Space Power Workshop

Electrical Power Distribution & Control Modeling & Analysis

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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 thesubmodels and the end-to-end model by test and analysis data

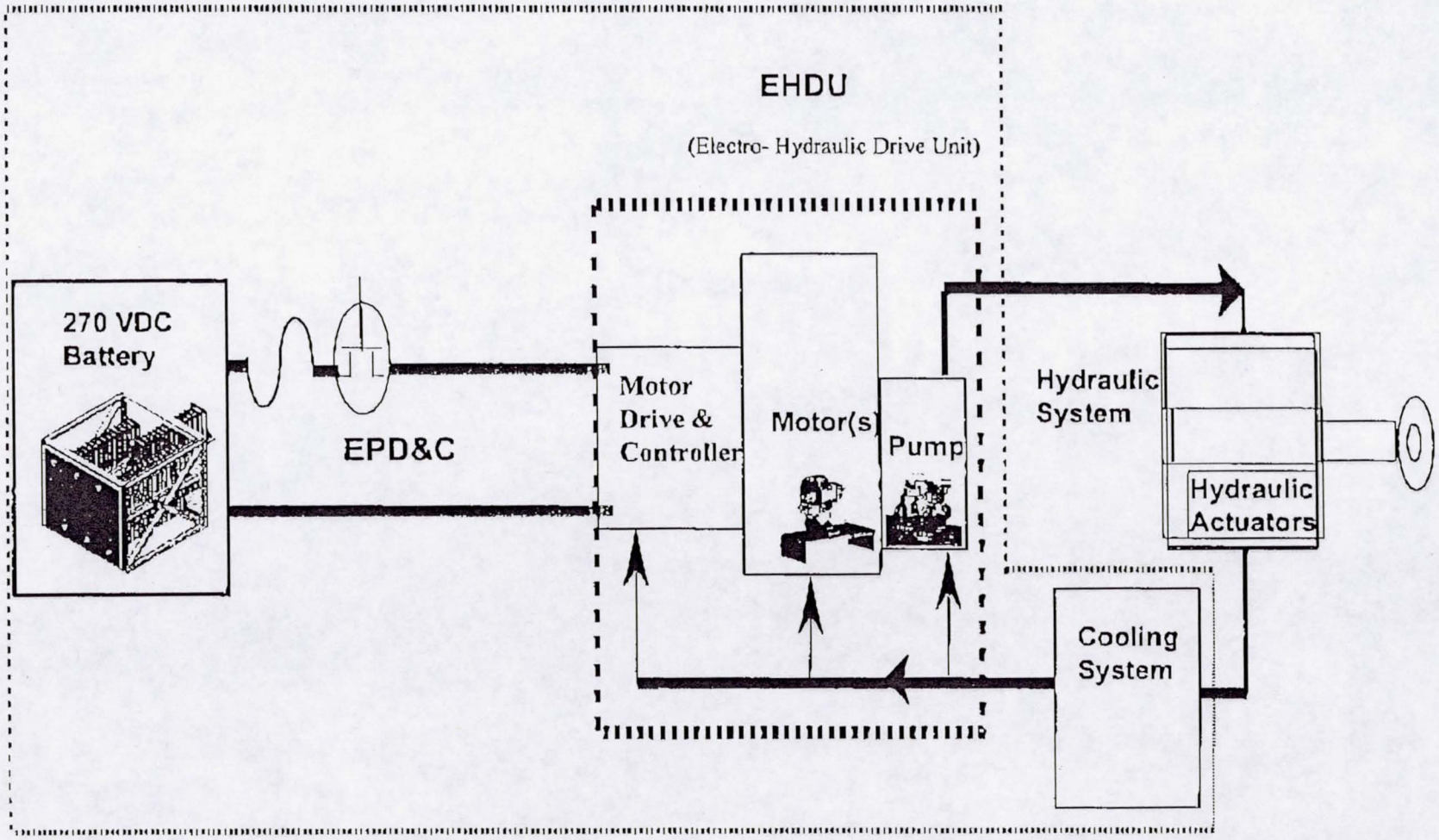
Electro-Mechanical-Hydraulic System Model

