Electric Power Load Analysis (EPLA) Overview

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1. Introduction

An electric power load analysis (EPLA) tracks all the electrical loads onboard the ship in an electric load list and may use one of several methods to model these loads to determine required characteristics of the power system to include the required power and energy capacity. The electric load list may include thousands of individual loads. The EPLA also supports analyses such as in-rush current analysis, pulsed load analysis, quality of service (QOS) analysis, endurance fuel calculations, and annual energy usage and annual energy cost calculations.

Early in the design process, many of the loads will not have been determined; there existence is modeled as proxy loads. A proxy load can represent in a single entity a multitude of small loads (such as all the light fixtures in a compartment). A proxy load can also represent equipment that is known will be onboard the ship, but the exact make and model of the equipment is not known, or details as to the equipment electrical properties are not known. As the design develops, the proxy loads are replaced with characteristics of the actual loads that are installed on the ship.

Details on conducting an EPLA are in IEEE Std. 45.1 and DPC 310-1

2. Load List

The electric load list is used to track all of the loads onboard the ship. As detailed in DPC 310-1, the load list is created based on the following documents:

- Master equipment list
- Mission systems description and one line diagram
- Electrical plant description and one line diagram
- Distributed system descriptions and one-line diagrams
- General/machinery arrangements
- Product model (if it exists)
- Discussions with system designers (if possible)
- EPLAs of similar ships (if available)

While the load list may eventually contain thousands of entries, early on, one should concentrate on the fifty to one hundred largest loads on the ship; these loads will typically comprise between 60% and 80% of the total load onboard the ship. If the equipment fulfilling these loads have not been selected, proxy loads should be used to represent these loads. Similarly, smaller loads (not part of the fifty to one hundred largest loads) may either have their own entry in the load list (if known), or may be aggregated into proxy loads.

The data that should be collected for each entry in the load list is expanded from the data defined in DPC 310-1:

- Nomenclature
- Ship Work Breakdown Structure (SWBS) code (3-digit) or other product breakdown structure identifier
- Location on the ship (zone and/or compartment) (needed for zonal equipment and distribution system sizing)
- Point(s) of connection to the power system (power panel, 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)
- Identification Plate (nameplate) rating (include units)
- Connected load (kW)
- Peak load (kW)
- Power type (voltage, number of phases, frequency)
- Cyclic and intermittent behavior
- Power requirements during different operating modes
- In-rush current demand (if applicable)
- Pulsed load characteristics (if applicable)
- Use during different ship operating conditions
- Temperature dependence
- Tolerance to power interruptions (for QOS analysis)
- Correlation with other loads (such as mutually exclusive loads)
- Load shed priority (mission priority)
- Reference to the source of data to enable traceability

Often, the above data will not initially be known; analysis must often proceed based on assumptions. These assumptions should be documented and periodically checked for validity. If significant changes are required, analyses should be repeated.

3. Analytic methods

3.1. Load factor analysis

Load factor analysis is the traditional technique for performing load analysis. Each load is assigned a load factor for each operational condition and ambient condition; the load factor is multiplied by its connected load to obtain its operating load for the combination of operational condition and ambient condition. The relevant operational conditions and ambient conditions (combination of exterior air temperature and humidity) are defined in the EPS-CONOPS.

The connected load is the rated electrical power and is one of the data elements of the load list. The rated electrical power is usually on the equipment nameplate. Some equipment however, will express the equipment rating in terms of mechanical power (HP) or current. These alternate ratings are converted to electrical power to obtain the connected load.

The operating load is meant to represent an average value over a given time interval for a given operational condition and ambient condition. The time interval is based on the intended purpose of the operating load. Traditionally, for power system equipment sizing, the operating load is intended to represent the average power over the period of time that the equipment can tolerate load excursions above its rated value. For power system equipment, the time interval is usually assumed to be on the order of minutes (although it may be wise to use a shorter time interval for power electronic converters). The load factor is therefore the average value of the load when it is on, divided by the connected load. For cycling loads that are on for less than minutes, then the load factor is usually chosen to be the duty factor of the load multiplied by the average value of the load when it is on, divided by the connected load. For the 24-hour average loads, the time interval is 24 hours; the load factor is the KW-h consumed by the load in 24 hours divided by the product of 24 hours and the connected load (kW).

The demand power for a piece of power system equipment for a given operating condition and ambient condition is the sum of the operating loads of all the supplied loads, margin, and service life allowance. The required power rating of the power system equipment is the maximum of the demand power across all operating conditions and ambient conditions. The 24 hour average loads are calculated in the same way.

