Voltage Drop Calculations on Shipboard Power Systems

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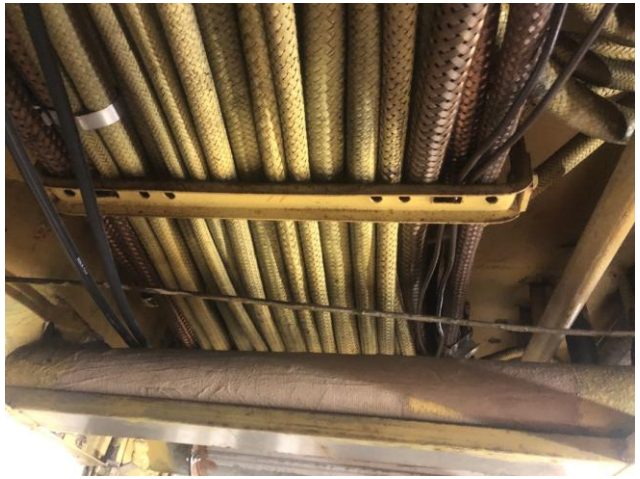
PRADS 2025

Ann Arbor MI

October 19-23, 2025

Motivation

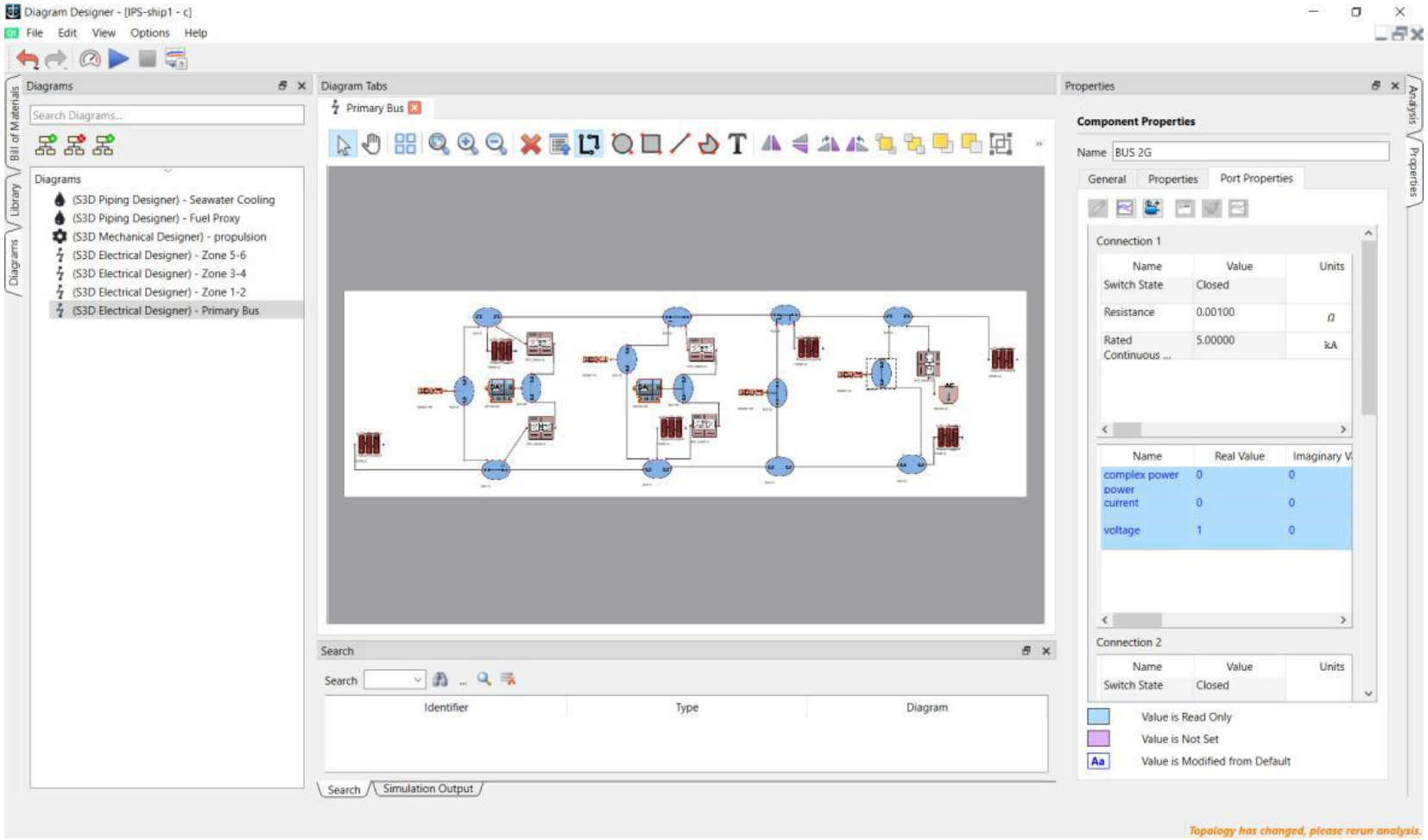
- Voltage drops in cables and transformers can lead to low voltages at the terminals of equipment
  - Equipment may not operate correctly
- Voltage drops primarily from
  - Resistance and inductance of cables
  - Voltage regulation characteristics of transformers



