Object Oriented Approach to the Simulation of Shipboard Electric Power Systems

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Naval Power Systems are Different

Relatively few number of highly complex objects.

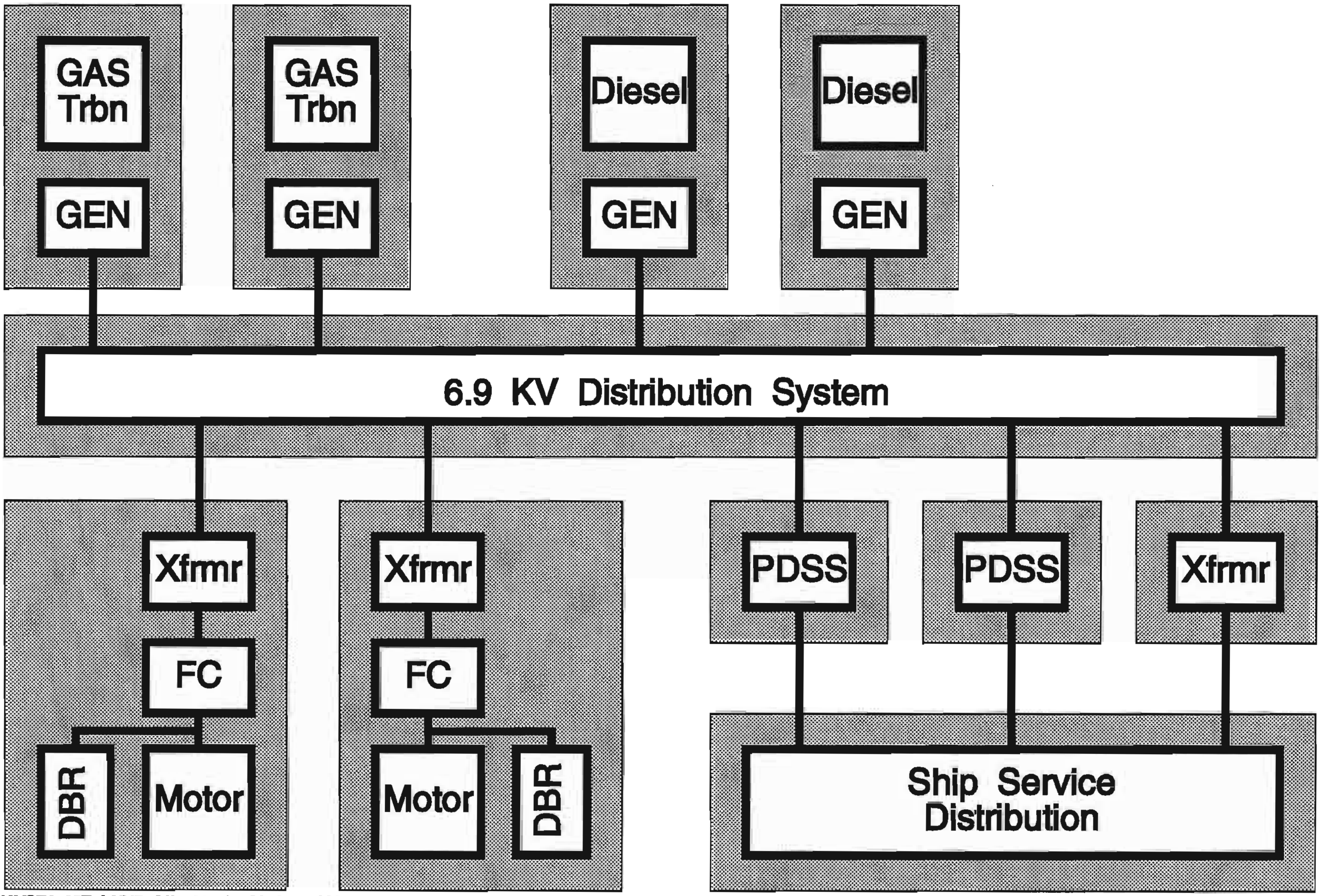
- Gas Turbine/Diesel Generators
- Load Commutated Inverter fed Direct Drive Motors
- Transformers, Circuit Breakers, etc.
- Ship Service Loads.

Lack of time scale separation.

Lack of Rotational Inertia.

Importance of control dynamics.

Integrated Electric Drive
Naval Electric Power System



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WAVESIM Features

Terminal Description Method.

System Variables as Waveforms.

Waveforms as a Data Type.

System Partitioning via System Structural Jacobian.

