200-1 provides details on the use of the 24-hour average electric load for endurance fuel calculations. It requires estimates for the 24-hour average load for each ambient condition in the ambient condition profile. For the 24-hour average ship service mission electric load profile, the ship service load is provided as a function of ship speed as well. The ship operating conditions used for the 24-hour average load calculation is defined in DDS 200-1.

While both the 24-hour average ship service endurance electric load calculation and the 24-hour average ship service sustained electric load calculation use the same operational condition, they may differ somewhat due to differences in online electrical loads to support propulsion plant configurations to achieve the endurance speed as compared to the sustained speed.

5.3.4 <u>Load factor analysis reports</u>.

5.3.4.1 <u>EPLA detailed report</u>. For each ambient condition, an EPLA detailed report shall at a minimum contain the following fields for each load on the ship:

1. Line number (or other unique identifier for load)
2. SWBS (3-digit)
3. Nomenclature of the equipment
4. Identification plate rating of the equipment (include units)
5. Connected load (kW)
6. Load factor and operating load (kW) for each ship operating condition
7. Reference or basis for the load factors for each load
8. Normal and alternate sources (switchboards, load centers, etc.)
9. Notes for documenting special considerations such as interdependencies with other loads
10. Vital/Non-vital status or mission prioritization information

5.3.4.2 <u>EPLA summary report</u>. The EPLA summary report shall provide for each ambient condition, the total operating load and ship demand power for every ship operating condition and/or 24-hour average load for applicable ship operating conditions.

The EPLA summary report shall also provide a breakdown of ship demand power by switchboard for each combination of ambient condition, ship operating condition and with/without serving as alternate source for loads with multiple power feeds.

Additionally, for each ambient condition, an EPLA summary report shall at a minimum contain the following fields for each 1-digit SWBS group of loads:

1. SWBS (1-digit) and SWBS group name
2. Connected load (kW)
3. Total operating load for each combination of ship operating condition and ambient condition

5.4 <u>Zonal load factor analysis</u>. Zonal load factor analysis is used to calculate zonal demand power for zonal power system elements. Zonal load factors account for the increased variability in load due to having fewer loads than for the total ship. Zonal load factor analysis is an extension of the load factor analysis method to zonal power system elements. In some cases zonal load factor analysis can be very conservative. If the difference in demand power calculated for zonal power system elements using load factor analysis (from 5.3) and zonal demand power is very large, consideration should be given to instead using either the stochastic or modeling and simulation methods.

5.4.1 Assigning zonal load factors.

Zonal load factor analysis is conducted in the same way as load factor analysis with the following exceptions:

a. A separate zonal load factor analysis is required for each zonal power system element to determine its zonal demand power for each ship operating condition and ambient condition. The zonal total operating load is the sum of the zonal operating loads plus the maximum residual zonal power demand. The zonal operating load of a served load is the product of its zonal load factor and connected load. The zonal demand power is calculated by applying margin and service life allowance to the zonal total operating load.

b. Only the loads served by the zonal power system element are incorporated into the analysis.

c. For a given ship operating condition, if a ship requires only n out of m redundant equipment online, the analysis assumes that the number of redundant equipment online that is served by the zonal power system element is the minimum of n and the number of redundant equipment served by the zonal power system element. For example, if a ship has 10 fire pumps, but only 3 are required online for a given operational condition, and a given zonal power system equipment has only 2 fire pumps connected to it, then the zonal load factor analysis would assume that the 2 connected fire pumps are online. Alternately, if a ship has 10 fire pumps, but only 3 are required online for a given operational condition, and a given zonal power system element has 4 fire pumps connected to it, then the zonal load factor would assume that 3 connected fire pumps are online.

d. For loads that can be provided power from two zonal power system elements, the electric and propulsion plant concept of operation will provide guidance on which zonal power system equipment is the primary source of power and which is the alternate source of power. The electric and propulsion plant concept of operation shall also provide guidance as to whether the calculations for the zonal demand power of the power system element serving as the alternate source of power should include the load. The electric and propulsion plant concept of operation may specify calculating the zonal load calculations for several different sets of assumptions.

e. The load factor used in load factor analysis for calculating ship demand power (as modified by the discussion above) is converted to a zonal load factor as indicated in equation 3 and figure 3. The demand power for the zonal element is initially calculated using load factor analysis (see 5.3). In producing the zonal load factor, equation 3 increases the load factor for an individual load based on the relative size of the peak load of the individual load as compared to the demand power of the zonal element as calculated using load factor analysis.

f. For each load served by a zonal power system element, the residual zonal power demand (kW) for a given ship operating condition is the difference between the peak load (kW) and the zonal operating load (kW).

g. The maximum residual zonal power demand (kW) is the largest residual zonal power demand of all the loads served by a given zonal power system element for a given ship operating condition.

$$L_{fz_j} = L_{f_j} + \left(\frac{P_{P_j}}{P_{L_j}} - L_{f_j}\right)\left(\frac{P_{P_j}}{\sum_{i=1}^{n} L_{f_i} P_{L_i}}\right) \text{for } \frac{P_{P_j}}{\sum_{i=1}^{n} L_{f_i} P_{L_i}} < 1.0$$

$$L_{fz_j} = \frac{P_{P_j}}{P_{L_j}} \text{ for } \frac{P_{P_j}}{\sum_{i=1}^{n} L_{f_i} P_{L_i}} \geq 1.0 \qquad [3]$$

where:

L_{fz_j} = Zonal load factor for load *j*

L_{f_j} = Load factor for load *j* for 24-hour average calculations (see 5.3)

P_{L_j} = Connected load (kW) for online load *j*

P_{P_j} = Peak load (kW) for online load *j*

n = Number of loads

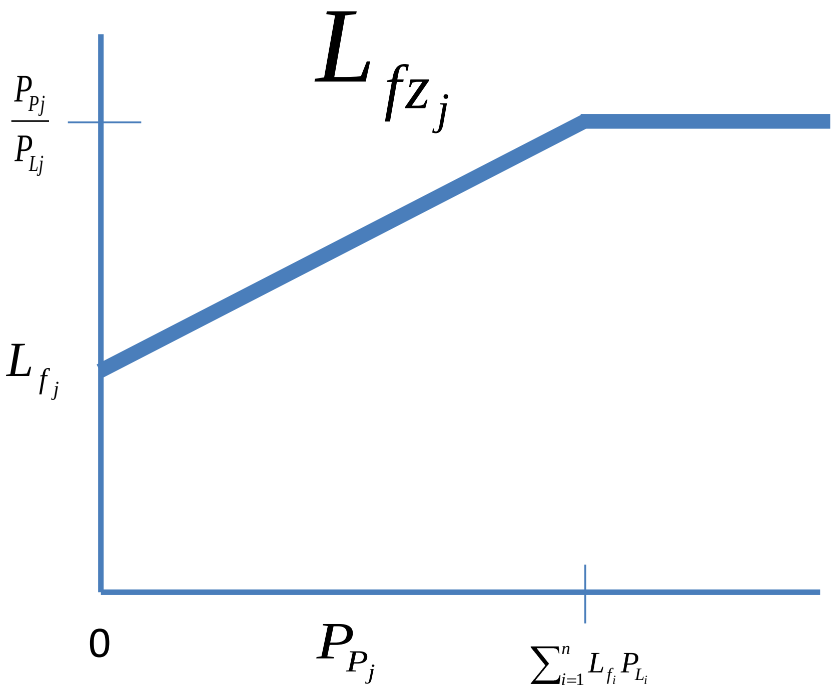

Figure 3. Zonal load factor.

For example, in a given operating condition, a 100 kW (connected and peak operating) load with a load factor of 0.4 (for 24-hour average calculations) is provided by power from a converter supplying a total operating load of 400 kW as calculated using load factor analysis. For this operating condition, the peak load is 25 percent of the total demand load using load factor analysis. The zonal load factor is calculated:

$$L_{fz_j} = 0.4 + (1.0 - 0.4)\left(\frac{100}{400}\right) = 0.55 \qquad [4]$$

The residual zonal power demand for this load is (100 - 0.55 × 100) = 45 kW

5.4.2 Zonal load factor analysis reports.

EPLA detailed reports are prepared for zonal power conversion equipment. If a zonal power conversion equipment has multiple outputs, then a detailed report is prepared for each output.

For each ambient condition, an EPLA detailed report shall at a minimum contain the following fields for each load served by the particular zonal equipment:

1. Line number (or other unique identifier for load – normally the same as that used for load factor analysis)
2. SWBS (3-digit)
3. Nomenclature of the equipment
4. Identification plate rating of the equipment (include units)
5. Connected load (kW)
6. Peak load (kW)
7. Load factor
8. Zonal load factor and zonal operating load (kW) for each ship operating condition

9. Residual zonal power demand (kW) for each ship operating condition
10. Notes for documenting special considerations such as interdependencies with other loads

For each ambient condition, an EPLA summary report shall at a minimum contain the following fields:

1. Power system equipment/component name
2. Power system equipment/component output group name (if applicable)
3. Power system equipment/component demand power (kW) calculated using load factors for each ship operating condition
4. Power system equipment/component zonal demand power (kW) for each ship operating condition
5. Maximum residual zonal power demand (kW) for each ship operating condition.

