Modeling Multi-domain Systems Using Simscape – A Battery Modeling Example

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Application Engineering
Control Design and Automation
Challenges of Developing Battery Models
Challenges of Developing Battery Models

- Hard to model exact electrochemical behaviour.
- Multidomain, nonlinear effects are challenging to model.
- Model must simulate quickly to enable extensive testing (drive cycles, temperatures, etc.)
- Model must provide results that compare well to test data
The Goal

Discharge current (A)

Output Voltage (V)

State of Charge

Battery Temperature (ºC)

ΔT = +16ºC
Today’s Example: Battery
Multi-domain Systems
Traditional Design Process

**Requirements**

- Designs are hard to validate against system requirements

**Design**

- Not possible to optimize system performance or detect integration issues in “Design”
- Errors are found late in the development process using expensive prototypes

**Implementation**

- Manual coding is slow, introduces defects, and is difficult to compare to design

**Integration and Test**
Model-Based Design Process

- **REQUIREMENTS**
  - Produce better designs by continuously comparing design and specification

- **SYSTEM LEVEL SIMULATION**
  - Optimize system performance by developing in a single simulation environment
  - Create physical prototypes only after thorough real time testing

- **IMPLEMENTATION**
  - Save time by automatically generating embedded code

- **INTEGRATION AND TEST**
  - Designs are hard to validate against system requirements
  - Not possible to optimize system performance or detect integration issues in "Design Manual coding is slow, introduces defects, and is difficult to compare to design Errors are found late in the development process using expensive prototypes Optimize system performance by developing in a single simulation environment
  - Save time by automatically generating embedded code

- **TEST & VERIFICATION**
  - Produce better designs by continuously comparing design and specification
Model-Based Design Process

1. **Requirements**
   - Produce better designs by continuously comparing design and specification

2. **System Level Simulation**
   - Optimize system performance by developing in a single simulation environment
   - Create physical prototypes only after thorough real-time testing

3. **Implementation**
   - Save time by automatically generating embedded code

4. **Integration and Test**
   - System-level simulation
   - Test & verification

Model-Driven Design Process Flowchart:
- Requirements
- System Level Simulation
- Implementation
- Integration and Test
Model-Based Design Process

**Key Message**

*System Level Simulation Helps in Addressing Challenges Involved in System Design & Optimization.*
Agenda

- Different Approaches for Modeling Dynamic Systems
- Creating Custom Components Using Simscape Language
- Modeling Multi-domain systems Using Simscape
- Enhancing Models with Simscape Add-on Libraries
- Automatically Estimating Model Parameters Based on Test Data
Agenda

Different Approaches for Modeling Dynamic Systems

- Creating Custom Components Using Simscape Language
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- Automatically Estimating Model Parameters Based on Test Data
Modeling Physical Systems With MathWorks Products

Modeling Approaches

First Principles Modeling

- Programming (MATLAB, C)
- Block Diagram (Simulink)
- Modeling Language (Simscape language)
- Symbolic Methods (Symbolic Math Toolbox)

Data-Driven Modeling

- Physical Networks (Simscape and other Physical Modeling products)
- Statistical Methods (Model Based Calibration Toolbox)
- System Identification (System Identification Toolbox)
- Neural Networks (Neural Network Toolbox)
- Parameter Tuning (Simulink Design Optimization)
Modeling RC Circuit in Simulink Requires the Equation

\[ \dot{x} = \frac{1}{RC} [f(t) - x] \]
Modeling RC Circuit in Simscape Requires Knowledge of Physical Topology
What if the resistance value changes with temperature?
Agenda

- Different Approaches for Modeling Dynamic Systems

Creating Custom Components Using Simscape Language

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Model Custom Physical Components in Simscape