- 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

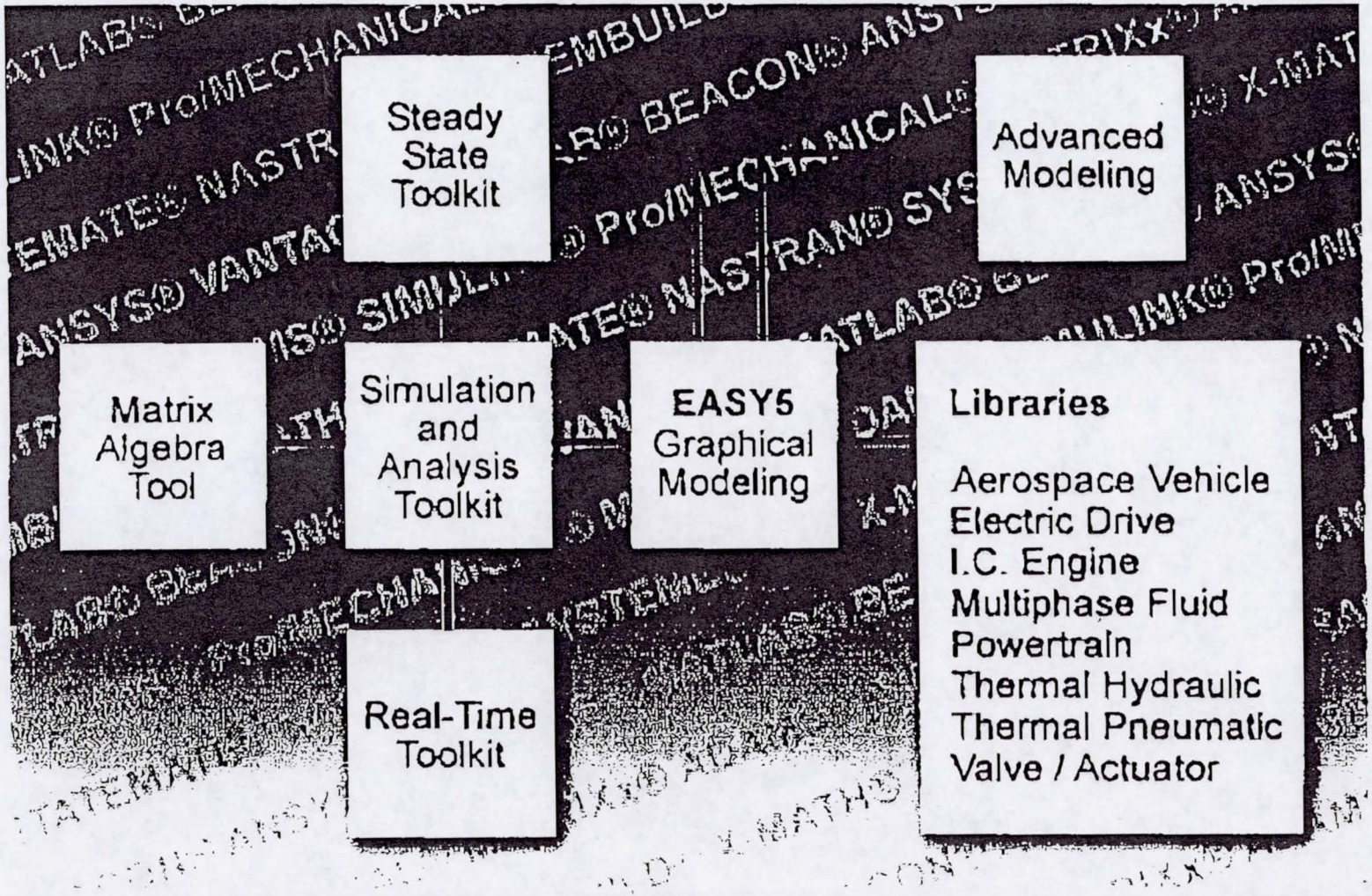
Space Shuttle Electric Auxiliary Power Unit