5.5 Demand factor analysis. Demand factor analysis is used to determine the circuit load current for selecting cable for bus feeders to load centers and the circuit breakers protecting the bus feeder.

The analysis consists of calculating the connected load for each bus feeder by summing the connected load of all the loads attached to the bus feeder. Margin and service life allowances are applied to this sum to produce the bus feeder connected load. The bus feeder and the circuit breaker protecting the bus feeder shall have the capability to service a total load calculated by multiplying the bus feeder connected load expressed in amps with the demand factor from figure 4 for 450 volt AC systems or by multiplying the bus feeder connected load expressed in kW with the demand factor from figure 5 for other voltages or DC systems.

Demand factor analysis is a legacy method and consideration should be given to using zonal load factor analysis or stochastic load analysis instead.

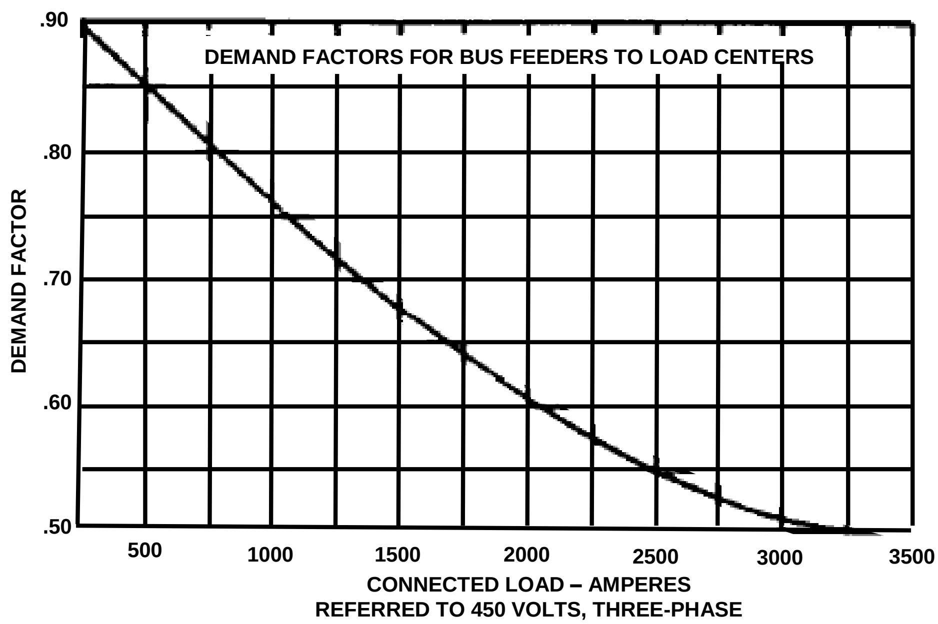

Figure 4. Demand factor curve (MS 18299).

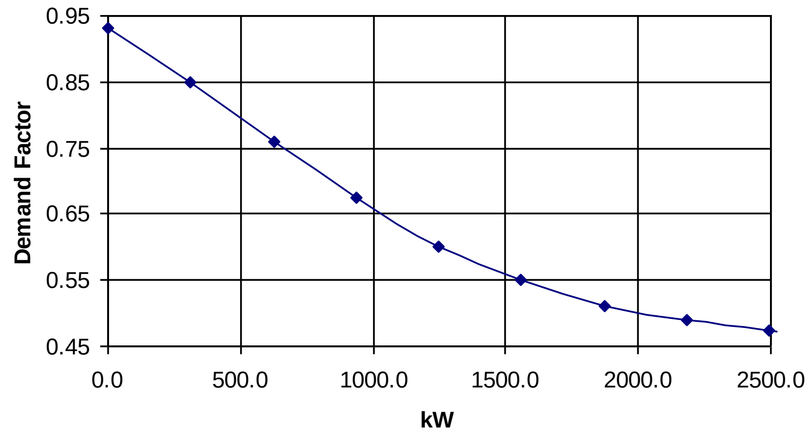

Figure 5. Demand factor curve based on connected load.

5.6 Stochastic load analysis. Stochastic load analysis is an alternative method for determining the ship demand power and equipment demand power. This method requires an individual competent in both stochastic methods and electrical load modeling. While this design data sheet provides an introduction to the concepts of stochastic analysis, particularly using the Monte Carlo Simulation Method, much more information on this topic is readily available in text books and other professional references.

5.6.1 Stochastic load analysis guidance.

5.6.1.1 Introduction.

While traditional load factor and zonal load factors account for uncertainty with margins, stochastic load analysis incorporates the uncertainty normally accommodated with margin in a PDF for each load. The definite integral of the PDF over an interval from x_1 to x_2 is the probability that the value for x will be between x_1 and x_2. The value for each load; therefore, is modeled as a function of one or more random variables, each characterized by a PDF.

A PDF accounts for many sources of uncertainty including:

a. Especially during early stages of design, the specific hardware to implement a load may not be selected. Many times, the particular piece of hardware is not chosen until detail design. The stochastic model of the load must account for the range of different equipment that could be chosen in detail design.

b. Especially for early stage design or new equipment, the load values provided by manufacturer's data sheets may not be completely reliable or reflective of the manner in which the equipment is integrated and employed onboard the ship.

c. The electrical power required by a variety of loads is determined by the mechanical power demand provided by the load to other systems. For example, the power consumed by a pump is determined by the flow requirements of the fluid system it serves. The uncertainty in the flow requirements is reflected as an uncertainty in the electrical load.

d. A load may cycle among several power levels. For example, a water heater may have zero, one, or two heating elements energized depending on the need to regulate the water temperature.

For a random variable X, the PDF of X is represented by $f_X(x)$. The probability that X is between x_1 and x_2 is given by:

$$\boldsymbol{Pr}(x_1 < X < x_2) = \int_{x_1}^{x_2} f_X(x)\,dx \qquad [5]$$

The cumulative distribution function (CDF) represented by $F_X(x)$ is the probability that the value of X is less than or equal to x.

$$F_X(x) = \int_{-\infty}^{x} f_X(y)dy \qquad [6]$$

For sizing electrical equipment, we are typically interested in the inverse of this problem: the load (value of x) for which the probability of X less than or equal to x is some fixed probability represented by the term (1 - α), where α represents the probability that the actual load is greater than x. In other words, we are seeking the value of x for which:

$$F_X(x) = \int_{-\infty}^{x} f_X(y)dy = (1-\alpha) \qquad [7]$$

The value for (1 - α) to use for calculating ship demand power or equipment demand power depends on the consequence of not having sufficient capacity. If the generators/equipment have a significant overload capability for a reasonable duration of time, and there are a significant amount of cyclic loads, then an appropriate value for (1 - α) would be on the order of 0.95 (there is a 5 percent chance that the equipment would be undersized). On the other hand, equipment such as power electronics which typically have only a small overload capability, an appropriate value for (1 - α) would be on the order of 0.99 (there is a 1 percent chance that the equipment would be undersized). The actual numbers to use for (1 - α) should be based on balancing the cost of adding additional power capacity against the risk of having undersized power system equipment.

For fuel consumption calculations, an average value is desired. While the median value corresponds to (1 - α) = 0.50, fuel consumption calculations typically should use the mean value ($\bar{x}$) which is calculated using equation 8.

$$\bar{x} = \int_{-\infty}^{\infty} x f_X(x)dx \qquad [8]$$

5.6.1.2 Load characterization.

Many loads can be characterized by three types of stochastic models:

a. Loads that are always "on" can be represented by a single random variable that corresponds to the uncertainty in estimating that load.

b. Loads that cycle on and off independently of other loads can be represented by a function of two random variables. The first random variable describes the fraction of time that the load is on and the second corresponds to the amount of electrical power the load consumes when on.

c. For loads that are dependent on configuration, make the configuration "number" a discrete random variable that provides the probability for each unique configuration. For each unique configuration, develop a model of the load as appropriate. A configuration can either be at the system level, or specifically for the individual load. A configuration can also refer to different models of equipment fulfilling the same function produced by the same or different manufacturers.

For example, at the system level, if 2 of 6 fire pumps are required to be on, then there are 15 different combinations or configurations that can meet this requirement. In this case, each of the 15 configurations would likely have the same probability. For each configuration a given fire pump would be either off, or have its own stochastic model for the load when on.