Types of Voltage Drop Calculations

- Quick Check
  - Focuses on voltage drop from the circuit breaker feeding a load to the load's terminals.
  - Traditional method for voltage drop calculations.
- Multi-level Check
  - Adds a load-flow analysis to determine the drop between the generator and the circuit breaker feeding the load. If system generates power at medium voltage, includes medium voltage transformers.
- Over-voltage Check
  - In systems with medium voltage transformers, ensures loads are not subjected to over-voltages when the transformers are lightly loaded.

Modeling Environment: S3D



Cable Modeling

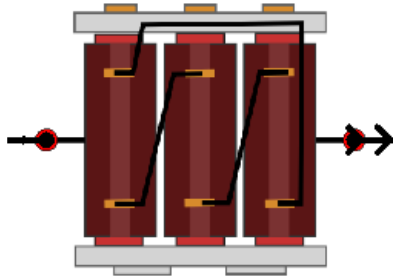
- Parameters
  - Inductance Per Unit Length (μH m^-1)
  - Resistance Per Unit Length (mΩ m^-1) (ρ)
    - $\rho_1=\rho_0(1+0.00393(T_1-T_0))$
  - Maximum Rated Current (kA)
  - Number of Cables in Bundle
  - Length (m)

PI 1

- Cables should also be checked for ampacity
  - Ensures conductor temperature does not become so high as to cause insulation damage.
  - Ampacity is provided for one set of installation detail assumptions; ampacity should be adjusted based on planned installation details.

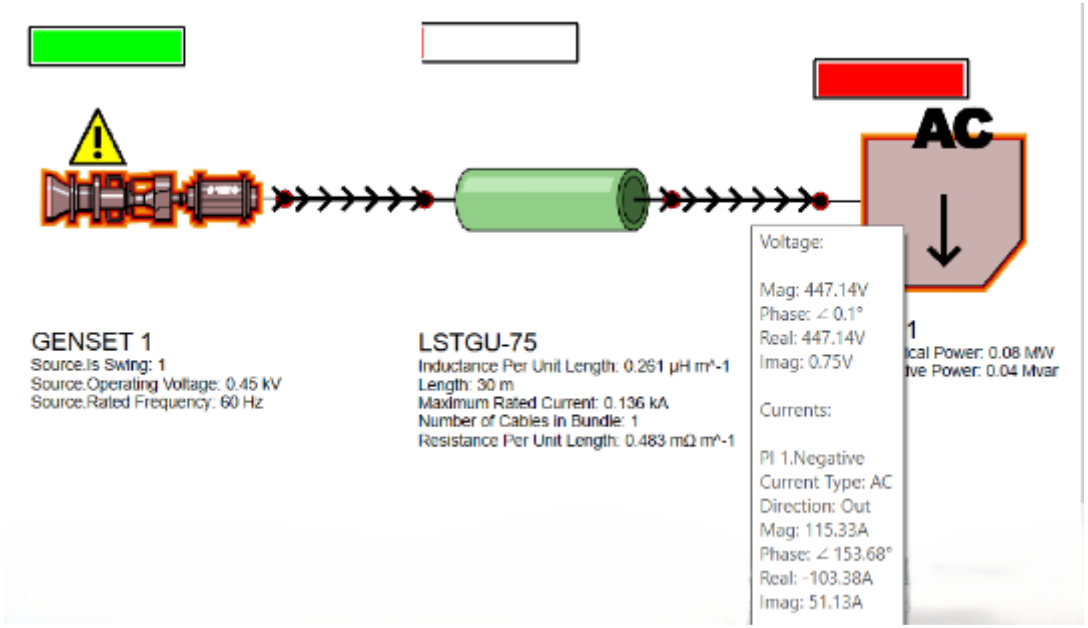
Transformer Modeling

- Parameters
  - Rated Apparent Power (MVA)
  - Rated Power Factor
  - Rated Frequency (Hz)
  - No Load Loss Factor (fraction of Rated Apparent Power)
  - Full Load Total Loss Factor (fraction of Rated Apparent Power)
  - Voltage Regulation
  - Rated Voltage for Primary port (kV)
  - Rated Voltage for Secondary port (kV)



