

Combining Loads

Norbert Doerry

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1. Introduction

A ship at sea may have thousands of electrical loads. These loads may not be fully defined until detail design and construction. Still, these loads must be modeled in some way in order to properly analyze the power system. Combining loads into proxy loads is one way of reducing the complexity and complicated aspects of understanding the loads onboard ship and performing calculations to determine required characteristics of power system equipment and the minimum size of fuel tanks. Loads may be combined because individual loads have not yet been defined; or loads may be combined to improve modeling efficiency when modeling individual loads is not necessary for the analysis being conducted.

2. Proxy loads

A proxy load may be used to represent a group of loads within the load list, or as part of load modeling; a load model may incorporate multiple loads from the load list. See IEEE Std. 45.3 for additional guidance on proxy loads.

Multiple small loads that connect to the power system at the same power system interfaces may be lumped together into a single proxy load; electric lighting and electric heaters are often grouped in this way. If the proxy load is part of the load list, all of the constituent loads normally should have the same product breakdown structure identifier (SWBS for naval systems).

Multiple loads (including proxy loads) defined in the load list may be combined into a proxy load for the purpose of simplifying calculations for a particular analysis. Many types of analysis do not require the individual identification of loads; knowing the total load at different interfaces of the power system is sufficient. Since these proxy loads only exist for a particular analysis, the constituent loads generally are not required to have the same product breakdown structure identifier.

If two loads are mutually exclusive (only one may be on at any time), then it may be beneficial to incorporate the two loads into a single proxy load. For equipment sizing purposes, only the load with the larger operating load is modeled; for 24-hour average purposes, both loads are modeled.

3. Load list

When initially creating a load list in the early stages of design, combining small loads with the same product breakdown structure identifier and the same connections to the power system is often done; limiting the total number of loads in the load list simplifies load management and load modeling. A group of loads may be identified as a package that is intended to fulfill a specific ship



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requirement; if the ship is assigned this requirement, then incorporating the group of loads into the ship design (and load list by extension) implies the requirement is partially or fully met. This package of loads may be modeled as a single proxy load if all the constituent loads connect to the power system at the same points.

Examples of the categories of loads that should be considered for combining into proxy loads include:

- Electric lighting
- Electric heaters
- Fan coil units
- Ventilation fans
- Galley equipment
- Convenience outlets
- Windshield wipers
- Data acquisition units
- Distributed network equipment
- Distributed internal communications equipment
- Water coolers (drinking fountains)
- Radio equipment
- Medical and dental equipment
- Laundry equipment

How to populate most of the data elements associated with a load list entry for many small loads is straight forward. Some data elements however, have nuances.

- **Location on the ship:** May be left blank if the constituent loads are not collocated.
- **Identification Plate (nameplate) rating (including units):** May be left blank.
- **Connected Load (kW and KVAR):** Use the sum of the connected loads of the constituent loads.
- **Peak Load (kW and KVAR):** If the peak load does not differ substantially from the average load, use the average load; otherwise consider using quasi-steady-state analysis or the zonal load factor method to estimate the peak load. One can also use engineering judgement based on knowledge of the loads and their usage to estimate the peak load.
- **Load behavior:** Use the load behavior that best matches the combination of all the constituent loads.
- **Use during different ship operating conditions:** For a given operating condition and ambient condition, if any of the constituent loads are on, then should use TRUE. If all of the constituent loads are off, then should use FALSE. Otherwise use UNKNOWN.



- **In-rush current demand:** Should be the worst case for the group of loads. If all the loads could come online at the same time (such as during a dark ship or dead ship recovery with Low Voltage Release (LVR) controllers) then it should be the sum of the in-rush current demands of all the loads. If all loads have a Low Voltage Protection (LVP) controller, then the in-rush current is the highest in-rush current of any of the loads plus the steady-state current of all the other loads. If some loads have LVR controllers and others LVP controllers, then the in-rush current is the greater of the sum of the in-rush currents of the loads with LVR controllers plus the steady-state current of the other loads; and of the load with the highest in-rush current and a LVP controller plus the steady-state current of the other loads.

In early stages of design, prior to the selection of LVR or LVP controllers, one can typically assume that emergency loads and high mission priority (such as vital loads) loads have an LVR controller, and all remaining loads with a high in-rush current have a LVP controller.