The EPS-CONOPS should detail the margin and service life allowance policy.

3.2. Zonal load factor analysis

The load factor method works well when there are many loads, and none of the loads are a sizeable fraction of the demand load. Hence, the load factor method is often employed at the total ship level for determining the required rating of generator sets. Since generator sets are normally not loaded beyond 95% of their rating, the chance of an overload is small. However, for many power system components such as medium voltage to low voltage transformers and power converters, a few large cycling loads could result in an overload if they all are on at the same time; the load factor method may underestimate the required rating of the equipment.

The zonal load factor method adjusts load factors (for 24 hour average load) based on the relative size of the peak load of each load with respect to the demand load. If the peak load is only slightly larger than the average load, then the zonal load factor is only slightly greater than the load factor; if the peak load is much greater than the average load, then the zonal load factor approaches the ratio of the peak load to the connected load. For each load, the zonal operating load is the product of the zonal load factor and the connected load. For each load, the residual zonal power demand for a given operating condition and ambient condition is the difference between the peak load and the zonal operating load. The zonal total operating load is the sum of the zonal operating loads plus the maximum residual zonal power demand. Applying margin and service life allowance to the zonal total operating load results in the zonal demand power; the power system equipment should have a power rating at least as great as the zonal demand power. The method for determining the zonal total operating load helps ensure that any one load operating at its peak load will not cause an overload; multiple loads operating at their peak load are also not likely to cause an overload.

As a note, if the peak load and the average load are the same for all loads, the zonal load factor method and the load factor method (for 24 hour average) produce the same results; the zonal method produces a larger load if loads have a peak load higher than their average load.

3.3. Stochastic analysis and modeling and simulation load analysis

Stochastic analysis and modeling and simulation load analysis offer improved methods to address the uncertainty associated with calculating the maximum demand power for power system equipment. In stochastic load analysis, the load is modeled as a function of statistically independent random variables; each random variable is represented by a probability density function (PDF). As described in DPC 310-1:

> "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."

In stochastic analysis, Monte Carlo simulation is usually used to estimate the PDF of the demand power for equipment or the ship. For a given demand power, the PDF is integrated to determine the probability that the load will exceed this value. For equipment that can tolerate overloads, the probability of an overload should generally be less than 5%. For equipment that are not able to tolerate an overload, such as many power electronic converts, the probability of an overload should be less, typically less than 1%. The PDF for the demand power gives the designer the opportunity to trade-off the risk of an overload against the additional cost of increased load capability.

For endurance fuel and annual fuel calculations, the mean value of the PDF is typically used.

Modeling and simulation load analysis typically employs quasi-steady-state models of loads that only consider dynamics slower than about a second. Individual load models are typically integrated together to form an overall system model; the integration may require modeling of electrical, control, and mechanical interfaces. Furthermore, the use-cases applied to the overall system model must be carefully crafted to ensure it aligns with the EPS-CONOPS, PS-CONOPS, other distributed system CONOPS, the overall mission systems CONOPS, and the operating condition definition. The use-cases should be realistic and stressing. The worst-case demand power across all of the simulations is typically used.

Modeling and simulation load analysis is particularly useful in determining the required energy capacity and power capacity of energy storage systems.

In any modeling and simulation effort, verification and validation should be performed on the individual models as well as the overall system model. Verification determines if the models accurately implement the theory documentation for the models. Validation determines if the models are the appropriate ones to use to represent the equipment on the ship.

3.4. Demand factor analysis

Demand factor analysis is a simple, legacy method for determining the required current / power rating of cables feeding load centers and power panels as well as the circuit breakers protecting these cables. The process consists of summing the connected load of all loads supplied by the cable and circuit breaker and applying margin and service life allowance to obtain the bus feeder connected load, obtaining a demand factor from Figure 1 based on the bus feeder connected load, then multiplying the demand factor by the bus feeder connected load to obtain the required rating of the cable and circuit breaker.

DPC 310-1 also has a demand factor curve based on connected load current for 450 volt three-phase ac power systems.

Zonal load factor analysis and stochastic load analysis are now preferred over using demand factor analysis.