Electric Auxiliary Power Unit



Model Development Software Tool

EASY5®



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

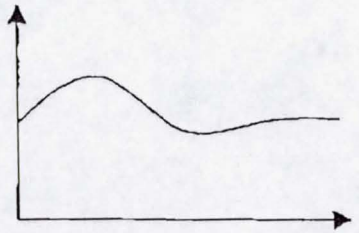
Lithium-Ion Battery Model
- Equivalent-Circuit Model
- Electrochemical Model

EPD& C
Architecture &
Parameters

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

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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

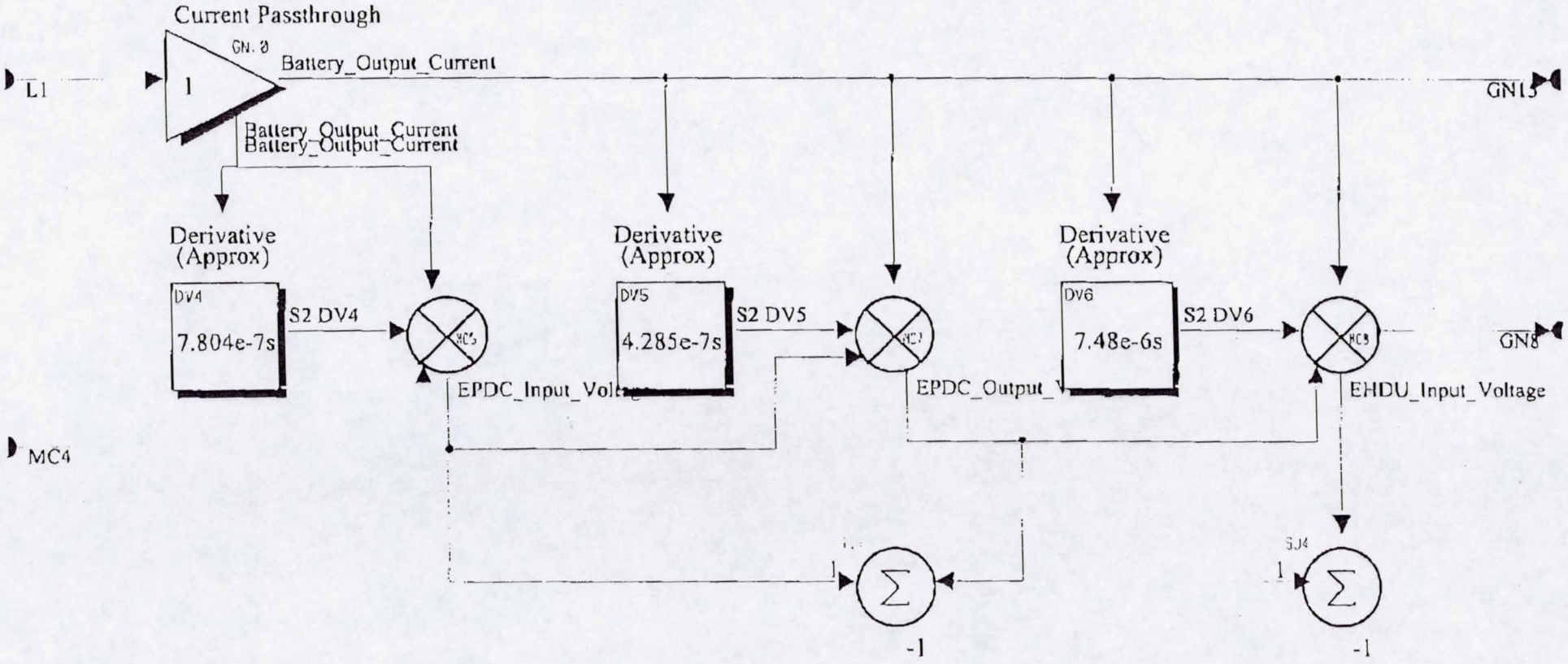
   EPD&C Output Cabling to EHDU: R=6.574 mΩ, L=7.48 μH