Another example, at the load level, could correspond to a radar with multiple modes of operation. Each mode of operation would correspond to a "configuration" and the associated load would be modeled as in case (a) or (b).

Note that cases (b) and (c) incorporate conditional probabilities where the probability only applies if a given condition happens (i.e., the load estimate only applies if the load is on).

Note that margins are not explicitly included in this method. The intended purpose of a margin, to account for uncertainty of the estimate, is accomplished through the PDFs for each load. On the other hand, service life allowances should be applied to the results of the stochastic analysis for determining the rating of the power system equipment. Service life allowances account for the growth of loads during the operational life of the ship following delivery and due to maintenance and modernization efforts.

While the three types of stochastic models will cover many if not all the loads typically encountered in an electric load analysis, special cases will undoubtedly occur which will require a different type of model. The stochastic modeler must be capable of recognizing this situation and developing an appropriate model. The level of detail of the model is bounded by the complexity needed and resources available to the user.

In modeling an electric load, PDFs of three standard types are typically employed: uniform, triangular, and discrete. In the uniform distribution (figure 6), a variable is uniformly likely to occur between a minimum and maximum value. In early stages of design, this is likely the most appropriate model to use when very little is known about the loads. Once a "most likely" value of a load is known (the mode), a triangular distribution (figure 7) can reflect the additional information available from more mature design information. A discrete distribution (figure 8) allows one to model different modes or configurations of a load or a load's system. The discrete distribution is composed of one or more impulse functions whose magnitude is equal to the probability of *x* having the value equal to the impulse functions location. While the normal distribution (figure 9) is commonly used in stochastic modeling, it should be used with caution in power system modeling. The normal distribution has unbounded lower and upper limits. Most loads cannot physically have a negative load, nor if they are working correctly, will they have a load larger than some maximum value. If a normal distribution is used, some provision in the modeling should be employed to address these anomalies.

Appendix C provides an example of modeling a cycling load based on a time history sampling of the load.

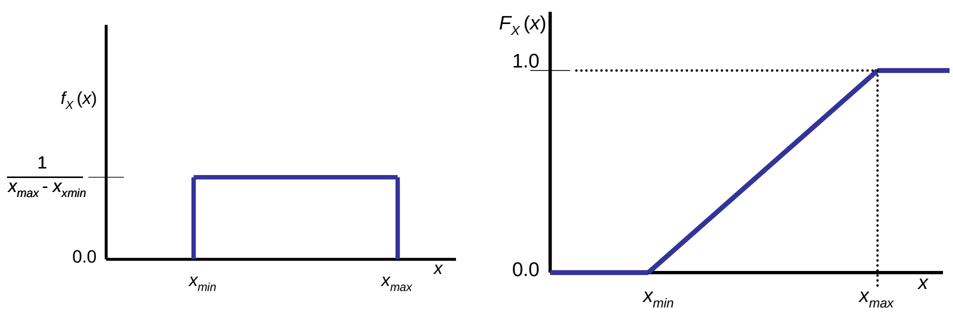

Figure 6. Uniform distribution PDF and CDF.

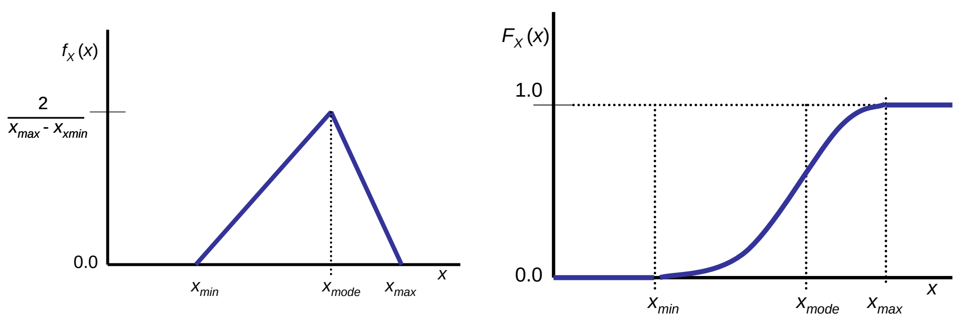

Figure 7. Triangular distribution PDF and CDF.

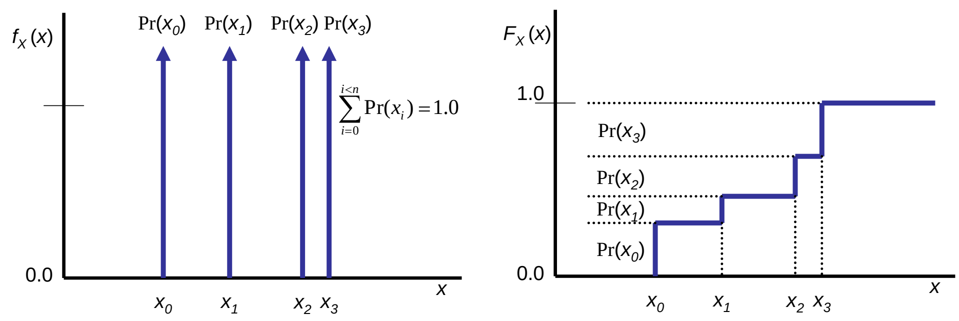

Figure 8. Discrete distribution PDF and CDF.

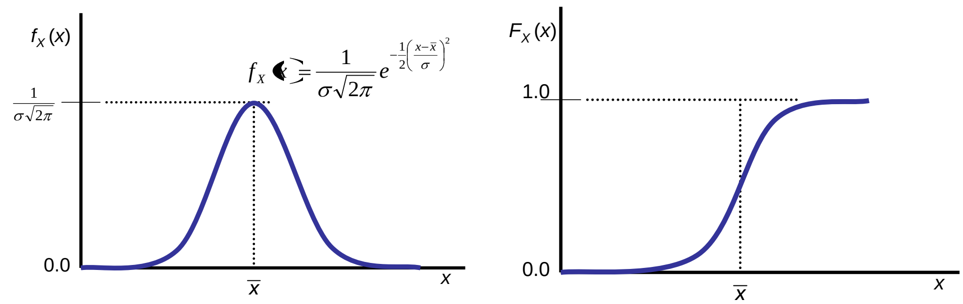

Figure 9. Normal distribution PDF and CDF.

5.6.1.3 Monte Carlo Simulation.

Determining the PDF for the total load served by a power system component is accomplished by summing the values, also expressed as a PDF, of the individual loads served. While there are a number of techniques for developing the PDF for the total load served, the method most often used is a variant of the Monte Carlo Simulation Method.

In a Monte Carlo Simulation, the process depicted in figure 10 is used:

a. A model of the system is developed using real numbers as inputs and producing real numbers as output.

b. PDFs are developed for each of the inputs.

c. The model of the system is executed multiple times. For each iteration:

(1) A value for each input is randomly chosen according to its PDF.

(2) The models output is recorded.

d. After an initial number of iterations are completed (typically on the order of 500 (should be large enough to develop a reasonable error estimate)), the mean and variance of the set of model outputs is calculated. From these values, an estimate of the error is made. If the error estimate is small enough (typically 2 percent of the mean value), then the output PDF is calculated and the process terminates. If the error estimate is too high, then an estimate for the number of iterations required is made and the additional iterations executed.

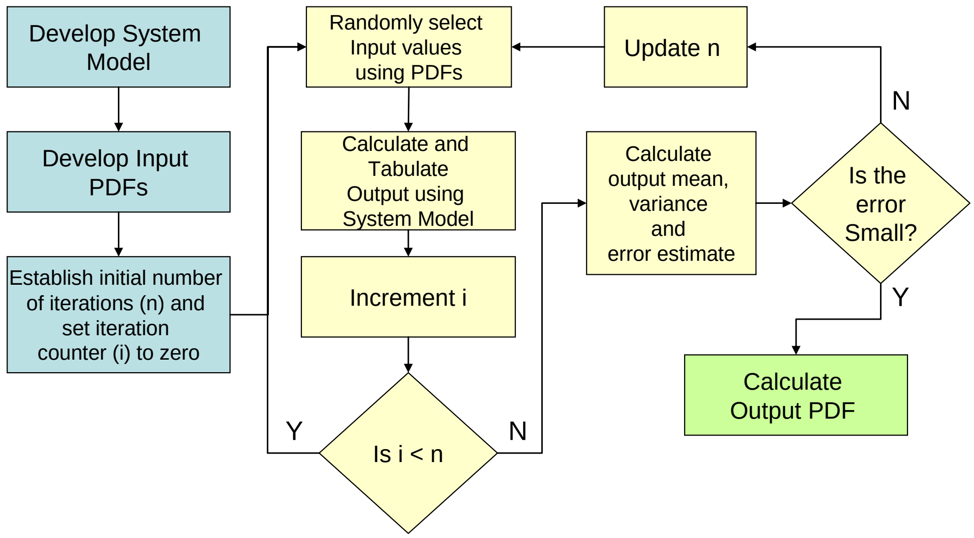

Figure 10. Monte Carlo Simulation Algorithm.