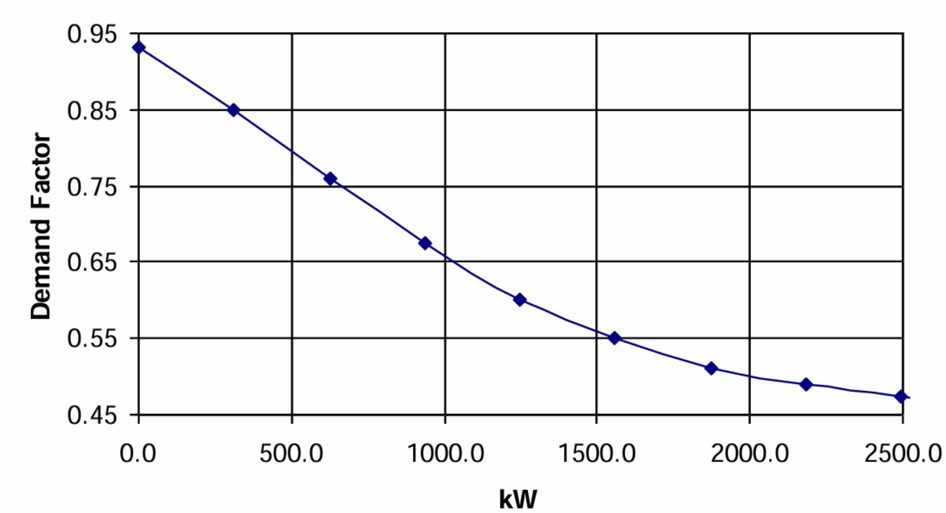

Figure 1: Demand factor curve based on connected load (DPC 310-1)

3.5. 24 hour average load

24 hour average loads are calculated at the total ship level to support endurance and annual fuel calculations as described in DPC 200-1 and DPC 200-2. The preferred ways to calculate the 24 hour average load are to use load factor analysis, modeling and simulation analysis, or stochastic analysis. If load factor analysis is used, the load factors should be based on a 24 hour time period: the kW-h consumed by a load over 24 hours divided by 24 h.

During the earliest stages of design (prior to preliminary design), load factors are often only estimated at the 10 °F and 100 °F ambient conditions for the purpose of determining generator set power ratings. An alternate method of estimating the 24-hour average load is to use a parametric equation based only on the Cruising operational condition at 100 °F. DPC 310-1 provides equations 1 for all ships except aircraft carriers and large deck amphibious assault ships, and equation 2 for aircraft carriers and large deck amphibious assault ships.

$$P_{24\_hour\_ave} = P_{prop-steering} + 0.75\left(P_{cruise} - P_{prop-steering}\right) \qquad [1]$$

$$P_{24\_hour\_ave} = P_{prop-steering} + 0.60\left(P_{cruise} - P_{prop-steering}\right) \qquad [2]$$

Where:

$P_{24\_hour\_ave}$ = 24-hour average load (kW) to use in all calculations described in DDS 200-1.

$P_{prop-steering}$ = Propulsion and steering system loads (kW)
(not including electric propulsion loads)

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

3.6. Load flow and limiting load flow

Load flow analysis determines the voltages, power, and current at each node of a power system for a given operational condition and ambient condition. When designing shipboard power systems, load flow analysis can determine if bus-ties and other power distribution equipment are susceptible to overloading under both normal conditions, and under abnormal and emergency conditions. As described by Doerry (2025b), load flow analysis can also support voltage drop calculations that can identify cases where voltages at load equipment fall outside of interface standard requirements.

Load flow analysis is a steady state analysis; the loads connected to each power panel, load center, and switchboard are based on the EPLA. Redundant loads complicate the conduct of load flow analysis; the choice of which loads of a redundant set of loads is online impacts the calculated voltages, power and current. Identifying the worst case for a specific bus-tie or power distribution equipment is not always obvious; many combinations may have to be explored for each operating condition and ambient condition.

Early in the design process, prior to preliminary design, the data and information to conduct a proper load flow analysis may not be available. Instead, a limiting load flow analysis may be conducted to calculate an upper bound to power and currents without a detailed understanding of the generator set and load configurations. Doerry (2025a) defines three levels of limiting load flow analysis: Simplest, less conservative, and least conservative. The simplest level provides an estimate based only on the generator set ratings. The less conservative level refines this estimate by also incorporating the power system topology. Finally, the least conservative approach includes the impact of loads, but without consideration for operational practices.

As the design progresses and details are developed, the limiting load flow analysis progresses through the three levels; when sufficient data is available, the analysis method transitions to the actual load flow method. In the end, the highest current or power calculated across all the operating conditions and ambient conditions is used at the required minimum rating for the bus-tie or power distribution equipment.

3.7. Energy storage capacity (power and energy) analysis

Energy storage can fulfill one or more functions detailed in Table I. EPLA results are generally needed to support the various studies (Table II) needed to determine the energy capacity and power capacity requirements for energy storage for the various energy storage functions.

