EPLA Overview
Electric Power Load Analysis (EPLA)

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Dr. Norbert Doerry
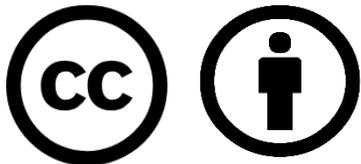
Essential Questions

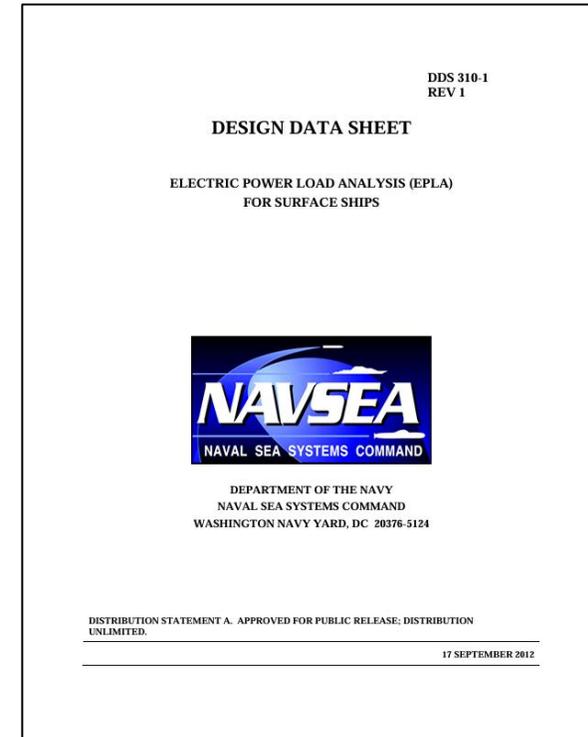|	
What is an Electric Power Load Analysis (EPLA) and what is it used for?	Understand
What are the different analytic techniques used in conducting an EPLA and used in conjunction with an EPLA?	Understand
What is a proxy load and how is it used in an EPLA and related analyses?	Understand
How does an EPLA evolve over a ship design?	Understand

Introduction
Electric Power Load Analysis (EPLA)

- Tracks all electrical loads onboard the ship in a Load List
    - Loads modeled directly, or
    - Loads modeled as part of a Proxy Load
- Models these loads to conduct analyses to determine required characteristics of the power system
    - Required power (current) ratings (power system components)
- Supports many related analyses and design
    - Energy storage
    - In-rush current
    - Pulsed loads
    - Quality of service (power reliability)
    - Endurance fuel (fuel tank size)
    - Annual fuel

DDS 310-1
REV 1

DESIGN DATA SHEET

ELECTRIC POWER LOAD ANALYSIS (EPLA)
FOR SURFACE SHIPS

NAVSEA
NAVAL SEA SYSTEMS COMMAND

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

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(DPC 310-1)
(formerly DDS 310-1)

Load list
Database of information about all the loads onboard the ship

- 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 disruption (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

Load factor analysis

- Traditional method for performing load analysis
  - Determining the rating of generator sets
- Works well if all individual loads are small relative to the demand power
- Load factors assigned to each load for each operational condition and ambient condition
  - Operating load is the load factor multiplied by the connected load
  - Operating load represents an average value for a given time interval
    - Minutes for most power system equipment sizing
    - 24 hours for endurance fuel calculations and annual fuel consumption calculations
  - Equipment that is not online have a load factor of 0.
- Demand power for the power system component for a given operational condition and ambient condition
  - Sum of the operating loads for all loads plus margin and service life allowance

Zonal load factor analysis
## Modification to the load factor method

- Applicable if at least one load is not small compared to the demand power.
- Zonal load factors are equal to or greater than load factors
  - Account for loads being large
  - Account for peak loads being greater than average loads
- Zonal operating load is product of zonal load factor and connected load
- Residual zonal power demand for a load is the peak load minus the zonal operating load
- Zonal demand power is the sum of the zonal operating loads plus the largest residual zonal power demand plus margin and service life allowance