5.6.1.4 Random variable generation.

There are a number of ways to create a random sample for a given PDF to generate an input value to drive the system model. Some computer software systems can directly create random numbers for specific types of PDFs such as a normal distribution. Virtually all systems can create a random number in the interval [0:1] using a uniform distribution. This uniform distribution, through the use of the Inverse Transform Technique (figure 11), can be used to produce random variables of an arbitrary PDF. The steps of the Inverse Transform Technique are:

a. Develop the CDF $F_X(x)$ from the PDF $f_X(x)$ using equation 6.

b. Create a sample u from a uniform distribution over the interval [0:1].

c. Solve the equation $F_X(x) = u$ for x. x is now a random sample from the PDF $f_X(x)$.

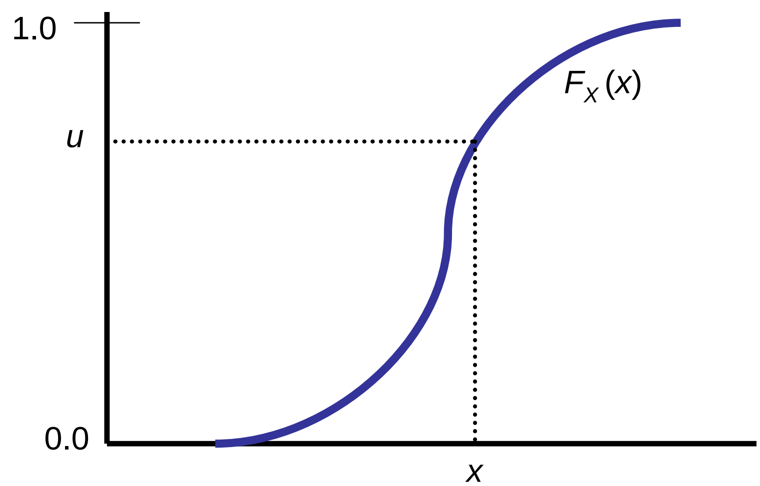

Figure 11. Inverse transform technique.

5.6.1.5 Estimating output PDF properties.

Estimating the mean ($\bar{x}$), standard deviation (σ_x), and variance (σ_x^2) of the output PDF from the set of outputs x_i for n iterations is straight forward:

$$\bar{x} = \frac{1}{n}\sum_{i=0}^{n-1} x_i \qquad [9]$$

$$\sigma_x^2 = \frac{1}{n-1}\sum_{i=0}^{n-1} (x_i - \bar{x})^2 \qquad [10]$$

Note that in equation 10, the term (n-1) is used instead of the n of the formal definition of a standard deviation. (n-1) reflects the common usage of Bessel's correction to account for the limited sample size of the output PDF. For large n, it doesn't practically matter whether one uses n or (n-1).

For electrical load analysis, characterizing the error (E) as a fraction of the mean value is a reasonable approach. A conservative estimate for E for a sufficiently large n is given by:

$$E = \frac{3\sigma_x}{\bar{x}\sqrt{n}} \qquad [11]$$

Typically, one would like this value of E to be less than or equal to 0.02. Once a sufficient number of iterations (500 is a good starting point) have been established to estimate σ_x and $\bar{x}$, then the number of iterations (n) required to achieve a given value of E can be calculated from:

$$n = \left[\frac{3\sigma_x}{\bar{x}E}\right]^2 = \frac{9}{E^2}\left(\frac{\sigma_x}{\bar{x}}\right)^2 \qquad [12]$$

5.6.2 Stochastic load analysis reports.

For each ambient condition, an EPLA detailed report shall at a minimum contain the following fields for each load on the ship:

1. Line number (or other unique identifier for load)
2. SWBS (3-digit)
3. Nomenclature of the equipment
4. Identification plate rating of the equipment (include units)
5. Connected load (kW)
6. For each operating condition, a description of the stochastic model used and a reference for model details
7. For each operating condition, the mean value and standard deviation of the operating load
8. Notes for documenting special considerations such as interdependencies with other loads
9. Vital/Non-vital status or mission prioritization information

For each ambient condition, an EPLA zonal summary report shall at a minimum contain the following fields:

1. Zonal power conversion equipment name
2. Zonal power conversion equipment output group name

3. Connected load (kW)

4. PDF, mean value, and standard deviation of the equipment demand power (kW) for each ship operating condition

For each ambient condition, an EPLA ship summary report shall at a minimum provide the PDF, mean value, and standard deviation of the ship demand power (kW) and contain the following fields for each 1-digit SWBS group of loads:

1. SWBS (1-digit) and SWBS group name (plus one row for the total ship)
2. Connected load (kW)
3. PDF, mean value, and standard deviation of the operating load for each ship operating condition

5.7 Modeling and simulation load analysis. Situations where specific loads are large compared to the generation or power system component capacity, have unusual electrical characteristics, require large amounts of rolling reserve not normally reflected in load averages, or when the correlation of many loads is complex and cannot be adequately modeled using one of the other methods described here, may benefit from the use of modeling and simulation load analysis. Examples include: crash-back of an electric propulsion system, firing large electromagnetic rail guns, large loads with high harmonic currents, and operating high power multi-mode radars.

5.7.1 Modeling and simulation load analysis guidance.

In modeling and simulation load analysis, a system model is typically created by integrating component models. Skill is required to ensure the component models and their interconnection properly capture the dynamics of interest. This may require modeling of electrical, control, and mechanical interfaces. Equally important is crafting the use-cases employed in the simulations. These use-cases must fully represent the anticipated operational conditions the system must successfully operate in as well as the planned concept of operations. The modeling and simulation effort should also include a sensitivity analysis to test the robustness of solutions to variation in modeling parameters. One method to perform the sensitivity analysis is to treat the modeling parameter as random variables and use Monte Carlo methods to determine the probability that the system will perform acceptably over the expected variability of the modeling parameters.

In planning modeling and simulation, the models and accompanying data must be verified and validated. Verification ensures the model development was done properly; the software, data, assumptions, and other tool attributes were correctly implemented. Validation ensures the model is an accurate representation of the real world. One of the challenges in successfully modeling and simulating a shipboard power system in early stages of design is that some of the critical data may be proprietary to the original equipment manufacturer and not available to the modeler. Another challenge is the lack of precise knowledge on the type, characteristics, quantity, and location of loads throughout the ship. In these cases, a significant sensitivity analysis is warranted.

5.7.2 Modeling and simulation load analysis reports.

For each ambient condition, an EPLA detailed report shall at a minimum contain the following fields for each load on the ship:

1. Line number (or other unique identifier for load)
2. SWBS (3-digit)
3. Nomenclature of the equipment
4. Identification plate rating of the equipment (include units)
5. Connected load (kW)
6. For each operating condition, a description of the dynamic model used and a reference for model details
7. For each operating condition, the PDF, mean value, standard deviation, and maximum value of the operating load
8. Notes for documenting special considerations such as interdependencies with other loads
9. Vital/Non-vital status or mission prioritization information

For each ambient condition, an EPLA zonal summary report shall at a minimum contain the following fields:

1. Zonal power conversion equipment name
2. Zonal power conversion equipment output group name
3. Connected load (kW)
4. PDF, mean value, standard deviation, and maximum value of the zonal operating load (kW) for each ship operating condition

For each ambient condition, an EPLA ship summary report shall at a minimum contain the following fields for each 1-digit SWBS group of loads:

1. SWBS (1-digit) and SWBS group name (plus one row for the total ship)
2. Connected load (kW)
3. PDF, mean value, standard deviation, and maximum value of the operating load for each ship operating condition

Modeling and simulation load analysis may also be conducted to support special studies. The requirements for these reports are as specified by the customer.

5.8 Quality of service (QOS) load analysis. Quality of service (QOS) load analysis is a key factor for determining the amount of standby power and reserve power that the system as a whole and each zone independently must have available in each operating condition to enable power continuity to loads in the event of a single failure in the power system (tripping of a protective device, failure of power systems equipment, or failure of the control system). The reserve power can take the form of "rolling reserve" of online generator sets, or in the power and capacity (kWh) of energy storage modules. The standby power is the power rating of the designated offline standby generator for each operational condition (as described in the electric and propulsion plant concept of operations). For un-interruptible loads, QOS places constraints on where in the system the reserve power is located; the power for un-interruptible loads cannot be impacted by switching and fault clearing transients within the power distribution system.

While QOS load analysis does not directly calculate QOS as a Mean Time Between Service Interruption, it collects and presents summary load breakdowns into the QOS categories so that system designers can produce ship designs that meet the QOS objectives.