- **Temperature dependence:** If any of the constituent loads have a temperature dependence, then should be set to TRUE. If all of the constituent loads do not have a temperature dependence, then should be set to FALSE. Otherwise, set to UNKNOWN.
- **Tolerance to power interruptions:** The lowest tolerance to power interruptions for the group of loads should be used. If only a few loads have a very low tolerance, one should consider moving these loads to their own proxy load; otherwise, the impact on the power system of providing a higher QOS level than needed could be significant.
- **Load shed priority (mission priority):** Should use the highest priority of any one load within the group of loads. If only a few loads have a very high priority, one should consider moving these loads to their own proxy load.

4. Load factors

Developing load factors for a proxy load depends on how the load factor will be used in analysis. If used for equipment sizing, the goal is to understand the maximum load that will occur over a relatively short time range of interest, usually on the order of seconds to minutes. MIL-E-7016 suggests time ranges of interest of five seconds and five minutes. Five seconds is appropriate for determining the rating of power electronic converter-based sources and five minutes is appropriate for generator-based sources. For 24-hour average calculations, the time range of interest is 24 hours (as expected).

4.1. Determining rating of sources

To determine the load factor over relatively short time ranges of interest (such as for determining the rating of sources – seconds to minutes), one estimates the fraction of the proxy load's connected load that represents the maximum average power the proxy load will consume over the time range of interest. There are several ways to generate this estimate, each requiring

a different level of modeling. The level of modeling to use should depend on the criticality of an accurate load factor. It may be beneficial to use a higher level of modeling if the proxy load represents a significant portion of the overall load for the intended analysis. Smaller proxy loads where a 100% error will not likely change any design decisions usually will not require a higher level of modeling.

4.1.1. Performing quasi-steady state simulation of all constituent loads together

If the loads are pulsed, cyclic, multi-mode, or not continuously on, and partially or completely coordinated via coordinated control action or other means, then a quasi-steady state simulation over a period of at least 100 times (preferably 1000 times) the time range of interest may be appropriate. The total load of all the constituent loads should be calculated at a time interval no greater than 10% (preferably 1%) of the time range of interest. At each point in time, the average of the power consumed by the loads over the previous time range of interest is calculated. The load factor is the highest value of this average divided by the proxy load's connected load. The connected load of the proxy load is equal to the sum of the connected loads of all the constituent loads.

4.1.2. Performing quasi-steady state simulation of individual loads

If the loads are pulsed, cyclic, multi-mode, or not continuously on, and uncoordinated, then quasi-steady state simulations for each load over a period of at least 100 times (preferably 1000 times) the time range of interest may be appropriate. The load of each constituent loads should be calculated at a time interval no greater than 10% (preferably 1%) of the time range of interest. At each point in time, the average of the power consumed by a load over the previous time range of interest is calculated. The highest values of this average for all the loads are summed and then divided by the connected load of the proxy load to produce the load factor. The connected load of the proxy load is equal to the sum of the connected loads of all the constituent loads.

This method does not require all of the constituent loads to be modeled at the same time. If identical constituent loads are operated in the same way, then one simulation may be used for all the identical constituent loads.

This method is simpler to model than modeling all the constituent loads together, but will likely result in a larger, more conservative, load factor.

4.1.3. Using zonal load factor method

The zonal load factor method as described in DPC 310-1 may be used to combine the constituent loads. This method requires that individual load factors (for 24-hour average calculations), peak loads, and connected loads be estimated for each of the constituent

loads. The resultant zonal total operating load is divided by the proxy load's connected load to obtain the proxy load's load factor. The connected load of the proxy load is equal to the sum of the connected loads of all the constituent loads.

This method has the advantage of requiring estimation of a minimal amount of information on each load, and does not require knowledge of the time range of interest. While this method can be a reasonable estimate, if the resultant zonal power demand is one of the largest 5% of the loads on the ship, using one of the previous modeling methods may be preferred.

4.1.4. Combining individual load factors

If all the constituent loads that are on in a given operational condition draw relatively constant power, then one need only know their individual load factors and connected load. The proxy load's load factor is the sum of the products of the individual load factors and individual connected loads, divided by the connected load of the proxy load. The connected load of the proxy load is equal to the sum of the connected loads of all the constituent loads.