$$L_{fz_j}$$

$\dfrac{P_{Pj}}{P_{Lj}}$

L_{f_j}

$0 \qquad P_{P_j} \qquad \sum_{i=1}^{n} L_{f_i} P_{L_i}$
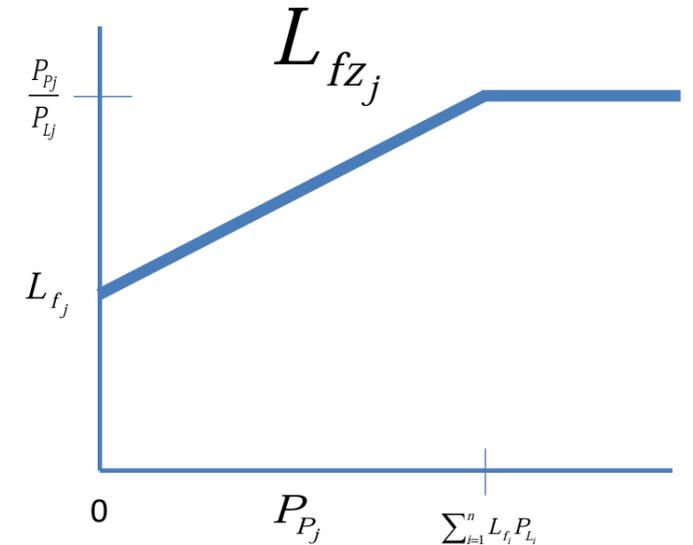
L_{fz_j} = Zonal load factor for load j

L_{f_j} = Load factor for load j for 24-hour average calculations

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

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

n = Number of loads

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Stochastic Analysis

- Models each load as a function of independent random variables
  - Random variables modeled as probability density functions (PDF)
- Margin should be reduced
  - Captured in the PDF
  - Smaller (perhaps ¼ of that used for load factor analysis) margin accounts for "missing" loads
- Service life allowance still applies
- Use Monte Carlo Simulation to determine the demand power
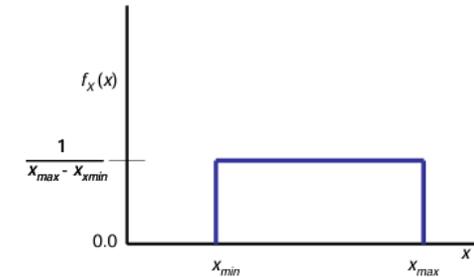
Example PDFs

Monte Carlo Simulation

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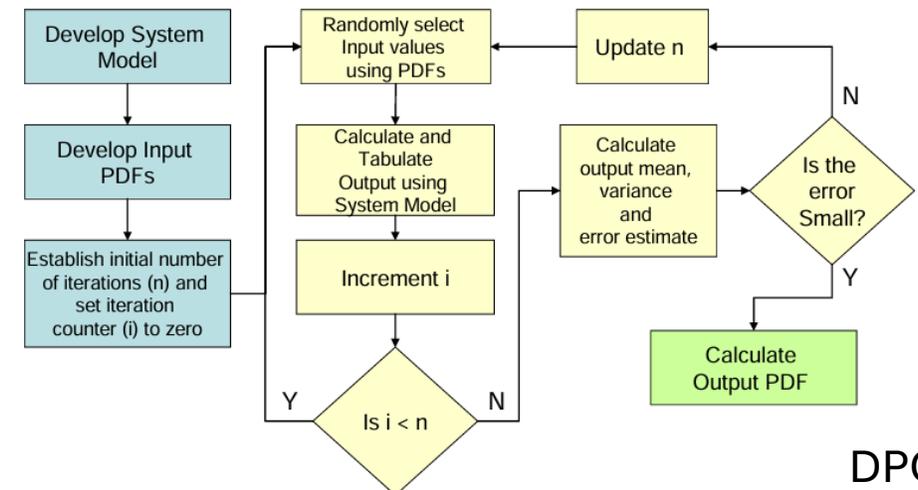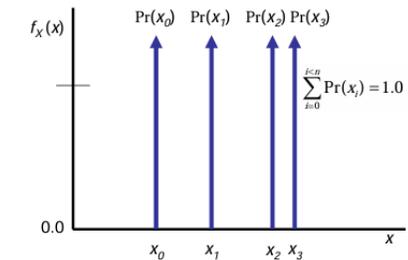
Modeling and simulation load analysis

- Useful when ...
  - Have large loads
  - Have loads with unusual electrical characteristics
  - Have loads requiring large amounts of rolling reserve
  - Correlation of loads is complex and cannot otherwise be adequately modeled by other means
- Typically employs quasi-steady state modeling
  - Only concerned with dynamics slower than about 1 second.
- Usually involves integrating individual load models
- Requires development of use-cases
  - Realistic and stressing
  - Aligned with EPS-CONOPS, PS-CONOPS, etc.
  - Aligned with operating conditions
- Worst-case demand power across all simulations typically used
- Should employ a rigorous Verification and Validation effort

Demand factor analysis

- Simple legacy method for determining
  - Current rating of cables feeding load centers and power panels
  - Current ratings of corresponding circuit breakers
- Zonal load factor method and stochastic load analysis are preferred methods
- Demand factor is obtained based on the sum of the connected loads expressed as current (for 450 V ac) or power for other voltages