   - 21.3 ft of 2 AWG wire and connector contacts

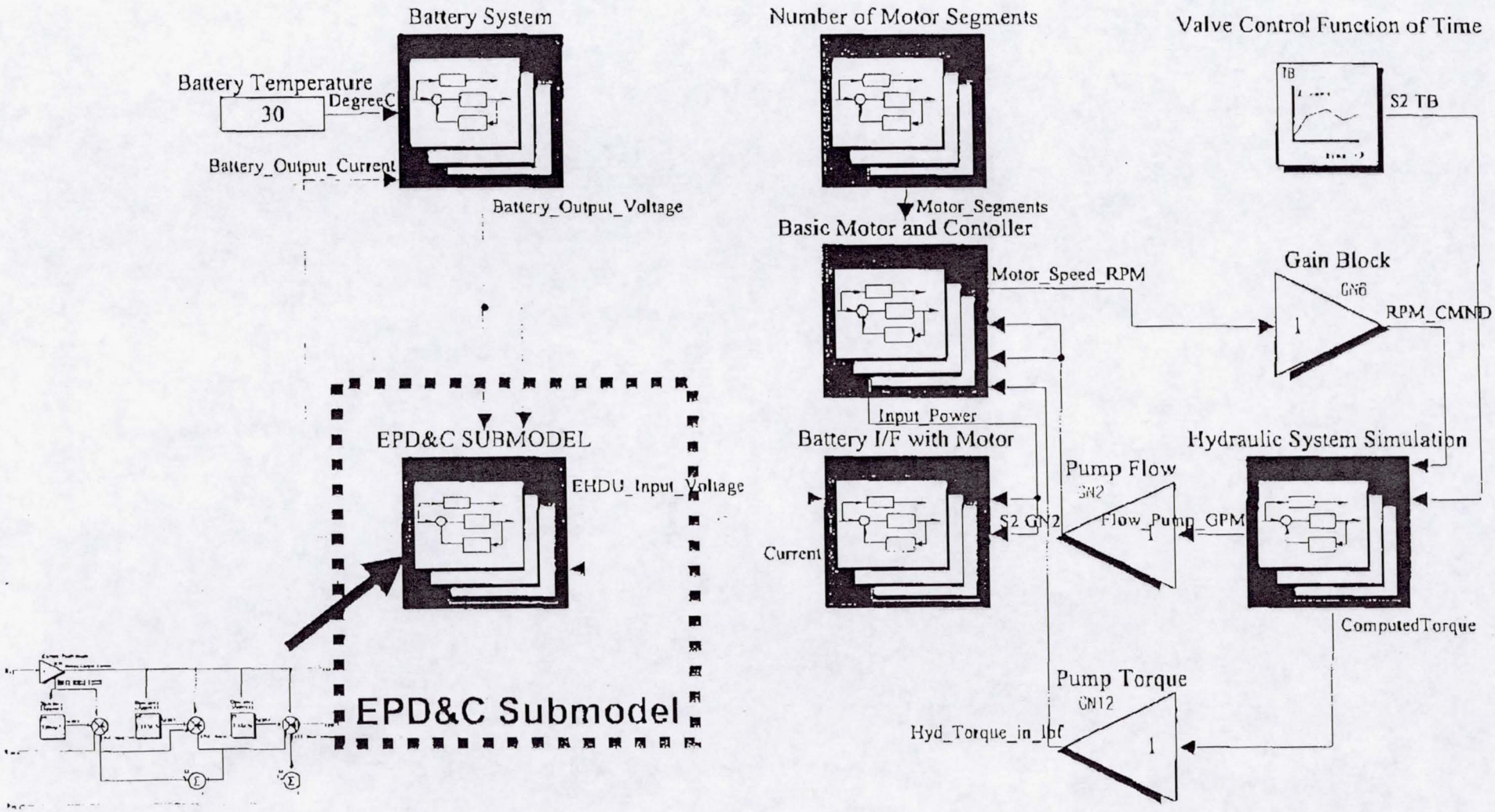
2. Model will include System and Component Characteristics, without the Detailed Power Electronics Modeling.