If a study trades off different combinations of generator sets and fault protection technologies, then the values of reconfiguration time (t1) and generator start time (t2) can vary. If t1 and t2 vary, then QOS load analysis must be conducted for the different values of t1 and t2.

Each load in the electric load list is assigned a QOS category (un-interruptible, short-term interrupt, or long-term interrupt) based on its tolerance to power interruptions as compared to t1 and t2. In assigning QOS categories the following shall be considered:

a. Resistive heating loads should normally be assigned as long-term interrupt loads.

b. Heating Ventilation and Air Conditioning (HVAC) loads should normally be assigned as long-term interrupt loads if the resulting change in space or equipment temperature following loss of HVAC is acceptable for duration t2 and if the air quality remains acceptable.

c. Any load with its own dedicated Un-interruptible Power Supply (UPS) with energy capacity sufficient for an outage of time t2 should normally be assigned as long-term interrupt load.

d. Damage control and emergency loads would normally be un-interruptible or short-term interrupt.

e. "Standby" units not associated with emergency loads and online for redundancy alone would normally be long-term interrupt.

f. Non-essential loads, such as galley equipment, laundry equipment, entertainment equipment, convenience outlets, and task lighting would normally be long-term interrupt loads.

g. Where emergency lighting is provided general illumination would normally be long-term interrupt loads, otherwise general illumination would normally be short-term interrupt loads.

h. For integrated power systems, that portion of propulsion load needed to exceed the minimum mission speed or needed to exceed a minimum emergency propulsion capability (typically 7 knots) as described in the electric and propulsion plant concept of operations is normally a long-term interrupt load. The propulsion load needed to achieve the minimum mission speed/minimum emergency propulsion capability is normally a short-term interrupt load.

Once all the loads have been assigned a QOS category, the total load for each QOS category at the ship level and at the zonal equipment level are calculated and tabulated for each operating condition and ambient condition using the general report format for the load analysis method used. Although other methods may be used, load factor analysis and zonal load factor analysis are typically employed.

5.9 Comparing trials data with load analysis.

To compare sea trial results with the EPLA, the load analysis must be modified to reflect the ambient condition and operational equipment line-ups actually experienced during sea trials. The analysis results are compared to the measured values from the trials data. Any major deviations are further explored to understand the needed adjustments to the load analysis. These adjustments to the load analysis are then used to update the traditional analysis for the operational conditions and temperatures used in the original EPLA.

Determining the temperature dependency of loads may prove challenging. In general, HVAC and equipment cooling system loads should be carefully examined and adjusted. Adjusting other loads should be considered if a temperature dependency can be justified. Items with (T) after their title in Appendix A should at a minimum be evaluated for temperature dependency.

APPENDIX A – LOAD FACTOR TABLES FOR SURFACE SHIPS

Note: Items with (T) after their title should at a minimum be evaluated for temperature dependency.

SWBS Group 2 - Propulsion Plant **General**	**ANCHOR**	**SHORE**	**CRUISING**	**FUNCTIONAL**	**EMERGENCY**
Auxiliary seawater circulating pump	0.3	0.3	0.6	0.6	0
Blow in door heater, gas turbine	0	0	0.9	0.9	0
Controllable pitch propeller hydraulic oil heater	0.3	0.3	0.3	0.3	0
Controllable pitch propeller hydraulic oil pump	0	0	0.9	0.9	0
Controllable pitch propeller hydraulic oil purifier heater	0.1	0	0.1	0	0
Controllable pitch propeller hydraulic oil purifier	0.3	0	0.3	0.3	0
Electric propulsion equipment space heaters	0.9	0.9	0	0	0
Electric propulsion exciter	0	0	0.9	0.9	0
Emergency feed booster and transfer pump	0	0	0	0	0
Fuel service pump	0.4	0.1	0.9	0.9	0
Inlet louver heater, gas turbine	0	0	0.9	0.9	0
Lighting off forced draft blower	0.1	0	0	0	0
Lube oil purifier	0.3	0	0.3	0.3	0
Main circulating MO valve	0	0	0	0	0
Main circulating pump	0	0	0.9	0.9	0
Main condensate pump	0	0	0.9	0.9	0
Main engine cooling fan, gas turbine	0	0	0.9	0.9	0
Main engine prelube pump	0	0	0	0	0
Main feed booster pump	0.1	0	0.9	0.9	0.5
Main turbine gland exhaust	0	0	0.9	0.9	0
Main vacuum pump	0	0	0.9	0.9	0
Main feed lube pump	0.2	0	0.9	0.9	0
Module equipment, gas turbine	0.4	0.4	0.2	0.2	0
Port fuel oil service pump	0	0.1	0	0	0
Port-use forced draft blower	0.2	0	0	0	0
Propulsion control console	0.5	0.2	0.6	0.8	0
Propulsion motor lubricating oil pump	0	0	0.9	0.9	0
Propulsion motor ventilation fan	0	0	0.9	0.9	0
Reserve feed transfer pump	0.2	0.2	0.2	0	0
Seawater booster pump	0	0	0.3	0.9	0
Shaft turning gear	0.1	0.1	0	0	0.1
Standby reduction gear lubricating oil pump	0	0	0	0	0.2
Standby lubricating oil service pump	0	0	0	0	0.2

SWBS Group 3 - Electric Plant General	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
Electrical plant control console	0.2	0.2	0.2	0.2	0.2
Emergency gen salt water booster pump	0	0	0	0	0.9
Forklift battery charger	0.2	0.2	0.3	0.3	0
Generator space heaters	0.9	0.9	0	0	0
Gas turbine gen enclosure cooling fan	0.9	0	0.9	0.9	0
Gas turbine salt water pump	0.9	0	0.9	0.9	0
Lighting machinery spaces	0.9	0.9	0.9	0.9	0.9
Lighting outside machinery spaces	0.6	0.4	0.6	0.6	0.4
Ship battery charger	0.2	0.2	0.2	0.2	0
STGEN circulating pump	0.5	0	0.5	0.9	0
STGEN condensate pump	0.5	0	0.5	0.9	0
STGEN start-up lubricating oil pump	0	0	0	0	0.9
STGEN vacuum pump	0.5	0	0.5	0.9	0
Aircraft Carriers					
Aircraft & helicopter start	0.1	0	0.1	0.5	0
Amphibious Ships					
Helicopter starting rectifier	0	0	0.1	0.1	0.1
Auxiliary Ships					
Helicopter starting rectifier	0	0	0	0	0
Cruisers-Destroyers-Frigates					
Helicopter starting rectifier	0	0	0	0	0
SWBS Group 4 - Command and Surveillance **General**	**ANCHOR**	**SHORE**	**CRUISING**	**FUNCTIONAL**	**EMERGENCY**
Bathythermograph winch	0	0	0	0	0
Combat information center	0.2	0	0.4	0.7	0
Degaussing system	0.8	0	0.8	0.8	0
Electronic countermeasures	0	0	0.4	0.7	0.5
Electronic cooling system	0.4	0.2	0.7	0.7	0.5
Entertainment system	0.1	0.1	0.3	0	0
IC system	0.2	0.2	0.4	0.7	0.4
Lighting, navigation	0.6	0.4	0.6	0.4	0.2
Missile fire control	0.1	0	0.1	0.6	0

SWBS Group 4 - Command and Surveillance - Continued General - Continued	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
Radar	0.2	0	0.5	0.7	0.5
Radio	0.2	0.1	0.4	0.7	0.4
Searchlight	0	0	0	0.2	0
Sonar	0	0	0.4	0.4	0
Amphibious Ships					
Fire control	0.2	0.1	0.3	0.4	0.4
Auxiliary Ships					
Fire control	0	0	0	0	0.6
Cruisers-Destroyers-Frigates					
Fire control	0.2	0.1	0.4	0.7	0.4

SWBS Group 5 - Auxiliary Systems General	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
A/C chilled water pump (T)	0.7	0.5	0.7	0.7	0.4
A/C compressor (T)	0.7	0.5	0.7	0.7	0.4
A/C purge recovery unit (T)	0.3	0.3	0.3	0.3	0
A/C seawater circulating pump (T)	0.7	0.5	0.7	0.7	0.4
Anchor windlass	0	0	0	0	0
Bilge & fuel tank stripping	0.1	0.1	0.1	0	0
Bilge pump	0.1	0.1	0.1	0.1	0
Boat winch	0	0	0	0	0
Capstan	0	0	0	0	0
Cargo refrigerator compressor (T)	0.3	0.3	0.3	0.3	0
Cathodic protection	0.9	0.9	0.9	0	0
Class circle W ventilation (T)	0.9	0.9	0.9	0.9	0.4
Class circle Z ventilation (T)	0.7	0.7	0.7	0	0
Class W ventilation (T)	0.9	0.9	0.9	0.9	0.4
Class X and Y ventilation (T)	0.7	0.7	0.7	0	0
Class Z ventilation (T)	0.9	0.9	0.9	0	0
Control air compressor	0.2	0	0.6	0.6	0
Disinfectant agent pump	0.1	0.1	0.1	0.1	0
Distiller plant	0.5	0	0.7	0.7	0
Drinking fountain	0.4	0.4	0.4	0.4	0
Duct heater class Z (T)	0.9	0.9	0.9	0	0