The individual load factors may be obtained from quasi-steady state analysis, analogy to equipment on other ships, or by using default load factors from IEEE Std. 45.1 or DPC 310-1.

4.2. 24-hour average

A simple way to estimate a load factor for a proxy load is to sum estimates of the kWh consumed by all the constituent loads in 24 hours for the given operational condition and ambient condition, then dividing the kWh by 24 hours and the proxy load's connected load (kW). The connected load of the proxy load is equal to the sum of the connected loads of all the constituent loads.

To obtain the kWh consumed by a load in a day, multiply its average power when on by the number of hours it is on in a day.

The amount of power consumed in 24 hours may be estimated based on quasi-steady state analysis, analogy to equipment on other ships, or by using default load factors from IEEE Std. 45.1 or DPC 310-1.

5. Zonal load factors

The zonal load factor method requires knowledge of the proxy load's load factor for 24-hour averages, peak load, and connected load. Section 4.2 describes how to calculate the proxy load's load factor for 24-hour averages, and connected load.



Calculating the peak load of the proxy load remains to be done. The simplest, but likely too conservative estimate is to sum the peak loads of all the constituent loads; the probability that all the constituent loads will be at their peak value is usually small.

Quasi-steady state analysis as described in 4.1.1 can provide the proxy load’s peak load directly.

Alternately, the zonal total operating load as calculated in 4.1.3 may be used as the proxy load’s peak load.

6. Stochastic models

A stochastic load model represents the load as a probability density function (PDF). For a random variable X , the probability that X is between x_1 and x_2 is the definite integral of the PDF ($f_x(x)$) from x_1 to x_2 (See equation 1). Each load within the proxy load is assigned a PDF. The PDF can in turn be converted to a cumulative distribution function (CDF – $F_X(x)$) which provides the probability that the value of X is less than or equal to x . Common PDF shapes that are typically used are the uniform distribution (Figure 1), triangular distribution (Figure 2), and discrete distribution (Figure 3).

$$Pr(x_1 < X < x_2) = \int_{x_1}^{x_2} f_x(x) dx \quad [1]$$

$$F_X(x) = \int_{-\infty}^x f_x(y) dy \quad [2]$$

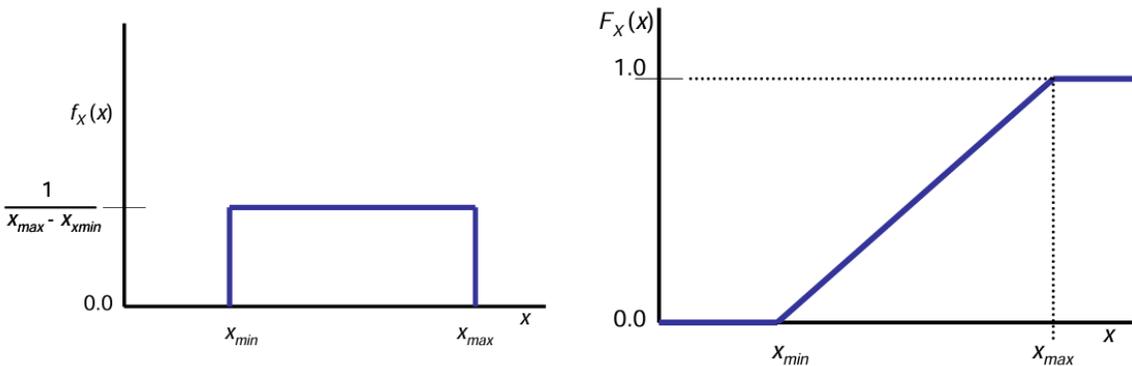


Figure 1: Uniform distribution PDF and CDF (DPC 310-1)