EPD&C Submodel

EASY5 Schematics

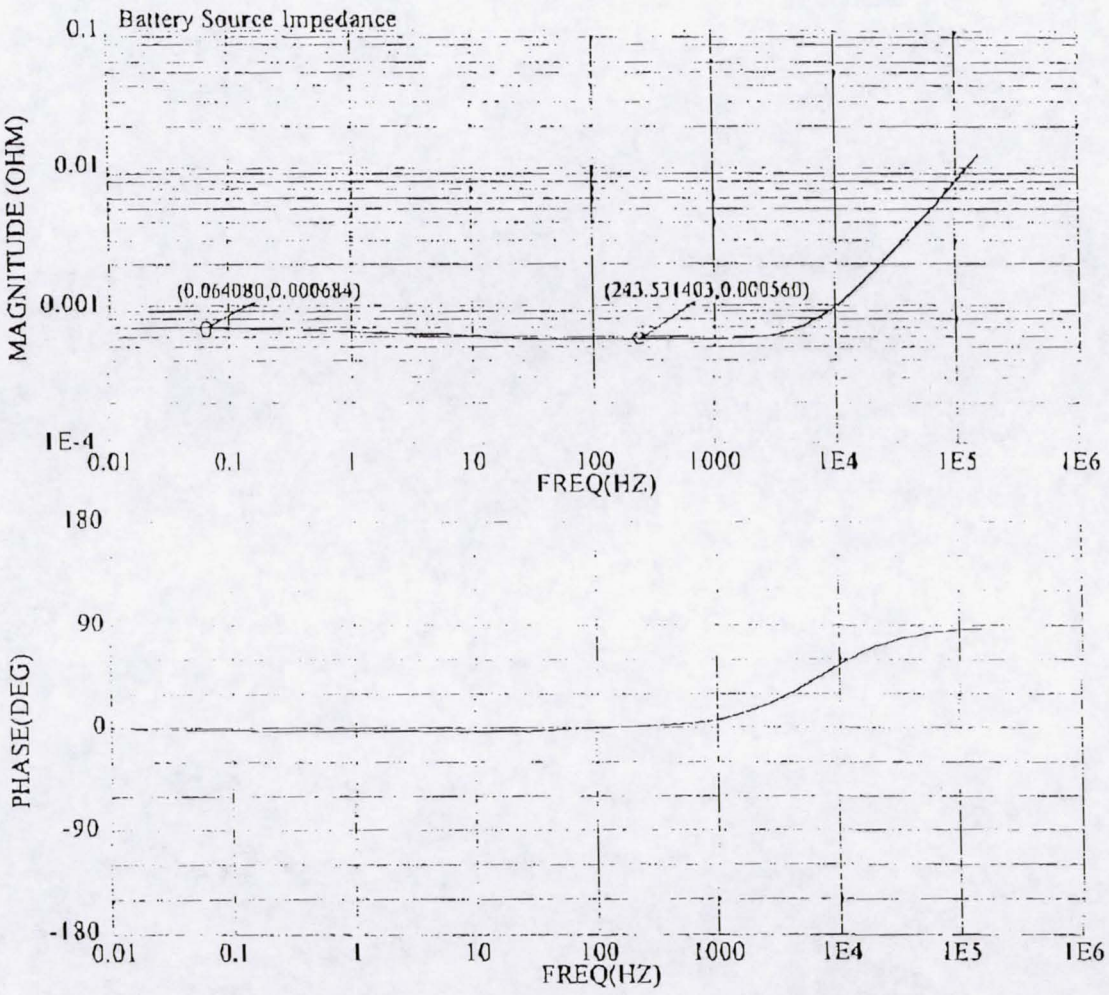


EAPU EASY5 Model Schematics



Battery Cell Impedance