SWBS Group 5 - Auxiliary Systems - Continued General - Continued	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
Duct heater class W (T)	0.9	0.9	0.9	0.9	0
Duct heater class circle W (T)	0.9	0.9	0.9	0.9	0
Dumbwaiter	0.1	0.1	0.1	0	0
Fire pump	0.2	0.2	0.2	0.4	0.4
Fuel drain and transfer pump	0.3	0	0.3	0.3	0
Fuel transfer pump	0.1	0.1	0.1	0.1	0
Fuel transfer pump purifier	0.3	0	0.3	0	0
Fuel tank stripping pump	0	0	0	0	0
Flushing system	0	0	0.1	0.1	0
Fresh water drain tank pump	0.3	0.1	0.6	0	0
General service pump	0	0	0.1	0.1	0
Gas turbine wash down pump	0	0	0	0	0
Gas turbine water wash tank heater	0.1	0.1	0.1	0.1	0
High pressure air compressor	0.1	0.1	0.1	0.1	0
Hot water circulating pump	0.3	0.3	0.6	0.6	0
HP air compressor air dryer	0.1	0.1	0.1	0.1	0
LAMPS equipment	0	0	0.1	0.5	0.5
Lubricating oil transfer pump	0.1	0.1	0.1	0	0
Main steering gear pump	0	0	0.3	0.3	0.3
02 N2 plant	0	0	0.9	0.9	0
PRAIRIE/MASKER compressor	0	0	0.9	0.9	0
Potable water booster pump	0.3	0.2	0.3	0.3	0
Potable water priming pump	0	0	0	0	0
Potable water pump	0.3	0.2	0.3	0.3	0
Sewage macerator	0.1	0.1	0.1	0.1	0
Sewage pump	0	0	0.1	0.1	0
Ship service air compressor	0.1	0.1	0.1	0.1	0
Soluble fog foam	0	0	0	0	0
Space heater class W (T)	0.9	0.9	0.9	0.9	0
Space heater class Z (T)	0.9	0.9	0.9	0	0
SS air compressor air dryer	0.1	0.1	0.1	0.1	0
SS refrigerator compressor	0.3	0.3	0.3	0.3	0
Steering auxiliary heater (T)	0.9	0.9	0	0	0
Steering gear control	0	0	0.5	0.5	0.5
Steering gear servo pump	0	0	0.5	0.5	0.1
Standby steering gear pump	0	0	0	0	0
Steering gear fill & drain pump	0	0	0	0	0
Towing machine	0	0	0	0.3	0

SWBS Group 5 - Auxiliary Systems - Continued General - Continued	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
Unit coolers (T)	0.2	0.2	0.2	0.2	0
Ventilation, no class (T)	0.9	0.7	0.9	0.9	0.4
Aircraft Carriers					
Aircraft/hydraulic test unit	0	0	0	0.5	0
Aircraft elevator side door	0	0	0	0.1	0
Aircraft component elevator	0	0.1	0.1	0.2	0
Aircraft cooling carts	0	0	0	0.5	0
Aircraft crane	0	0	0	0	0
Aircraft elevator main pump	0	0	0.2	0.2	0
Aircraft elevator sump pump	0	0	0.1	0.1	0
Aircraft positioner	0	0	0.1	0.1	0
Arresting gear system	0	0	0	0.2	0.2
Aviation gasoline pump	0	0	0	0.1	0.9
Barricade standby hydraulic pump package	0	0	0	0.1	0
Catapult system	0	0	0	0.2	0
Decanning boom hoist	0.1	0.1	0.1	0	0
Elevator platform gate valve	0	0	0.2	0.2	0
Hangar division door	0	0	0	0.1	0
Island elevator	0.2	0.2	0.2	0.2	0
Jet blast deflector hydraulic pump	0	0	0	0.2	0
JP-5 defueling pump	0	0	0	0.2	0
JP-5 purifier	0	0	0	0.2	0
JP-5 service pump	0	0	0	0.2	0
JP-5 tank drain pump	0	0	0	0	0
Personnel elevators	0.2	0.1	0.2	0.2	0
Replenishment-at-sea system	0	0	0.2	0	0
Stern hoist, flammable liquid	0.2	0.2	0	0	0
Stores conveyor	0.1	0.1	0.1	0	0
Amphibious Ships					
Aircraft crane	0	0	0	0	0
Aircraft elevator main pump	0	0	0.2	0.2	0
Aircraft elevator sump pump	0	0	0.2	0.2	0
Aircraft engine hoist	0.2	0.2	0.2	0.2	0
Automotive gas defueling pump	0.2	0.2	0	0	0.2
Aviation gasoline pumps	0	0	0.2	0.2	0.2
Automotive gasoline pump	0.2	0.2	0	0.2	0.2

SWBS Group 5 - Auxiliary Systems - Continued Amphibious Ships - Continued	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
Avionics outlets	0	0	0	0	0
Cargo elevator	0.2	0.2	0	0.2	0.2
Cargo elevator emergency hoist	0	0	0	0	0
Deck edge door	0	0	0.2	0.2	0
Jib crane hoist	0.2	0.2	0	0	0
JP-5 cargo stripping pump	0	0	0	0	0
JP-5 defueling pump	0	0	0.2	0.2	0
JP-5 purifier	0	0	0.2	0.2	0
JP-5 service pump	0	0	0.2	0.2	0
JP-5 transfer pump	0.2	0.2	0.1	0.1	0
Replenishment-at-sea system	0	0	0.2	0	0
Stores conveyor	0.2	0.2	0.1	0	0
Wire rope hoist	0.2	0.2	0.2	0.2	0.2
Auxiliary Ships					
Cargo crane	0.3	0.3	0.1	0.3	0
Cargo crane heater	0.2	0.2	0.2	0	0
Cargo elevator	0.2	0.2	0	0.3	0
Cargo elevator door	0.1	0.1	0.1	0.1	0
Cargo fuel stripping pump	0	0	0	0	0
Component transfer lift	0	0	0	0.2	0
Highline winch	0	0	0	0.6	0
Helicopter boom	0	0	0	0	0
JP-5 priming pump	0	0	0	0	0
JP-5 purifier	0	0	0.1	0.3	0
JP-5 service pump	0	0	0.1	0.3	0
JP-5 transfer pump	0	0	0	0	0
Outboard and inboard saddle winch	0	0	0	0.3	0
Outhaul and inhaul winch	0	0	0	0.3	0
Package conveyor	0	0.7	0	0.5	0
Power operated hangar door	0	0	0	0	0
Rammer cart	0	0	0	0.2	0
Retrieving line winch	0	0	0	0.3	0
Retrieving line winch heater	0	0	0	0	0
Sliding block power unit	0	0	0	0.3	0
Snaking winch	0	0	0	0.3	0
Span wire winch	0	0	0	0.6	0

SWBS Group 5 - Auxiliary Systems - Continued Cruisers-Destroyers-Frigates	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
Fast elevator system	0.1	0.1	0.1	0	0
Helicopter winch	0	0	0	0	0
JP-5 purifier	0	0	0.1	0	0
JP-5 service pump	0	0	0.1	0	0
JP-5 transfer pump	0	0	0	0	0
Package conveyor	0	0.3	0.1	0	0
Torpedo hatch cover	0	0	0	0	0

SWBS Group 6 - Outfit and Furnishings General	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
Arc welders AC/DC	0.1	0.1	0.1	0.1	0
Bake oven	0.2	0.2	0.2	0	0
Bakery chilled water	0.3	0.2	0.3	0.1	0
Bread slicer	0.3	0.2	0.3	0.1	0
Cash register	0	0	0	0	0
Centrifuge	0	0	0	0	0
Coffee maker	0.3	0.2	0.3	0.3	0
Coil winder	0.2	0.2	0.2	0	0
Deep fat fryer	0.4	0.4	0.4	0	0
Dishwasher	0.3	0.2	0.3	0.2	0
Drill press	0.1	0.1	0.1	0	0
Dryer	0.2	0.2	0.2	0	0
Finisher	0.2	0.2	0.2	0	0
Flatwork ironer	0.2	0.2	0.2	0	0
Fry kettle	0.4	0.2	0.4	0.4	0
Garbage disposal	0.2	0.2	0.2	0	0
Garbage grinder	0.2	0.2	0.2	0	0
Generator test stand	0.1	0.1	0.1	0.1	0
Griddle	0.3	0.2	0.3	0.3	0
Grinder	0.1	0.1	0.1	0	0
Hand iron	0	0	0	0	0
Heated glass	0	0	0	0	0
Hydraulic test stand	0.1	0.1	0.1	0.1	0
Ice cream equipment	0.3	0.2	0.3	0.2	0
Ice maker	0.3	0.2	0.3	0.3	0
Lathe	0.2	0.2	0.2	0	0