DEMAND FACTORS FOR BUS FEEDERS TO LOAD CENTERS

CONNECTED LOAD – AMPERES
REFERRED TO 450 VOLTS, THREE-PHASE
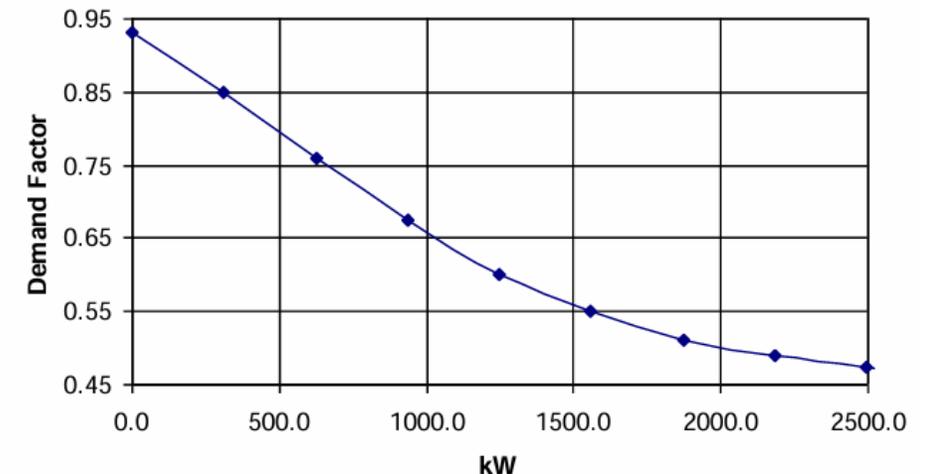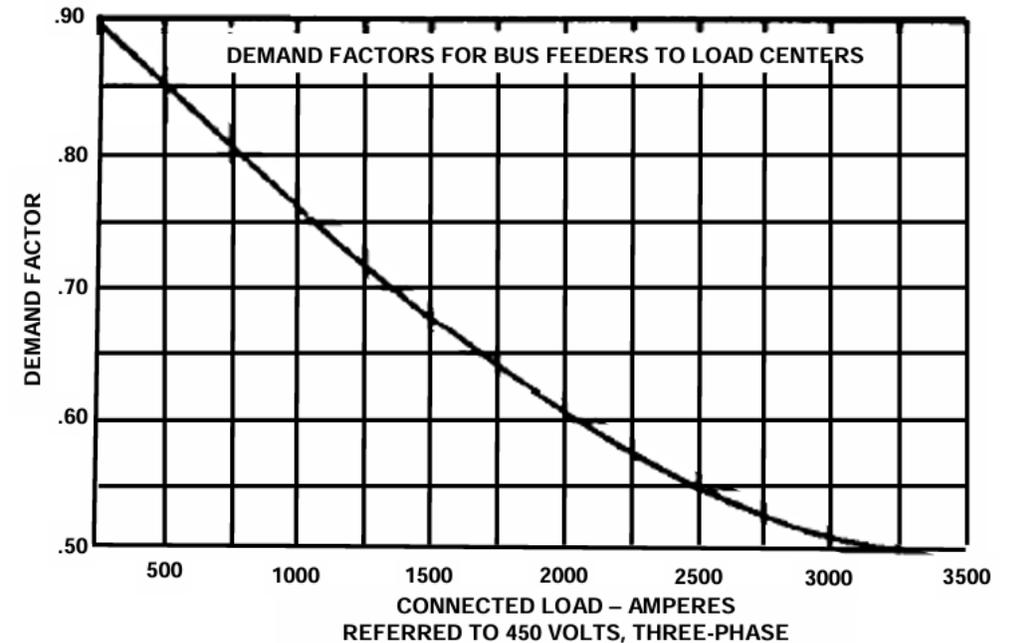
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24-hour average load

- Calculated at total ship level to support
  - Endurance fuel calculations
  - Annual fuel calculations
- Load factor analysis
  - Load factor is kWh consumed in 24 hours divided by 24
- Parametric equations may be used early when only have load factors for 100 °F ambient conditions for the purpose of determining generator set power ratings
  - Legacy method, other methods preferred
  - Should not be used in preliminary design or later
  - Equation [1] for all ships except aircraft carriers and large deck amphibious assault ships.
  - Equation [2] for aircraft carriers and large deck amphibious assault ships.

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

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

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.¶

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Load flow and limiting load flow

- Load flow analysis
  - Determines voltages, power, and current at each node of a power system for a given operational condition and ambient condition.
    - Steady state analysis
    - Based on load properties from EPLA
  - Useful for determining
    - Bus-tie current rating
    - Power distribution equipment rating
  - Supports
    - Voltage drop calculations

- Limiting load flow
  - Calculates an upper bound for power and currents without a detailed understanding of generator and load configurations
  - Levels
    - Simplest level: based only on generator set ratings
    - Less conservative level: refines simplest level by incorporating power system topology
    - Least conservative level: refines less conservative level by incorporating the impact of loads

Energy storage capacity (power and energy) analysis

- Five energy storage functions (ESM)

- Multiple analyses to support the 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

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.