EQUIVALENT-CIRCUIT BATTERY CELL MODEL @ SOC=1



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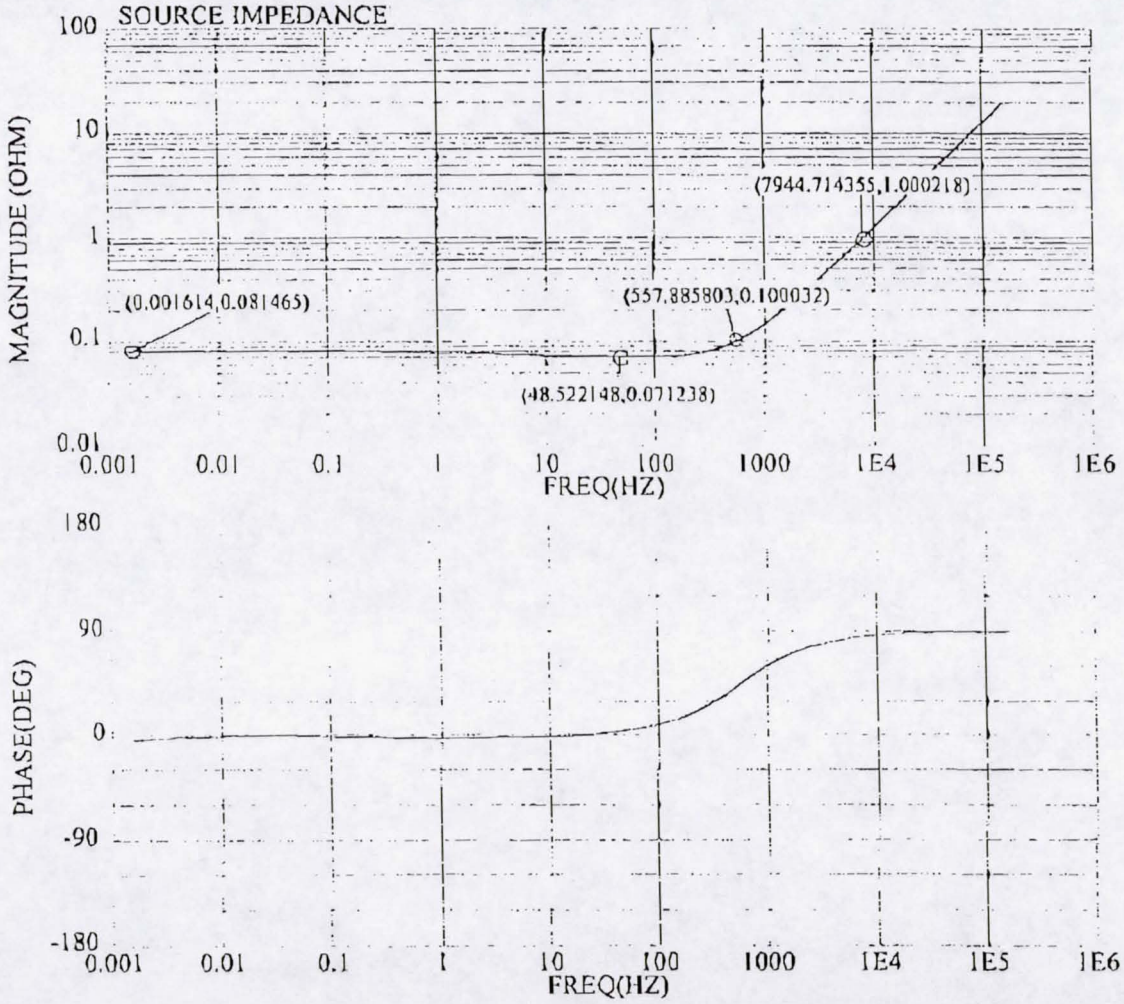
EPD&C Source Impedance

