Space Power Workshop

Electrical Power Distribution & Control Modeling & Analysis

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Boeing Phantom Works
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Modeling Requirements

- Electrical Power Distribution and Control (EPD&C) Model Capabilities:
  - EPD&C steady-state, transient and stability characteristics
  - Interface requirements of EPD&C with power source and power loads
  - Integration in the End-to-End System Model which may include electrical mechanical, hydraulic and chemical system models
  - Software tool used for modeling and simulation also supports analysis
Modeling Approach
System Integrator’s Perspective

A. Top-Down Analysis of System Architecture
   - Decompose the entire system into submodels
   - Define the submodels in the integrated system model
   - Define interface parameters between submodels
   - Determine the fidelity of submodels and component models.

B. Bottom-Up Model Development Process
   - Develop component models
   - Integrate component models in the submodels
   - Integrate submodels in the end-to-end system model

C. Model Validation
   - Validate the submodels and the end-to-end model by test and analysis data
Electro-Mechanical-Hydraulic System Model

• EPD&C in the End-to-End Electro-Mechanical-Hydraulic Model
  – Power Source, e.g., Battery
  – EPD&C
  – Electrical Loads
  – Mechanical Loads
  – Hydraulic Loads

• Example - EPD&C for Space Shuttle Electric Auxiliary Power Unit
Electrical Power Distribution & Control
Space Shuttle Electric Auxiliary Power Unit

Electric Auxiliary Power Unit

270 VDC Battery

EPD&C

Motor Drive & Controller

EHDU

(Electro-Hydraulic Drive Unit)

Motor(s)

Hydraulic System

Pump

Hydraulic Actuators

Cooling System

BOEING
Model Development Software Tool

EASY5®

Steady State Toolkit

Matrix Algebra Tool

Simulation and Analysis Toolkit

EASY5 Graphical Modeling

Advanced Modeling

Real-Time Toolkit

Libraries
- Aerospace Vehicle
- Electric Drive
- I.C. Engine
- Multiphase Fluid
- Powertrain
- Thermal Hydraulic
- Thermal Pneumatic
- Valve / Actuator
EASY5®
http://www.boeing.com/easy5/

• A family of commercial software tools used to model, simulate and analyze dynamic systems.
• Developed by Boeing and used world wide.
• Model and simulate dynamic systems containing hydraulic, pneumatic, mechanical, thermal, electrical and digital sub-systems.
  – Systems are conveniently modeled with functional blocks (summers, dividers, wave generators, integrators, etc.) and/or with pre-defined components representing physical elements (pumps, gears, engines, etc.), as well as user-defined models in FORTRAN code or C code.
  – A complete set of user-friendly control system modeling, analysis and design features is included.
• Virtual prototyping of entire systems via links to other CAE software for multi-body and structural dynamics, controls, controller code generation, integrated circuit design, etc.
• Source code is automatically generated to support real-time simulation.
EPD&C Modeling Approach
EASY5 Model Development

Lithium-Ion Battery Model
- Equivalent-Circuit Model
- Electrochemical Model

EPD&C Architecture & Parameters

EAPU/EPD&C Model

EASY5
- Libraries
  - General Purpose
  - Electric Drive
  - Thermal Hydraulic
- Macro

EHDU Model

Simulation & Analysis
- Steady State Analysis
- Transient Response
- Power Quality
- Stability

Output Variables
- Voltage
- Current
- Impedance
EPD&C Modeling

• Develop EASY5 Power Distribution System Submodel and integrated with Battery and EHDU Models for End-to-End EAPU System Analysis
• Use the Stand-alone EPD&C Submodel for Detailed Simulation and Analysis

Initial Assumptions:
1. Parameters Obtained from Flight Unit Design:
   EPD&C Input Cabling from Battery: R=1.732 mΩ, L=0.7804 μH
   - 2 ft of 0 AWG wire and connector contacts
   EPD&C : R=2.643 mΩ, L=0.4285 μH
   - Bus bars, fuses, contactors and connector contacts
   EPD&C Output Cabling to EHDU: R=6.574 mΩ, L=7.48 μH
   - 21.3 ft of 2 AWG wire and connector contacts
2. Model will include System and Component Characteristics, without the Detailed Power Electronics Modeling.
EAPU EASY5 Model Schematics

Battery System
- Battery Temperature [30 Degrees]
- Battery Output Current
- Battery Output Voltage

Number of Motor Segments
- Motor Segments
- Motor Speed RPM
- Input Power
- Battery I/F with Motor

Valve Control Function of Time
- Gain Block
- Hydraulic System Simulation
- Pump Flow GPM
- Computed Torque
- Pump Torque GN12
- Hyd_Torque_in_lbf

EPD&C Submodel
- EPD&C Submodel
- EHDU Input Voltage
Battery Cell Impedance

EQUIVALENT-CIRCUIT BATTERY CELL MODEL @ SOC=1

EPD&C EASY5 Simulation
Hydraulic Load Dynamics

Hydraulic Load Simulation
- A metering valve controls valve flow area
- System flow and pressure command pump displacement
- Battery, EPD&C and Motor react to pump torque changes
EPD&C EASY5 Simulation
EPD&C Response to Hydraulic Load Variations

EPD&C Modeling

EPD&C Modeling

Conclusion

• EPD&C Modeling approach is discussed
• Status of model development and analysis examples are reported
• Model build-up continues
  – Additional power control algorithm and power distribution hardware dynamics will be added to the model
• Transient, stability and abnormal conditions will be analyzed