Space Power Workshop

Electrical Power Distribution & Control
Modeling & Analysis

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Boeing Phantom Works

Source of Acquisition
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Space Power Workshop

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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

EHDU
(Electro-Hydraulic Drive Unit)

Motor
Drive & Controller
Motor(s)
Pump

Hydraulic System
Hydraulic Actuators

Cooling System
Model Development Software Tool

EASY5®

- Steady State Toolkit
- Simulation and Analysis Toolkit
- Real-Time Toolkit
- Graphical Modeling
- Advanced Modeling

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 worldwide.
- 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

EHDU Model

EAPU/EPD&C
Model

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

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.
EPD&C Submodel
EASY5 Schematics

Current Passthrough

Battery_Output_Current

Derivative (Approx)

DV4 7.804e-7s

S2 DV4

EPDC_Input_Voltage

Derivative (Approx)

DV5 4.285e-7s

S2 DV5

EPDC_Output

Derivative (Approx)

DV6 7.48e-6s

S2 DV6

EHDU_Input_Voltage

\[ \sum \]

-1

\[ \sum \]

-1

MC4

L1

1

Battery_Output_Current

L1
Battery Cell Impedance

EQUIVALENT-CIRCUIT BATTERY CELL MODEL @ SOC=1

[Graph showing battery source impedance over frequency (Hz) with magnitude and phase angle (deg) plotted against frequency (Hz).]

EPD&C Source Impedance

EPD&C WITH EQUIVALENT-CIRCUIT BATTERY MODEL

100
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
1,000
1E4
1E5
1E6
MAGNITUDE (OHM)

SOURCE IMPEDANCE

FREQ(HZ)

90
0
-90
-180
0.001
0.01
0.1
1
10
100
1,000
1E4
1E5
1E6
PHASE(DEC)

FREQ(HZ)

Model: Impedance, Runid: tran_func, Case: 1, Display: 3. 01-FEB-2001, 16:11:38
**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