

Voltage Drop Calculations on Shipboard Power Systems

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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



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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

The screenshot displays the S3D Diagram Designer software interface. The main window shows a schematic diagram of a power distribution system with various components like buses, switches, and breakers. The interface includes a menu bar (File, Edit, View, Options, Help), a toolbar, and several panels:

- Diagrams Panel:** Lists available diagrams for selection, including (S3D Piping Designer) - Seawater Cooling, (S3D Piping Designer) - Fuel Proxy, (S3D Mechanical Designer) - propulsion, (S3D Electrical Designer) - Zone 5-6, (S3D Electrical Designer) - Zone 3-4, (S3D Electrical Designer) - Zone 1-2, and (S3D Electrical Designer) - Primary Bus.
- Diagram Tabs:** Shows the current diagram being edited, labeled 'Primary Bus'.
- Properties Panel:** Displays the properties of the selected component, 'BUS 2G'. It includes a 'General' tab and a 'Port Properties' tab. The 'Port Properties' tab shows the connection details for 'Connection 1' and 'Connection 2'.

Connection 1 Properties:

| Name | Value | Units |
|------------------|---------|----------|
| Switch State | Closed | |
| Resistance | 0.00100 | Ω |
| Rated Continuous | 5.00000 | kA |

Connection 2 Properties:

| Name | Value | Units |
|--------------|--------|-------|
| Switch State | Closed | |

Simulation Output Panel: Shows the results of the simulation, including a table of values for 'complex power', 'power', 'current', and 'voltage'.

Legend:

- Value is Read Only (Blue square)
- Value is Not Set (Purple square)
- Value is Modified from Default (Aa square)

Status Bar: Displays the message "Topology has changed, please rerun analysis."

Cable Modeling

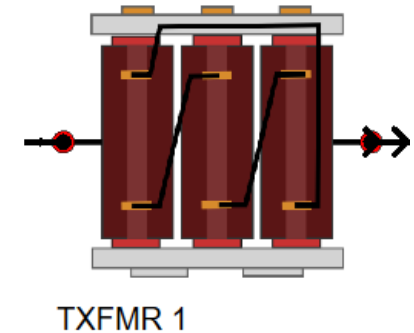
- Parameters
 - Inductance Per Unit Length ($\mu\text{H m}^{-1}$)
 - Resistance Per Unit Length ($\text{m}\Omega \text{ m}^{-1}$) (ρ)
 - $\rho_1 = \rho_0(1 + 0.00393(T_1 - T_0))$
 - Maximum Rated Current (kA)
 - Number of Cables in Bundle
 - Length (m)
- Cables should also be checked for ampacity
 - 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.



PI 1

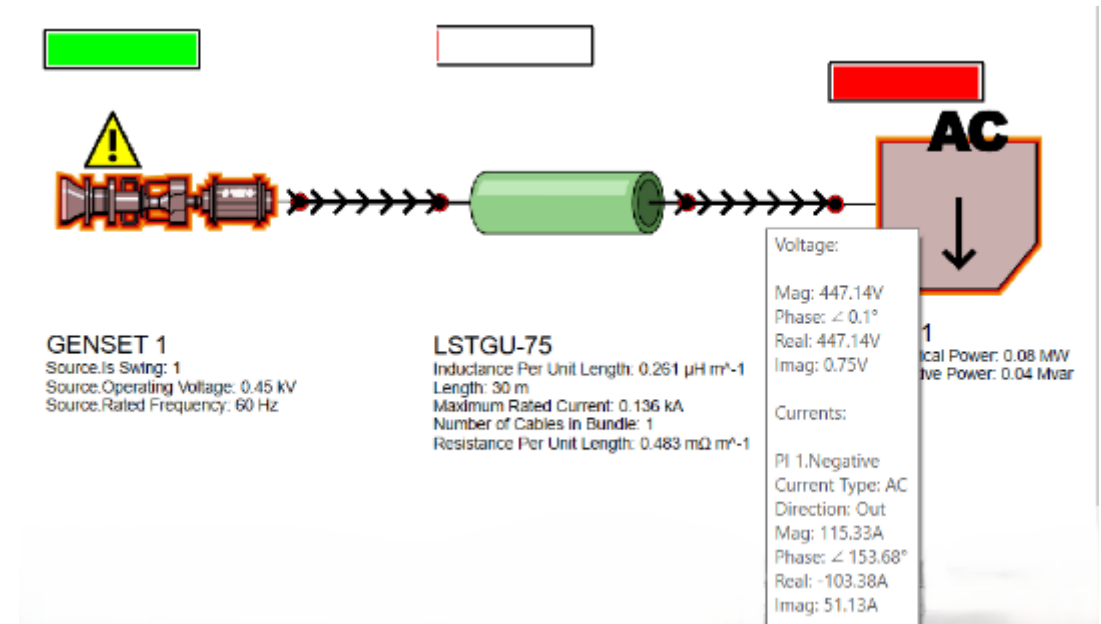
Transformer Modeling

- 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)



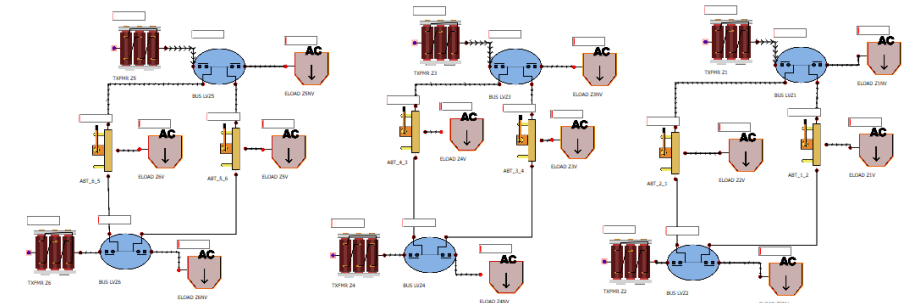
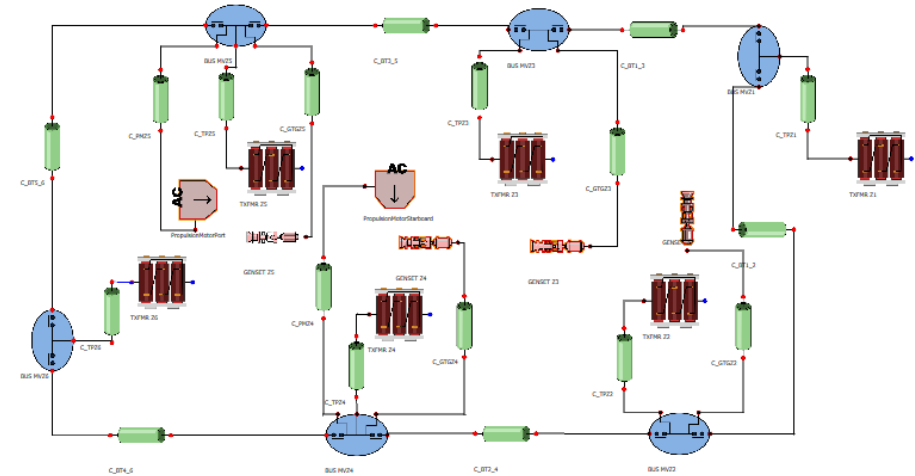
Quick Check

- 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.