**Model:**

Temperature 250K – 350K

**Problem:** Add custom equation to model thermal effect on resistor

**Solution:** Use the Simscape language to model the component.

```matlab
parameters
R = {1, 'kOhm'};  \% Nominal resistance
a = {0.001, '1/K'};  \% Temperature coefficient
T0 = {300, 'K'};  \% Reference temperature
T = {300, 'K'};  \% Current temperature
end

equations
v == R*(1+a*(T-T0))*i;
end
```
Modeling Physical Systems in the Simulink Environment

Modeling Approaches

First Principles Modeling

- Code (MATLAB)
- Block Diagram (Simulink)
- Modeling Language (Simscape language)
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Data-Driven Modeling

- Physical Networks (Simscape and other Physical Modeling products)
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Simscape Enables Bidirectional Flow of Power Between Components

\[ R_1 \rightarrow \mathbf{i} \rightarrow C_1 \rightarrow v_1 \]

\[ R_1 \rightarrow \mathbf{i}_j \rightarrow C_1 \rightarrow i_2 \rightarrow R_2 \rightarrow C_2 \rightarrow v_2 \]

Simulink: Input/Output

Simulink: Physical Networks
Agenda

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- Creating Custom Components Using Simscape Language

Modeling Multi-domain systems Using Simscape

- Enhancing Models with Simscape Add-on Libraries
- Automatically Estimating Model Parameters Based on Test Data
Modeling Battery Using Equivalent Circuit: Simscape

Model:

Using Simscape Foundation Library Components:

- DC Voltage Source
- Resistor
- Capacitor
- Diode
Customization Is Required For Modeling the Dependency of Components

- Use Physical Modeling methods to build electrical and thermal network

Battery cell equivalent discharge circuit
Resistors, capacitor, and voltage source are dependent upon SOC, DOC, and temperature

\[ v = i \cdot R20 \cdot \exp(A21 \cdot (1 - \text{pow}) \cdot v \cdot i); \]
\[ \text{end} \]
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- Creating Custom Components Using Simscape Language
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- Enhancing Models with Simscape Add-on Libraries
  - Automatically Estimating Model Parameters Based on Test Data
Battery Models
Generic, Pre-Defined

- **Generic**
  - Charge dependent voltage source
  - Parameters found on data sheets

- **Pre-Defined**
  - Several pre-defined models
  - Full parameterization
  - Documentation provides extensive detail
Physical Systems in Simulink

Simscape

- Mechanical
- Hydraulic
- Electrical
- Thermal
- Pneumatic
- Magnetic

Custom Domains via Simscape Language

Multidomain physical systems

Electrical power systems

Fluid power and control

Multibody mechanics (3-D)

Mechanical systems (1-D)

Electromechanical and electronic systems
Modeling Physical Systems in the Simulink Environment

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Data-Driven Modeling

- Neural Networks (Neural Network Toolbox)
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Physical Networks (Simscape and other Physical Modeling products)
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Automatically Estimating Model Parameters Based on Test Data
Problem: Simulation data does not match measured data because the parameters are incorrect

Solution: Use Simulink Design Optimization to automatically tune model parameters

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Estimating Parameters Using Measured Data

- Steps to Estimate Parameters
  1. Import measurement data and select estimation data
  2. Identify parameters and their ranges
  3. Perform parameter estimation
  4. Validate estimation

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Summary

System Level Simulation helps in addressing challenges involved in system design and optimization.

Simscape helps you in building multi-domain system models.

It enables you to simulate plant and controller in single environment.
MathWorks Certification Program- for the first time in India!

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- Validates proficiency with MATLAB
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- Can help increase productivity and project success and thereby prove to be a strategic investment

- Certification exam administered in English at MathWorks facilities in Bangalore on Nov 27, 2013

Email: training@mathworks.in  URL: http://www.mathworks.in/services/training  Phone: 080-6632-6000
## Scheduled Public Training for Sep–Dec 2013

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<td><strong>MATLAB based Optimization Techniques</strong></td>
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Thank You For Attending The Session

Q & A