Margin and Service Life Allowance

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1. Introduction

For the electrical power system, margin and service life allowance (SLA) are extra capacity required of power system components beyond the maximum estimated operating load for the components. Margin (also known as acquisition margin) is employed during the design and construction process to account for uncertainty in the maximum estimated operating load. This uncertainty is largely due to uncertainty in individual elements, as well as the possible omission in the load list of loads that are required for the ship to meet all of its requirements. SLA is expended while the ship is operational to account for increased energy usage from equipment degradation, increased energy usage of other systems due to growth in their loads, as well as the installation of replacement or additional equipment.

Margins and SLA are also applied to characteristics of the ship (weight, space, stability, propulsion, accommodations, etc.) as well as capacity for other distributed systems (chilled water, cooling water, ventilation, etc.). This document however, focuses on margin and SLA for the electrical system.

2. Margin and Service Life Allowance policy

At the beginning of a design effort, a margin and service life allowance policy should be documented. Often, the margin and service life allowance policy is incorporated into the Electrical Power System Concept of Operations (EPS-CONOPS). The ship design manager is responsible for establishing the margin policy and working with the customer to establish the service life allowance policy. See S9800-AC-MAN-010.

The margin and service life allowance policy often allocates margin to different stages of design and construction; all of the margin should not be consumed early in the design. Typical allocations are for preliminary and contract design, detail design, and construction (build margin). The total margin and allocations of the margin should be based on an assessment of the uncertainty of the operating load calculations and should consider:

a. The completeness of the load list; what is the probability that additional loads will be added to the load list, or loads on the load list will be replaced with other loads?
b. The accuracy of the connected load; to what degree is the connected load of the largest 100 loads validated? To what degree is the connected load of the remaining loads validated?
c. The accuracy of load models; to what degree are the load models of the largest 100 loads validated? To what degree are the load models of the remaining loads validated?

d. If a power system component is discovered to be undersized, how difficult is it to replace it with a component having a higher rating?
e. Are specific load equipment specified, or is the shipbuilder allowed to choose equipment during detail design based on performance requirements?
f. The type of load models employed. Most margins are specified based on load factor analysis described in DPC 310-1. IEEE Std. 45.1 and IEEE Std. 45.3. If stochastic load analysis or modeling and simulation load analysis is used and the models account for some or all of the uncertainty, then lower margins may be warranted. See S9800-AC-MAN-010 for additional details.
g. The overall design method employed. Most margins are specified based on a point-based design method using the design spiral (Fleisher and Catton 2024) where design decisions for power system sizing are made prior to when detailed information on load models is known. If set-based design (see Singer et al. 2017) is employed where design decisions for power system sizing are not made until the load models are mature, then smaller design margins are warranted.
h. Whether the design is a clean-sheet design, a modified repeat design, or a conversion design.

Margin is typically specified as a percentage of maximum estimated operating load.

The SLA requirement should be documented in the margin and service life allowance policy, should depend on an evaluation of the sources of load growth while the ship is in-service and should consider:

a. The degree to which equipment aging results in increased load.
b. Whether installation of specific additional equipment is planned while the ship is in-service.
c. The probability that new regulations will require the installation of additional equipment that has not been specifically identified. (IMO MARPOL and SOLAS may be sources of new regulations)
d. The probability that equipment related to the function of the ship will require replacement during the service life of the ship.
e. If power system equipment is discovered to be undersized, how difficult is it to replace the equipment with equipment having a higher rating?
f. If the design is severely weight or volume constrained, the impact of adding additional capacity on the overall ship design. High speed craft may have less SLA than a comparable low speed displacement vessel.

SLA is typically specified as a percentage of maximum estimated operating load, but may also have a component that is a fixed value for equipment that is anticipated to be installed while the ship is in-service. Ultimately the requirement for the minimum amount of SLA to provide is determined by the customer. The customer in turn, is likely to base the SLA requirement on a comparison of the value provided by the SLA to the additional cost of providing it.

3. Margin

3.1. New Design

A new "clean-sheet" typically has the greatest uncertainty. Preliminary and contract design margins on the order of 10% of the maximum estimated operating load and detail design and construction margins on the order of another 10% are not unusual. These values should be adjusted based on the factors identified in section 2.

After the construction contract is completed and the ship is in-service, any unused margin is converted to SLA. The unused margin should be calculated based on an updated EPLA from measurements taken during sea trials or during ship operations when in-service.

3.2. Modified Repeat Design and Conversion Design

If the changes to the ship design are very extensive, then the margin policy for new design should be used. Otherwise, the margin should be based on the sum of loads removed from the ship design and on the sum of loads added to the ship design. The margin on the removal of loads is based on the possibility that the estimated load for the removed loads is more than the actual load of the removed loads. Similarly, the margin on the addition of new loads is based on the possibility that the estimated load for the additional loads is less than the actual load of the added loads. The margin on the removed and added loads is typically about 10% for preliminary and contract design, and another 10% for detail design and construction. These values should be adjusted based on the factors identified in section 2. If the load model of the removed load has been validated with measured data, then it may be appropriate to not apply the margin to the removed load.

