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Electric Power Load Analysis

Introduction

Between 1980 and 2012, Design Data Sheet DDS 310-1 was used to estimate the electric load of surface ships for the purpose of sizing electric generators. DDS 310-1 presents a calculation method based on the connected load of all the ships' loads, and an associated load factor for each operating condition. Created in a time when most loads were small in comparison to the rating of the generators, and power systems could tolerate short-term overloads, this method was sufficient. With the growth in electric load, more and more ships are employing medium voltage distribution systems and zonal transformers and/or power electronics-based power conversion. While the assumptions associated with DDS 310-1 were still generally applicable to the sizing of generators, it was not clear that these assumptions were still applicable for determining the rating of transformers and power conversion equipment. The variance in load around the long-term average due to cycling loads, and the limited overload capability of power electronics, called for improved methods to estimate load for determining the rating of equipment. Furthermore, advances in modeling and simulation offered improved insight of the electric load expected for power generation and power conversion equipment.

Recently, improving estimates for the 24-hour average load became increasingly important due to its use in estimating annual fuel consumption and selecting energy conservation projects. Previously, the 24-hour average load was used primarily by DDS 200-1 for the purpose of sizing fuel tanks. Since the electric load was typically a small fraction of the propulsion power at the endurance speed, errors in its estimation did not significantly impact the required size of the fuel tanks. Now however, the 24-hour average load is used with a speed-percent time profile to estimate a fuel rate, and to calculate annual energy usage as described in DDS 200-2. At lower speeds, the electric load may be larger than the propulsion load, hence improvements in 24-hour average estimates were needed.

In 2005, Doerry and Clayton introduced the concept of Quality of Service (QOS) to provide a metric for the reliability of the power system, and enable design decisions to achieve the desired reliability. QOS is a useful concept for determining optimal ratings of individual generator sets, energy storage, power conversion equipment, and distribution system equipment. While closely associated with the EPLA, official guidance was needed to conduct consistent QOS analysis.

A long-standing issue exists concerning the lack of guidance for the use of sea trial data to validate the EPLA. Because the assumptions on environmental conditions and energized loads are generally different from the conditions experienced during sea trials, the measured data from sea trials cannot be directly compared to the EPLA. No guidance previously existed for enabling a comparison of measured data and previous estimates.

For these reasons, NAVSEA initiated a project in 2010 to update DDS 310-1. Following extensive review within the technical community, on September 17, 2012, NAVSEA issued DDS 310-1 Rev 1, "Electric Power Load Analysis (EPLA) for Surface Ships." This revised DDS is a significant change from the previous version. As shown in Figure 1, DDS 310-1 Rev 1 is organized as a number of tasks that are interrelated. An EPLA is not required to accomplish all tasks; only those tasks that are needed for a specific purpose need be accomplished.

Electric Load List

In DDS 310-1, no differentiation was made between compiling the Electric Load List from the actual Load Factor Analysis. Because DDS 310-1 Rev 1 introduces additional methods for estimating load (modeling and simulation load analysis and stochastic load analysis), breaking out the creation of the electric load list as an independent activity is beneficial. The electric load list is essentially now a database of all electrical loads on a ship and the associated load data. Specific load data is identified in the DDS.

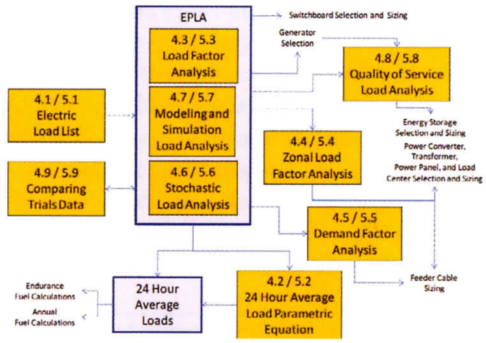

FIGURE 1. DDS 310-1 Rev 1 task relationships.

Estimating Load

Previously, DDS 310-1 only presented the load factor analysis method for estimating load. In some cases, load factor analysis may not produce the optimal rating for power system components. Consequently, DDS 310-1 Rev 1 recognizes two additional means for estimating load. These two new methods, stochastic load analysis and modeling and simulation load analysis, are likely more expensive to perform correctly, but may result in a better, and less costly, system design.

Load Factor Analysis

The load factor analysis method in DDS 310-1 Rev 1 has not changed significantly from the previous version. The new DDS does recognize that load factors for 24-hour average computations may differ somewhat from that used to size equipment. The load factor for 24-hour average computations reflect the long-term average of the load. For equipment sizing, the load factor is increased somewhat for cycling loads to account for variance in the instantaneous power requirement from the long-term average. A method for developing this load factor is provided. Additionally, the new DDS requires the incorporation of electric load estimates for distribution system inefficiencies when they are significant.