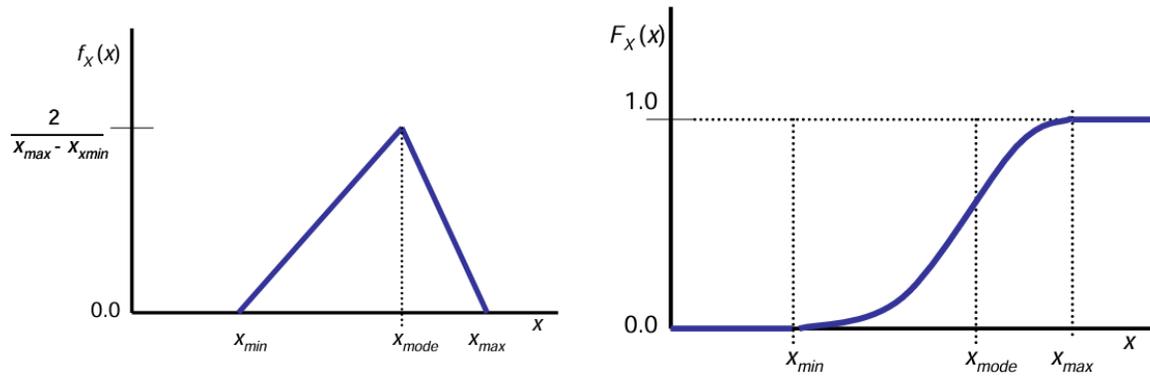


Figure 2: Triangular distribution PDF and CDF (DPC 310-1)

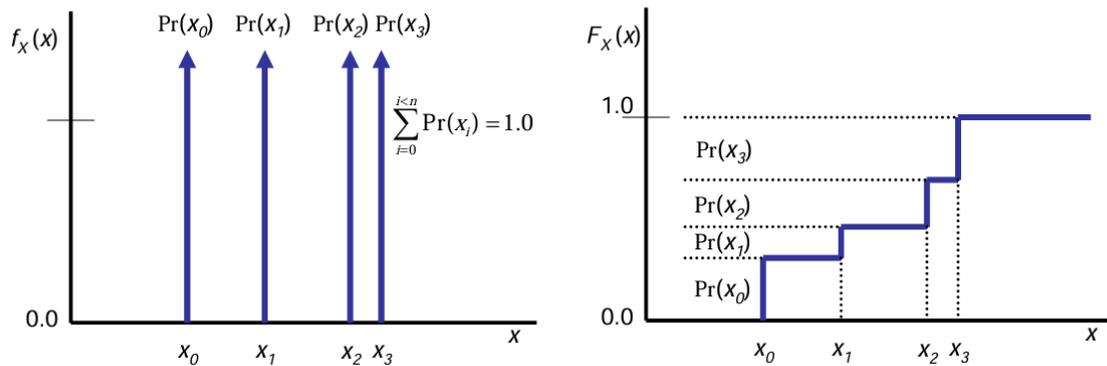


Figure 3: Discrete distribution PDF and CDF (DPC 310-1)

A Monte Carlo Simulation (see DPC 310-1) is typically used to develop a PDF (from which the CDF can be derived) of the sum of the constituent loads of a proxy load. This PDF and the derived CDF are then used to model the proxy load in further analysis.

7. Simulation models

Simulation models are typically quasi-steady state models based on the time range of interest. Constructing a simulation model for a proxy load is very dependent on the interdependency of the loads, other control inputs, as well as the time range of interest. The load models should be constructed so that when constituent loads are removed from the proxy load, modifying the load model is straight-forward.

8. Managing proxy loads representing multiple loads

At the earliest stages of designs, the load list may consist entirely of proxy loads. These proxy loads may be based on the equipment on a similar ship, or may be based on parametric equations. Even when specific loads are identified, enabling them to be broken out of the proxy load, specific

data elements may not be known with precision. Work should be conducted to develop realistic values for these data elements before the study or analyses requiring the data element commences. During detail design, all of the proxy loads in the load list should be replaced with the actual equipment that will be installed in the ship. Work should continue to properly model each of these loads for use in the various types of analysis. Proxy loads may still be used in specific analysis to group multiple loads that have the same connection to the power system; the proxy loads may enable analysis to be conducted faster.

9. References

DPC 310-1 Electric Power Load Analysis (EPLA) for Surface Ships.

IEEE Std 45.1 IEEE Recommended Practice for Electrical Installations on Shipboard – Design.

IEEE Std 45.3 IEEE Recommended Practice for Shipboard Electrical Installations – Systems Engineering.

MIL-E-7016 Military Specification - Electric Load and Power Source Capacity, Aircraft, Analysis of.

Doerry, Dr. Norbert and Dr. John Amy Jr., "Electric Load Modeling," presented at ASNE Intelligent Ships Symposium, Philadelphia PA, April 9-10, 2019.