For example, if 100 kW of non-validated load is removed from the maximum estimated operating load, 150 kW of load is added to the maximum estimated operating load, and a 10% margin is applied for both preliminary-contract design, and detail design and construction, then the margin for preliminary and contract design would be 10% of (100 kW + 150 kW) = 25 kW. Likewise, the margin for detail design and construction would also be 25 kW. The total load added to the maximum estimated operating load would be 150 kw – 100 kW + 25 kW + 25 kW = 100 kW.

Usually, a portion of the original SLA may be expended to account for the design modifications ("original" refers to parent design for modified repeat and the actual ship for conversions). The customer should specify how much SLA should remain when the ship is delivered. Customers may specify an SLA at delivery as a percentage of the maximum estimated operating load per year of remaining estimated service life; values between 0.5% to 1.0% per year are typical. If the SLA at delivery is projected to be too small, then the design should be altered to either increase power system capacity or reduce the maximum estimated operating load.

After the construction contract is completed and the ship is in-service, any unused margin is converted to SLA. The unused margin should be calculated based on an updated EPLA from measurements taken during sea trials or during ship operations when in-service.

4. Service life allowance

SLA accounts for growth in the electrical load once the ship is in-service. SLA may also be known as service life margin. As detailed by Fleisher and Catton (2024), some organizations split SLA into In-Service Growth Margin (ISGM) (sometimes called Through-Life Growth Margin) and Capability Upgrade Margin (CUM). ISGM accounts for increased electrical load due to equipment degradation, increased loading on other distributed systems, and other uncontrolled changes. CUM addresses the addition, modification, or modernization of systems to ensure the ship remains relevant over its remaining service life.

The amount of SLA should depend on the expected growth in load over the ship's service life. Some simple commercial ships may not be allocated any SLA. Ships where considerable growth in load is expected should consider assigning an SLA of 30% or more of the maximum estimated operating load. While expressing SLA as a percentage of maximum estimated operating load is the norm, in some cases, the SLA is expressed in terms of a fixed amount of power (kW). Other ships incorporate both a percentage of the total operating load and a fixed amount of power (usually for a specific load that is intended to be installed when the ship is operational). Internationally, it is not unusual for naval ships to have an SLA between 10% and 20%. Commercial ships typically have a lower SLA, or in many cases may not deliberately incorporate one; the SLA is whatever excess capacity remains due to the incremental nature of equipment rating (the load may require 18 kW, but the next larger size for the power system components is rated for 20 kW, providing a 2 kW SLA). It may be desirable to specify a required SLA of at least 5% to account for growth in load due to equipment degradation. A higher SLA may be appropriate based on the considerations listed in section 2.

5. Management

5.1. Design

Design margin is typically not consumed until the power distribution system is placed under configuration control; typically, configuration control begins during preliminary design. Prior to configuration control, the ratings of generator sets and other power distribution equipment are adjusted to serve the maximum estimated operating load plus margins and SLA. In set-based design, the configuration is established later than when using the design spiral, hence the consumption of design margin is also delayed.

Many designs experience a step jump in the maximum estimated operating load when the basis of estimate shifts from parametric equations within proxy loads to specific loads based on system designs. Best practice is to establish configuration control after this transition.

The consumption of margin is often used as a measure of design convergence. If load growth is projected to consume all margin applicable to the stage of design, then proactive changes should be made sooner rather than later. Increasing power system capacity and reducing maximum estimated operating load are appropriate mitigation activities.

5.2. Construction

Detail design and construction margin may be consumed by the shipbuilder. The owner should be aware of the rate of margin consumption; margin consumption should be reported in design reviews and construction progress reviews. If all the margin is consumed, it can be very expensive to modify the design to reduce total operating load or increase power system capacity. Often the only remaining option is to consume SLA. Consumption of SLA prior to ship delivery is undesirable because it may result in the ship being unable to affordably remain relevant over its intended service life. The detail design and construction contract should provide the proper disincentives for consuming SLA; ideally the shipyard should track margin consumption and take early proactive steps to avoid consuming all the margin prior to delivery.

5.3. In-Service

Once the ship is in-service, the EPLA should be periodically updated and validated based on measurements while the ship is operational; updates prior to major overhauls are ideal. Where possible, the fifty to one hundred largest loads should be individually measured to tune their load models. Many of these loads already have instrumentation installed that can be used to perform these measurements. The remaining loads may be adjusted based on measurements at switchboards or load centers. With an updated EPLA, the actual remaining SLA can be determined and managed.

In reality, the EPLA is usually not validated after ship delivery. The EPLA may be modified based on estimates of equipment removal and addition, but considerable uncertainty still remains as to the adequacy of the power system capacity. Some ships discover when operational that they are power capacity limited and must either undergo costly modifications to increase capacity (modifications that were initially unplanned), or loads are shed under normal conditions to enable continued operations. In many cases, the costs of validating the EPLA is considerably less than the cost of disruptions due to unanticipated modifications to increase capacity or reduce maximum estimated operating load.

6. 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.

S9800-AC-MAN-010 NAVSEA Ship Design Manager (SDM) and Systems Integration Manager (SIM) Manual.

Fleisher, S., and Catton, L., "Margins – their use as Metrics and Key Performance Indicators when Designing and Building Warships," Conference Proceedings of INEC, INEC 2024, November 6, 2024, https://doi.org/10.24868/11168.

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