Modeling and Simulation Load Analysis

As stated in DDS 310-1 Rev 1:

> "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."

The DDS provides guidance for using modeling and simulation to estimate the load for each load on the electric load list, and the amalgamation of loads for total ship power generation and for specific power system equipment.

Stochastic Load Analysis

DDS 310-1 Rev 1 provides guidance for conducting stochastic load analysis. In stochastic load analysis, loads are modeled as probability density functions (PDF). Aggregation of loads is typically done through a variant of the Monte Carlo simulation method. For 24-hour average computations, the mean value of aggregated loads is used. For generator sizing computations, guidance is provided for determining an acceptable probability for the load exceeding the generation plant capacity.

Zonal Load Factor Analysis

Zonal load factor analysis is used to determine the required rating of zonal power system elements such as transformers and power conversion equipment. Zonal load factor analysis modifies the traditional load factor analysis method to accommodate the reduced number of loads within a zone (as compared to the total ship), and the resulting increase in variability of amalgamated load. The DDS provides a method for increasing the load factor of individual equipment based on the demand load of the zonal power system element as calculated by traditional load factor analysis, and on the peak load of the individual load. This modified load factor is called the zonal load factor of the individual load for the particular zonal power system element. If the required rating for a power system element is significantly different when comparing the traditional load factor method and the zonal load factor analysis, the power system engineer should consider using stochastic load analysis or modeling and simulation to refine the required rating.

Demand Factor Analysis

Demand factor analysis is used to determine the current rating of bus feeder cables, load centers, and circuit breakers protecting the cables. The

DDS invokes the demand factor curve from MS 18299 for 450 Volt AC systems, and presents another demand factor curve based on connected load for DC systems and AC systems of voltages other than 450 VAC. This second demand factor curve was developed by the DDG 1000 program.

Quality of Service Load Analysis

DDS 310-1 Rev 1 now provides guidance for conducting Quality of Service load analysis. As stated in the DDS:

> "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."

24-Hour Average Load Estimation

The 24-hour average load estimate is used in endurance fuel calculations as described in DDS 200-1 and in annual fuel consumption calculations as described in DDS 200-2.

PARAMETRIC EQUATION

In the earliest stages of design, the EPLA is generally only produced at the temperature extremes (10° F and 100° F ambient) to the level needed to estimate the required rating of electrical generator sets. When this is the only data available, a parametric equation is provided to estimate the 24-hour average load estimation based on the 100° F ambient estimate for determining the rating of the generator sets.

LOAD ANALYSIS

In later stages of design, one or more of the other methods of load estimation (load factor, modeling and simulation, and stochastic load analysis) should be used to develop a better estimate for the 24-hour average. In particular, the dependence of the 24-hour average on ship speed should be modeled to ensure the correct estimated ship service load is used for each ship speed in the speed-percent time profile.

Comparing Trials Data

DDS 310-1 provides guidance in adjusting an EPLA to reflect measured trials data. In particular, loads that are sensitive to environmental conditions, specifically temperature, must be adjusted. Any significant differences between the measured data and the EPLA should be investigated to determine if adjustments to the EPLA are warranted.

Future Work

While DDS 310-1 Rev 1 is a significant update, additional work is needed to fully implement the processes it describes.

First, standardized design tools are needed to implement the process. Currently, spreadsheets, data bases, and simulations are custom-crafted for each application of the process. While this method works, it does require a significant amount of effort to implement the process each time. Additionally, validating custom tools can be difficult and calculation errors may be introduced, but not readily noticed.

Additionally, updated load factors for the load factor table are needed. The current load factors have not been updated from the previous document, and in many cases may not reflect the current way the equipment is operated. Additionally, the existing load factor table does not include many modern electrical loads.

In general, more work is needed to develop accurate models of electrical loads. These models can be as simple as updated load factors, or more complex stochastic or dynamic models.

CONCLUSION

DDS 310-1 Rev 1 is a significant revision. It offers new options to the power systems engineer and provides guidance in areas that were not previously addressed. The improved methods described in this DDS should ensure that the electrical power system equipment in future ship designs are properly sized.

Copies of Design Data Sheets 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." Additionally, DDS 310-1 Rev 1 has been submitted to the Defense Technical Information Center (DTIC) and soon should be available on its website (http://www.dtic.mil/dtic/).

REFERENCES

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AUTHOR BIOGRAPHY

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