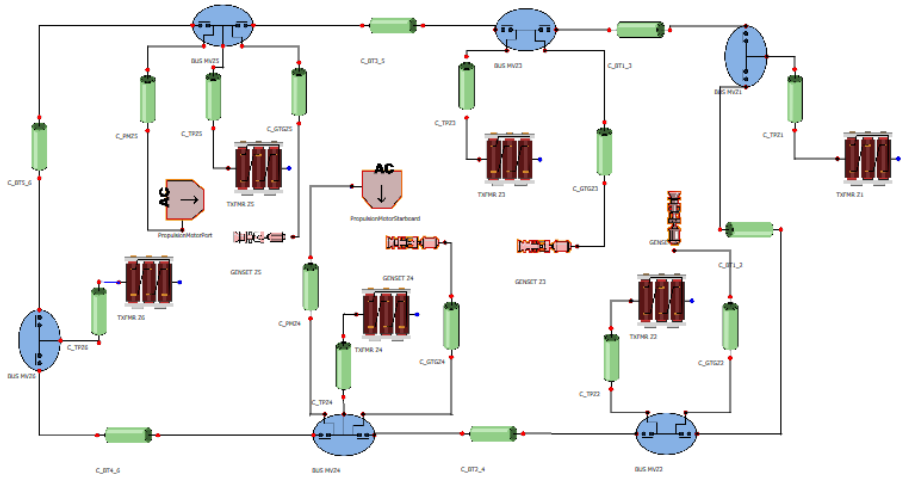
Quick Check

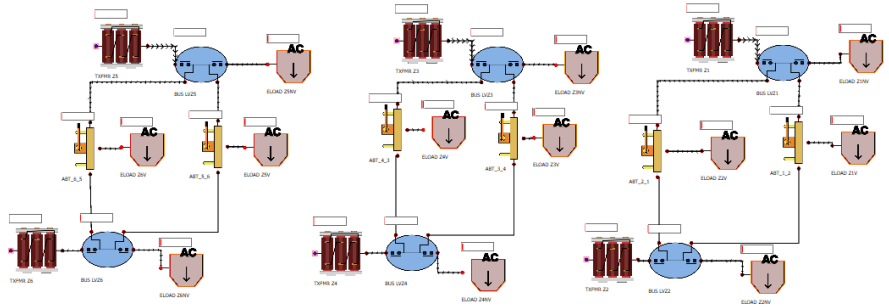
- Generator Set configured to provide electrical power at the nominal system voltage.
- Load modeled for the highest steady-state load.
- Can use a run matrix to perform multiple quick checks.
- Analyze system and record voltage magnitude at the load
  - Flag cables where the voltage magnitude at the load is too low.



Multilevel Check

- Step 1: Load Flow Analysis
  - Determine the lowest voltage at the circuit-breaker feeding a cable.
  - Requires
    - Electric Power Load Analysis (EPLA)
    - Electrical Power System Concept of Operation (EPS-CONOPS)
    - Propulsion System Concept of Operation (PS-CONOPS) for electric propulsion
    - Details on all cables, transformers, power conversion equipment, and bus transfers
  - Model loads at load centers as proxy loads; include margin and service life allowance.
  - Create a run-matrix for all the operational conditions, plant lineups, and ambient conditions.
  - Analyze system and record lowest voltage at each load center
- Step 2: Modified Quick Check
  - Perform the quick check analysis, except the lowest voltage for the connected load center should be used as the generator voltage instead of the nominal system voltage.





Over-voltage check

- Performed as a load-flow analysis in same manner as multi-level check step 1 except:
  - Margin and Service Life allowance not included in loads
  - Seeking configurations with the minimum load
  - Record the maximum voltage at each load center
- If the maximum voltage at any load center exceeds the maximum permissible value, then the design should be modified.

Summary

- Voltage Drop Calculations determine if the voltages at loads are within tolerance over the expected range of operation.
- Primary contributors to voltage drop are:
  - Cable resistance and reactance (impedance)
  - Transformer regulation
- Three types of analysis
  - Quick check
  - Multi-level check
  - Over-voltage check
- Analysis tools such as S3D are useful in performing voltage drop calculations.