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
  - Equipment in-rush current requirements detailed in load list

- Equipment with large in-rush current
  - Large transformers
  - Induction motors
  - Solenoid valves
  - Equipment with large input filter capacitors

- Study cases
  - Many loads with large inrush come online at the same time
    - Dark ship recovery
    - Dead ship recovery
  - A load with large inrush current during shift in operating mode

In-rush current remediation technologies

- 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.

Pulsed load analysis

- Examines ability of power system to support pulsed loads without impacting power quality to other loads
- EPS CONOPS describes the intended ways for the power system to be operated to support pulsed loads
  - Subject pulse directly to the generator sets
  - Use energy storage to reduce impact on generator sets
  - Redirect power (when available) from other loads (such as propulsion)
- EPLA provides an understanding of the other loads expected to be online and functional
- Analysis should confirm
  - Power quality is maintained throughout the power system
  - Generator sets and other power system equipment are operated within their specification
  - The fault protection system has the capability of discriminating between the pulse and a fault

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U.S. Navy Railgun Test
(US Navy Photo)

Quality of service analysis

- Computes t1 and t2
  - Reconfiguration time (t1)
  - Generator start time (t2)

- Assigns QOS category to all loads
  - Uninterruptible
  - Short term interrupt
  - Long term interrupt

- Evaluates if Mean Time Between Service Interruption (MTBSI) requirements met
  - Requires estimating reliability properties of power system equipment
  - Redundancy (or lack thereof) can identify critical components to concentrate data collection efforts on

Endurance fuel calculations

- Primary purpose is to determine the size of the fuel tanks
- Endurance specified as one or more endurance set of metrics
  - Economical Transit
    - Economical transit distance and Endurance Speed
  - Surge to Theater
    - Surge to theater distance and Sustained Speed
  - Operational Presence
    - Operational mission
    - Speed – Time Profile
    - Operational Presence Time
- Requires calculation of 24-hour average load for the applicable endurance set of metrics
  - Typically uses load factor analysis
  - May use parametric equation in early design stages

USS Donald Cook (DDG 75)
USNS Laramie (T-AO 203)
(US Navy Photo)

Annual energy usage and annual energy cost calculations

- EPLA provides estimates for 24-hour averages for the different operational conditions.
  - When coupled with propulsion power requirements, used to estimate annual fuel consumption.
- Annual fuel consumption used for
  - Determining whether ship meets energy efficiency requirements
  - Provide a basis for estimating the cost of fuel over the ship's service life
  - Evaluate whether the shore-side and replenishment fleet refueling capacity is sufficient (naval ships)

USNS Earl Warren (T-AO 207) (US Navy Photo)

Proxy Load

Electric Heater
USS Wisconsin (BB 64)
(Photo by Norbert Doerry)

- A proxy load is used to represent a load or group of loads
- Uses of proxy load
    - Specific equipment may not be selected; proxy load provides an estimate of the load characteristics while not necessarily being derived from specific equipment.
    - Data is not available for selected equipment; the proxy load could have characteristics of similar, but not identical equipment for which the data is available.
    - Properties of loads or groups of load are parametrically estimated and assigned to the proxy load.
    - Lumping together multiple smaller loads that have the same connection to the power system. (electrical lighting and electrical heaters for example).
    - Combining loads that depend on each other, or are exclusive to each other; managing the interdependency with a proxy load may be convenient.
    - Combining many loads, whether defined or not, that have the same connection to the power system for the purpose of simplifying system models; this technique is useful for load flow analysis, endurance fuel calculations, and annual fuel calculations.
- Proxy loads should clearly identify the equipment or types of equipment they contain.
    - If the proxy load includes a group of equipment, members of the group should be identified and the estimated characteristics for those members identified.

EPLA Evolution

- In earliest stages of design, virtually all the loads in the load list are likely to be proxy loads.
  - For each load, the load list may only estimate the connected
  - Load factors based on default values

- As the design matures, update the load list
  - Add additional information to loads as needed by analysis
    - Concentrate on the largest 50 to 100 loads
  - Remove from proxy loads and model separately, loads that are defined
    - Adjust (or eliminate) the proxy loads to reflect the load removal

- Model the loads using one or more of the modeling techniques
  - May employ proxy loads to group multiple loads from load list

- During detail design and construction
  - Replace all proxy loads in the load list with actual loads
  - Improve the load models

- During sea trials and ship operations
  - Instrument loads (preferably the 50 – 100 largest loads) to update load models