Table I: Energy storage functions

ESM Function	Description
ESM-F1	Provide power during short term power disruptions of up to the reconfiguration time (t1)
ESM-F2	Provide power during power disruptions of up to the generator start time (t2)
ESM-F3	Provide power for the emergency starting of generator sets
ESM-F4	Provide power for load leveling for pulsed loads, generator sets with slow dynamics, and generator sets operating near their capacity
ESM-F5	Provide primary power with or without generator sets online

Table II: Energy storage studies

Energy Storage Study	Functions addressed	Description
UPS vs fast circuit breaker	ESM-F1	Determines if it less expensive to use UPS or fast circuit breakers to prevent service interruptions to uninterruptible and short term interrupt loads
Standby generator start	ESM-F2	Determines need for and required capacity of energy storage when an online generator set trips off and before the standby generator set comes online.
Reserve power	ESM-F2	Determine the adequacy of energy storage to serve loads that grow beyond rating of online generator sets and before the standby generator set comes online.
Dark ship start	ESM-F2 ESM-F3	Evaluates the adequacy of the power system to restart the electrical system with all generator sets offline, but energy storage is available. Study evaluates whether the correct loads to enable the standby generator set(s) to start and operate are provided power.
Load-leveling	ESM-F4	Evaluates the adequacy of the power system to perform load-leveling to include: compensating for sources without fast enough dynamic response, operating sources near their power rating.
Zonal and compartment survivability	ESM-F5	Evaluates the adequacy of energy storage along with the power system to provide zonal and compartment survivability.
Endurance energy calculations	ESM-F5	Similar to endurance fuel calculations, determines the power and energy capacity required of energy storage to transit using energy storage alone at a given speed for a given distance.

3.8. In-rush current analysis

In-rush current analysis compares the in-rush current requirements of loads with the capability of the generator sets or other sources to provide the in-rush current while maintaining interface standards. The transient voltage requirements are usually the interface requirement of greatest concern.

The greatest demands for in-rush current are typically from large transformers, induction motors, solenoid valves, and equipment with large filter capacitors. The most critical time for in-rush current is when recovering from a dark ship or dead ship when many loads could potentially start at the same time. The in-rush current properties of each load should be described in the appropriate entry in the load list.

If the results of the in-rush current analysis show a potential issue with providing in-rush current, means to reduce the in-rush current demand or means to improve the sourcing of in-rush current should be explored. Possible technologies include:

- Use of soft starters or variable speed drives on induction motors.
- Use of a pre-excitation system for initializing the magnetic field on large transformers.
- Use of current limiters on equipment with large in-rush currents.
- Use of energy storage to provide the inrush current.
- Increase the rating of power electronic converters so they can provide more in-rush current.
- Use of control systems, interlocks, or Low Voltage Protection (LVP) controllers to prevent multiple loads with high in-rush current from starting at the same time.

In particular, power systems where the sources are power electronic converters should be studied carefully. Often, power electronic converters are limited as to the amount of in-rush current they can provide as compared to synchronous generators.

Certain loads may have large in-rush currents during their normal operation and not necessarily only at start-up. Cycling loads, load with solenoids, and loads with multiple modes are examples of loads that can have significant in-rush current after initial energization. These loads should be investigated to ensure the sources are capable of providing the necessary in-rush current.

3.9. Pulsed load analysis

In pulsed load analysis, the characteristics of the current waveform of the pulsed load is characterized and compared with the capability of the power system to provide the current waveform while maintaining the voltage within interface requirements. The load list should include the pulsed load characteristics. The capability of the power system includes both the ability of the generator sets and associated energy storage to provide the pulsed current waveform, and the ability of the protection system to discriminate between the pulse and a fault.

In some systems, pulsed loads may be supported in different ways based on the operating condition and electric plant lineup. The EPS CONOPS should describe the intended ways the power system is designed to provide power to pulsed loads. Options include subjecting the pulse directly to the generator sets, use of energy storage, redirection of power from other loads such as propulsion, or a combination of the other options. It is not necessary (or usually even desirable) to always use the same option. Redirection of power may be preferrable if there is sufficient power being consumed that can be redirected; if not, then the use of energy storage and/or applying the pulsed current waveform to the generator set may be required. The EPLA is useful in that it provides an understanding of the other loads that are expected to be online in a given operational condition.

3.10. Quality of Service analysis

QOS analysis computes t1 and t2 for each separately derived system within the overall shipboard power system; uses the calculated t1 and t2 values to characterize all the loads on the load list to one of the QOS categories; and evaluates whether the Mean Time Between Service Interruption (MTBSI) requirements are achieved.