SWBS Group 6 - Outfit and Furnishings - Continued	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
General - Continued					
Lube unit	0.1	0.1	0.1	0	0
Meat preparation equipment	0.3	0.2	0.3	0	0
Milling machine	0.1	0.1	0.1	0	0
Mixer	0.2	0.2	0.2	0.2	0
Oven	0.4	0.2	0.4	0.4	0
Photo equipment	0.1	0.1	0.1	0.1	0
Planer and joiner	0.1	0.1	0.1	0	0
Power saw	0.1	0.1	0.1	0	0
Pre-rinse booster pump	0.3	0.2	0.3	0.2	0
Range	0.4	0.2	0.4	0.4	0
Recharge pump	0.2	0.2	0.2	0	0
Refrigerator/freezer combination	0.5	0.5	0.5	0.5	0
Refrigerator - small	0.3	0.3	0.3	0.3	0
Sewing machine	0.2	0.2	0.2	0	0
Shearing machine	0.2	0.2	0.2	0	0
Shirt folding machine	0.2	0.2	0.2	0	0
Shop hoist	0.1	0.1	0.1	0	0
Sterilizer - dressing	0	0	0.1	0.7	0.1
Sterilizer - instrument	0.1	0.1	0.1	0.7	0.1
Stitcher	0.2	0.2	0.2	0	0
Test switchboard	0.1	0.1	0.1	0.1	0
Toaster	0.3	0.2	0.3	0	0
Trash burner fan	0.1	0	0.1	0	0
Ultrasonic cleaner	0.1	0.1	0.1	0	0
Valve replacer	0.2	0.2	0.2	0	0
Vegetable cutter	0.2	0.1	0.2	0	0
Vegetable peeler	0.2	0.1	0.2	0	0
Vertical sleever	0.2	0.2	0.2	0	0
Waffle iron	0.1	0.1	0.1	0	0
Washer extractor	0.2	0.2	0.2	0	0
Water heater	0.1	0.1	0.5	0.5	0.1
Window wipers	0	0	0	0	0
X-ray machine	0.1	0.1	0.1	0.2	0.2
Aircraft Carriers					
Accommodation ladder	0	0	0	0	0
Photo equipment	0.4	0	0.4	0.4	0

SWBS Group 7 - Armament	**ANCHOR**	**SHORE**	**CRUISING**	**FUNCTIONAL**	**EMERGENCY**
General					
Gun mounts	0	0	0	0.6	0.6
Magazine bridge crane	0.2	0.2	0.1	0.1	0
Missile launcher	0.2	0	0.2	0	0
Weapons elevator	0.2	0.2	0	0.7	0
Weapons handling hoist	0.2	0.2	0	0.7	0

APPENDIX B – LOAD AMALGAMATION

The load factor and zonal load factor methods take advantage of the Central Limit Theorem to develop load estimates using scalar quantities rather than random variables. While each of the loads on a ship is better modeled as a random variable than a scalar, the computational effort and cost for directly using random variable are considerably greater than for using scalars.

The Central Limit Theorem states that for a sufficiently large set of random variables (either all identically distributed, or under specific conditions non-identically distributed), the sum of the random numbers will be normally distributed. Furthermore, the standard deviation of the sum divided by the mean value of the sum will become smaller as the size of the set increases. For example, if 100 independent random variables with normal distribution, mean m and standard deviation s are summed, then the mean value of the sum would be $100m$, but the standard deviation would be the root-sum-square, or $10s$. For a single random variable, the ratio of standard deviation to the mean is s/m. For 100 independent random variables with the same mean and standard deviation, the ratio of the standard deviation to the mean is $s/10m$. As expected, the variability of the total load decreases as the number of individual loads amalgamated increases. For a sufficiently large number of loads, such as for the total ship level (assuming no one, single load is a large fraction of the total load), one can safely use the load factors applied to the connected load and ignore the load variation. With the fewer number of loads at the zonal level, however, the variance of the total load can be a sizeable fraction of the mean total load, hence the rating of zonal components should account for this variability.

APPENDIX C – STOCHASTIC MODELING EXAMPLE

This appendix provides an example of creating a stochastic model of a load. The load modeled is the Collection Hold and Transfer (CHT) sewage system on a Coast Guard cutter. Figure C-1 contains a picture and diagram of the system. The sewage collection tank is maintained under a vacuum by periodic operation of one or both vacuum pumps. The vacuum is used to suck waste water from vacuum toilets, urinals, and the garbage grinder. Discharge pumps are used to pump the waste water to a holding tank.

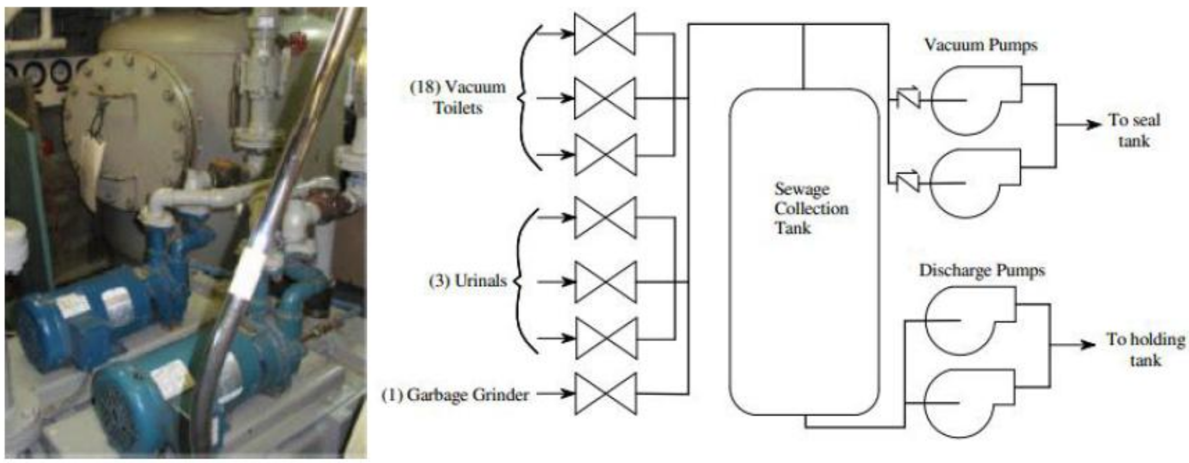

Figure C-1. Collection Hold and Transfer (CHT) sewage system.

The connected load of the CHT system is about 1600 watts. Under normal operation the load is considerably less. As shown in figure C-2, for most of the time, only the controller draws power at a level between 40 and 100 watts. When the vacuum has decreased sufficiently, one of the two vacuum pumps is energized and after a motor starting transient of very short duration, the load settles to between 600 and 800 watts for a few moments.

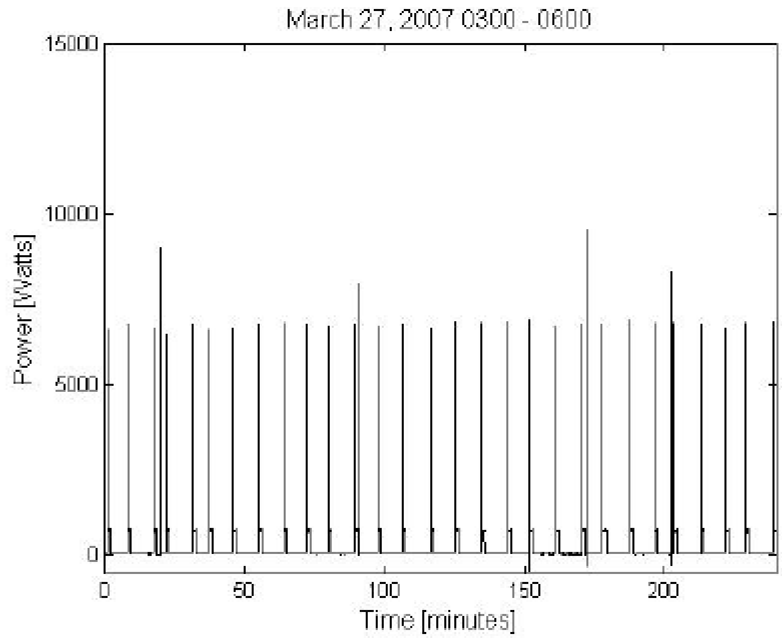

Figure C-2. Electric load time history.