Terminal Description Method

Device Characterized by:

- Constitutive Equations (including dynamics)
- Parameters
- State Variables
- Interface Terminals (and associated Interface Variables)
  - Normal Terminals
    - Potential Variable (Import and Export)
    - Flow Variable (Import and Export)
  - Information Terminal
    - Potential Variable (Import and Export)

System Consists of

- Multiple Devices with terminals attached to ...
- Nodes
  - Normal (KCL and Potential Difference Eqtns)
  - Information (Potential Difference Equation Only)

Resistor Device

V_1 = Import Potential
V_2 = Import Potential
I_1 = Export Flow
I_2 = Export Flow

$$I_1 = \frac{V_1 - V_2}{R}$$

$$I_2 = \frac{V_2 - V_1}{R}$$

$$J = \begin{vmatrix} DD \\ DD \end{vmatrix}$$

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Terminal Description Method Details

Device Normal Terminal Restrictions

- Nbr. of Export variables must equal Nbr. of Normal Terminals.
- Nbr. of Import variables must equal Nbr. of Normal Terminals.

Nodes satisfy Kirchhoff's Current Law (KCL)

Devices are not required to satisfy KCL

- Allows flow losses (i.e. Power)
- KCL Group Numbers
  - Set of Terminals whose flow variables ...
    - satisfy KCL by definition.
  - Group 0 reserved for terminals whose flow variables ...
    - are not part of KCL Group.

Terminal Description Method Details II

Connection Problem

Normal Nodes

- One or more Normal Terminals with ...
  - Any combination of import and export variables.
- Zero or more Information Terminals with ...
  - Associated import variables.

Information Nodes

- Information Terminals only ...
  - One and only one Export Potential variable.
  - Zero or more Import Potential variables.

Reference Device vs. Reference Node

Single Terminal Device

- Import flow, Export Potential, KCL Group 0.

Identify a set of nodes connected by common KCL Groups.

- At least one member node must be connected to a KCL Group 0 terminal.

Waveforms

Description of variable over a time interval.

- Variable Name.
- Vector of Numbers (along with its size).
- Type indicator.
  - Data Series.
  - Fourier Coefficients.
  - Polynomial.
  - Chebyshev Coefficients.
  - Legendre Coefficients.
- Time Interval.

Waveform Operators

- Conversion Routines.
- Arithmetic Operators.
- Dynamic Operators.
  - Linear Matrix Operations.
  - Numerical Stability is not an issue for all but Data Series.
- Return both Waveforms and Jacobian Matrices.

System Equations

System Variables (y)

Node Potentials

Normal Node Potentials (n_n)

Information Node Potentials (n_i)

Import Flow Variables (n_f)

System Equations (Nonlinear Algebraic)

Potential Difference Equations (g)

Normal Node Export Potentials (n_f)

Information Node Export Potentials (n_i)

Normal Node Kirchhoff Current Law (KCL) Equations (n_n) (f)

$$0 = f(h(x(y)) , y)$$
$$0 = g(h(x(y) , y)$$

where

$x(y)$ are the device import variables

$h(x)$ are the device export variables

System Partitioning: System Structural Jacobian

Device Structural Jacobian Matrix

Relationship of Export Variables with respect to Import Variables:

0	Zero	Structural Zero (always Zero)
I	Identity	Always the Identity Matrix
D	Diagonal	Always a linear diagonal matrix
L	Linear	Always a linear time invariant matrix
N	Nonlinear	Nonlinear matrix
U	Unknown	Treated as a nonlinear element

System Structural Jacobian Matrix

Relationship of system equations with respect to system equations.

Created by combining Device Structural Jacobian Matrices.

Structural Jacobian element algebra:

$x + y = x$ for $x > y$ $\qquad$ $x + x = x$ for $x \neq \mathrm{I}$

$x - y = x$ for $x > y$ $\qquad$ $x - x = x$ for $x \neq \mathrm{I}$

$\mathrm{I} + \mathrm{I} = \mathrm{D}$ $\qquad$ $\mathrm{I} - \mathrm{I} = 0$

System Partitioning:
Presolve and Postsolve Blocks

Presolve Block (of size *n*)

n rows which only have nonzero elements in the same *n* columns.

Postsolve Block (of size *n*)

n columns which only have nonzero elements in the same *n* rows.

Once a block has been identified:

System Rows and Columns ignored in further block identification.

Blocks should be identified from smallest to largest.

Reset *n* to 1 after identifying a block.

Blocks are solved in a specific order:

Presolve Blocks in the order of identification.
Postsolve Blocks in the reverse order of identification.

Concluding Thoughts

Terminal Description Method Well Suited for Naval Electric Power System Simulation.

Waveforms

Convergence Testing.
Truncation Error Control.
Discontinuity Time Prediction.
Improved Continuation Methods.
Waveform Smoothing.

Waveform Relaxation

Use System Structural Jacobian to aid in partitioning.