EPD&C WITH EQUIVALENT-CIRCUIT BATTERY MODEL



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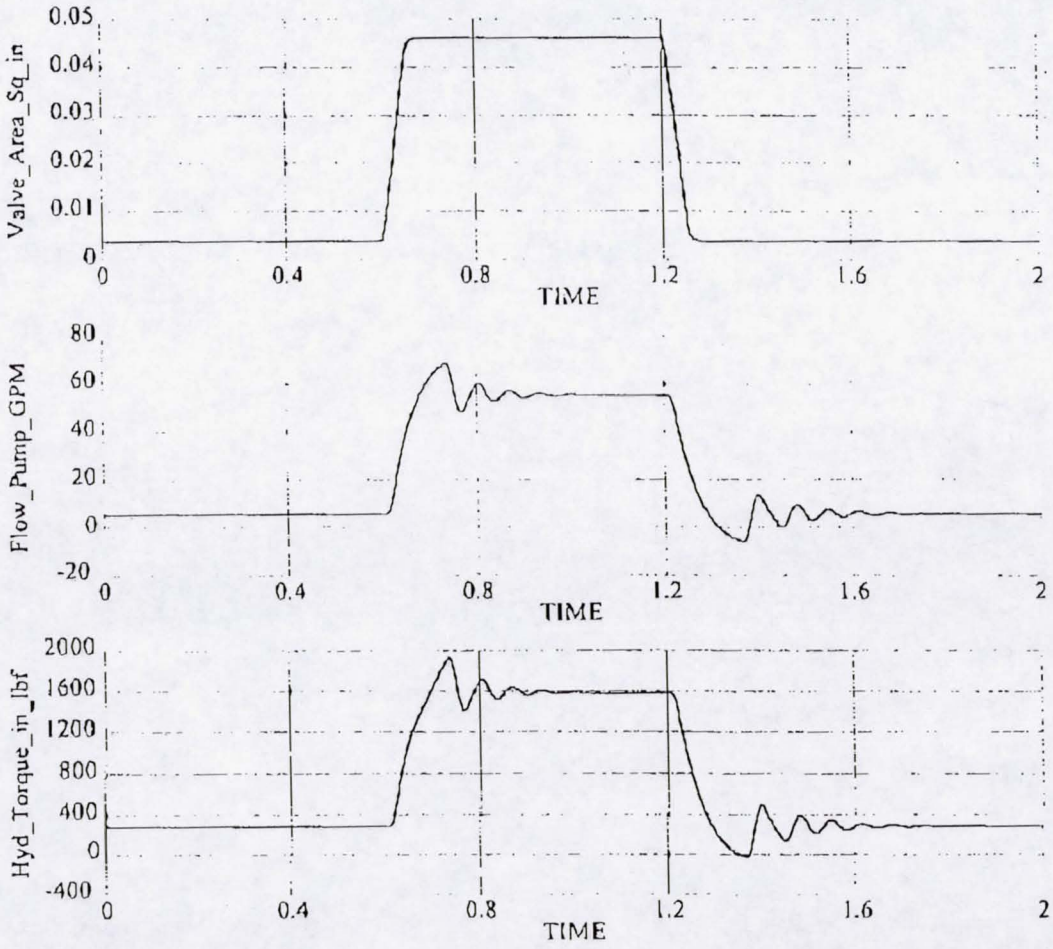
EPD&C EASY5 Simulation

Hydraulic Load Dynamics

EPD&C Modeling



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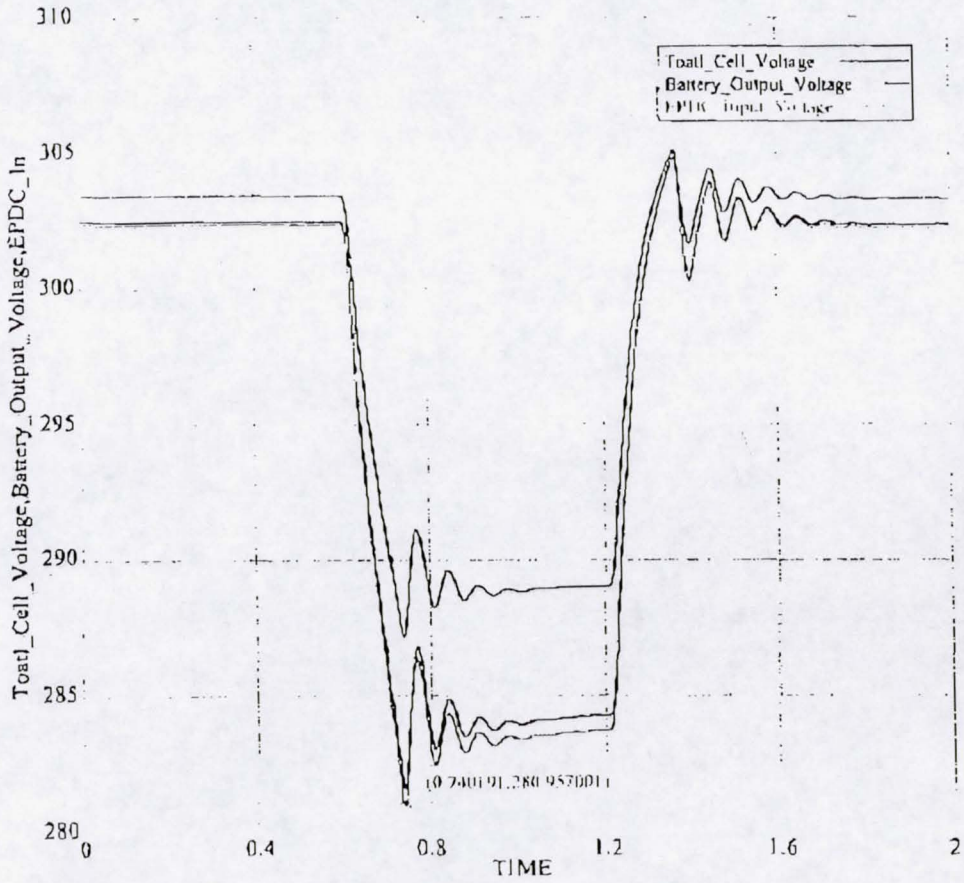
Hydraulic Load Simulation