Figure C-3 captures the power usage history in the form of a histogram where the load is collected in 25-watt 'bins'. For example, all load measurements between 100 and 125 watts are credited to 112.5 watts in calculating the percent of total operating time. The histogram clearly shows that the majority of the time (86 percent) is spent in a low power mode with a smaller percentage of time (14 percent) at a higher power level.

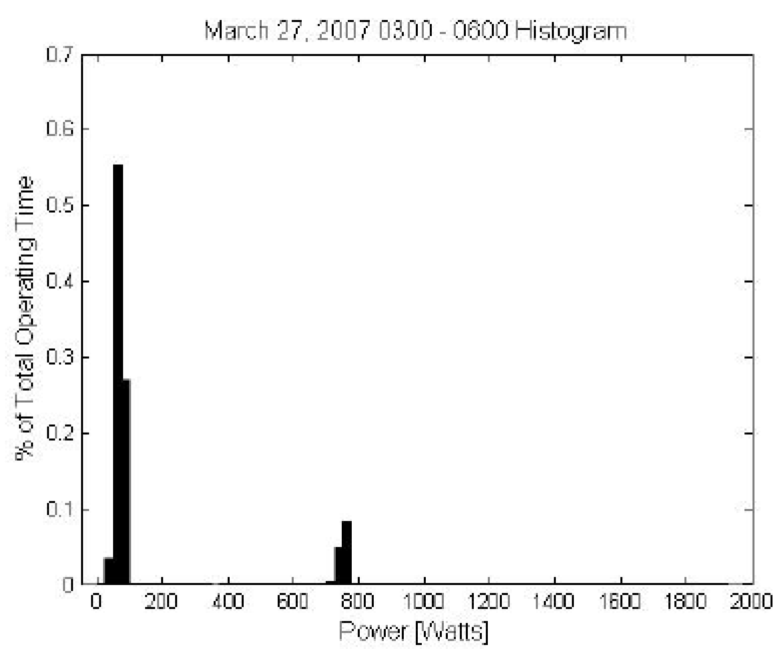

Figure C-3. Histogram of CHT power usage.

Figure C-4 converts the histogram of figure C-3 into a PDF by dividing the probability of each point in the histogram by the 'bin' size (25 watts for this example). The probability density is assumed constant across the 25-watt breadth of each bin.

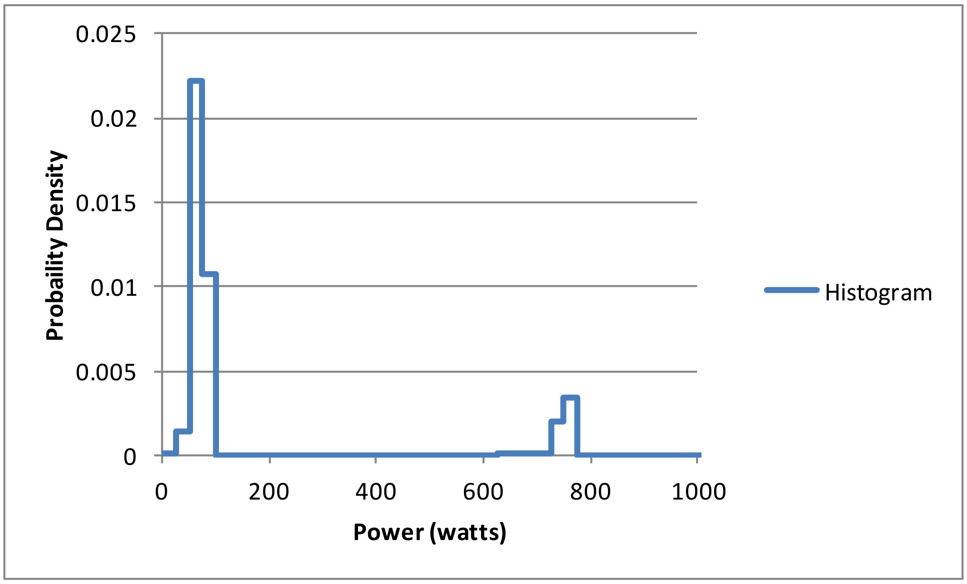

Figure C-4. PDF of histogram for CHT power usage.

While figure C-4could be used directly in stochastic modeling, a simpler model shown in figure C-5 based on triangular distributions will improve the speed of calculations and facilitate improvements to the model. As shown in figure C-6, the triangle based distribution approximation closely matches the PDF of the histogram. The triangle based approximation has the following values:

Low Power Mode: (86% of time)

x_{min} = 37.5 watts
x_{mode} = 62.5 watts (with probability density of 0.022 W^{-1})
x_{max} = 112.5 watts

High Power Mode: (14% of time)

x_{min} = 712.5 watts
x_{mode} = 762.5 watts (with probability density of 0.0034 W^{-1})
x_{max} = 787.5 watts

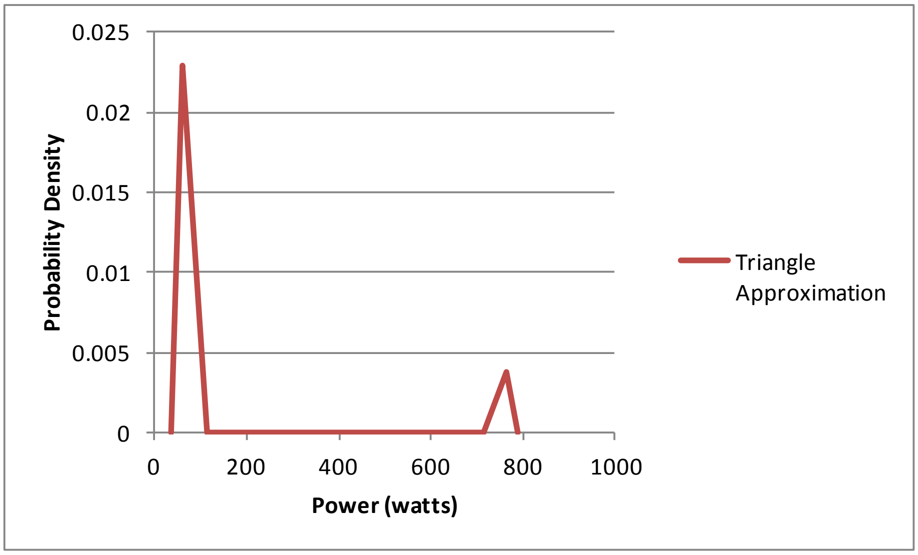

Figure C-5. Triangle distribution approximation.

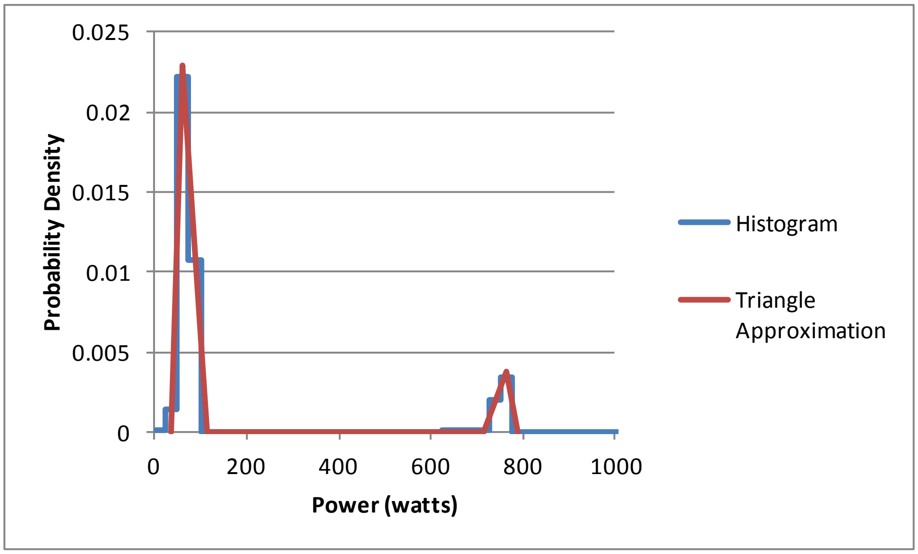

Figure C-6. Comparison of histogram and triangle approximation.

While the model in figure C-5 reflects the data collected for this particular ship over a particular 3-hour period of time, it is not clear how representative this distribution is for application on other ships. The source of the biggest variation is likely the percentage of time in the high power mode due to varying numbers of fixtures serviced, the frequency of fixture usage, and the effectiveness of the check valve seals. To account for the uncertainty in this percentage, the model could be modified by keeping the two triangular distributions for the low power and high power modes, but using another random variable for the percentage of time spent in the high power mode.

Note: This example is provided courtesy of Steven B. Leeb, Uzoma Orji, Christopher Schantz and Jim Paris of MIT.