In many cases, the reliability data to establish an accurate MTBSI value will not be known during the earliest stages of design. However, the impact of redundancy can be used to greatly simplify calculations. In early studies, reliability data may be estimated based on reliability requirements in equipment specifications. In many cases, the MTBSI can be shown to depend on the reliability of relatively few components (usually single-points of failure); concentrating data collection and testing on these few components is usually the best investment of resources in ensuring overall QOS requirements are met.

3.11. Endurance fuel calculations

Endurance fuel calculations are defined in DPC 200-1. The primary purpose of endurance fuel calculations is to determine the required size of the fuel tanks. The endurance fuel calculations depend on the EPLA to provide the applicable 24-hour average loads for the total ship: 24-hour average endurance ship service electric load, 24-hour average ship service sustained electric load, and 24-hour average ship service mission electric load. The 24-hour average loads for individual components may be obtained by dividing the kW-h the load is estimated to use in a day by 24 hours. The other methods in DPC 310-1 may also be used to calculate the 24-hour average ship service loads.

3.12. Annual energy usage and annual energy cost calculations

Annual energy usage and annual energy cost calculations are detailed in DPC 200-2. The EPLA provides estimates for 24-hour average loads for when the ship is underway, anchored, and in port. These calculations are used to ensure the ship design meets energy efficiency requirements; to provide a basis for estimating the cost of fuel over the ship's service life; and to evaluate whether the shore-side and replenishment fleet refueling capacity is sufficient.

4. Proxy Load

A proxy load is used to represent a load or group of loads.

Particularly early in the design process, specific equipment may not be chosen, a proxy load is used to provide estimates of its characteristics while not necessarily being derived from specific equipment. In some cases, data is incorporated from equipment similar, but not identical, to the equipment that is anticipated will be used.

In other cases, properties of loads are parametrically estimated and assigned to proxy loads. As the load level of definition increases, the proxy load estimates are updated. 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.

In some analyses, it may be useful to define a proxy load that combines multiple loads that are individually defined in the load list. Combining loads can significantly improve the run time of simulations.

It may also be useful to combine loads that depend on each other, or are exclusive to each other in a single proxy load. Managing this interdependency at the proxy load may prove convenient.

The definition of a proxy load should clearly identify what loads it represents and the assumed properties of each of the constituent loads. As the design evolves, portions of the proxy load will be defined and can be broken out of the proxy load into a separate element in the load list. Knowing how much power was allocated for that load in the proxy load is important as the proxy load is adjusted to eliminate the newly broken out load.

For example, initially, all the galley equipment with the same connection to the power system could be lumped together into a galley equipment proxy load. The proxy load would identify all the individual galley equipment functionality it encompasses, and an estimate of the connected load for each of the equipment. The galley equipment proxy load could contain a function called "microwave oven" and assign a connected load of 1.5 kW based on a market survey of microwave ovens. The proxy load could also include a "Miscellaneous" component to account for numerous small loads that should be accounted for, but need not be separately identified until detail design. As the design progresses, and equipment is specifically identified, the equipment can be removed from the proxy and separately identified as a load in the load list. When a specific microwave oven is identified, the microwave oven function is eliminated from the proxy load and a new load for “microwave oven” is created with its specific power level (perhaps 1.8 kW).

Another example is determining the fuel rates for endurance fuel calculations. A proxy load may be used to model all of the ship service loads for a given operational condition and temperature. The EPS CONOPS with its generator set scheduling table determines which generator sets are online and how power is shared among the online generator sets. Once the power provided by a generator set is known, its fuel rate can be determined. The fuel rates of all the online generator sets can be combined to determine the overall fuel rate.

5. EPLA Evolution

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.

During sea trials and periodically while the ship is operational, the electrical power system should be instrumented to validate or update load models for specific operational conditions and ambient conditions. Ideally, the largest 50 to 100 loads would be individually instrumented in addition to instrumentation installed on generator sets, power conversion equipment, energy storage systems, and switchboards. These updated models should be used to track the consumption of service life allowance over the ship’s service life. Additionally, when the service life allowance is completely consumed, the updated models may be used to identify ways to either increase power capacity, or lower the worst case power demand.

6. References

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

DPC 200-1 Calculation of Surface Ship Endurance Fuel Requirements

DPC 200-2 Calculation of Surface Ship Annual Energy Usage, Annual Energy Cost, and Fully Burdened Cost of Energy

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

Doerry, Norbert, "Shipboard power system limiting load flow and load flow analysis", IEEE ESTS 2025, Alexandria VA, August 5-8, 2025. (2025a)

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