- 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



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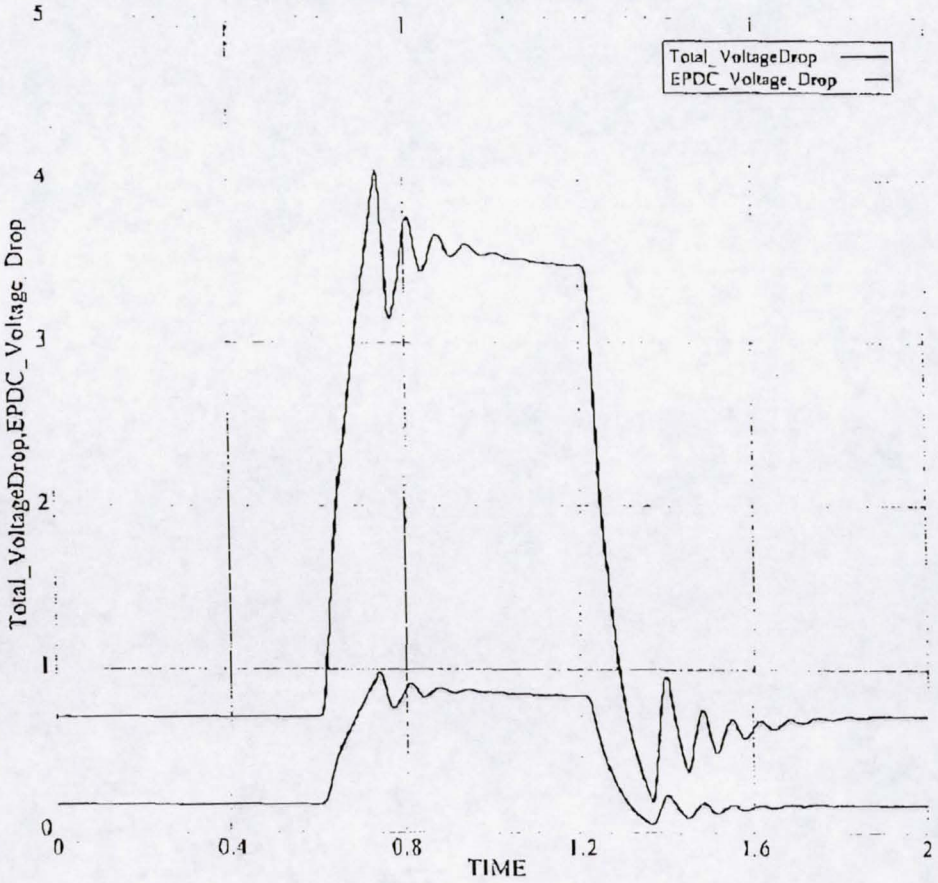
EPD&C Modeling



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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