Modeling a Hybrid Electric Vehicle and Controller to Optimize System Performance

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Key Results

1) **Integrating the requirements** in model and simulation is **critical for effective development**

2) Effective use of **control design tools** and **optimization algorithms** improves overall design

3) Simulating plant and controller **in one tool** allows engineers to understand and optimize performance **of the entire system**
Agenda

- Introduction to HEV Model 5 min
- Improving Development Process 5 min
  - Linking Design and Specification
  - Comparing Performance and Specification
- Optimizing HEV System 15 min
  - Linearized Model
  - Nonlinear Model
- Questions and Answers 5 min
System Optimization Challenge

- HEV with two PI controllers
  - Speed Controller, Voltage Controller

- Must meet performance requirements
- Conflicting goals
  - Improving speed response degrades voltage bus response
HEV Electromechanical System

Battery

Braking Chopper

Three-Phase Bridge

SimPowerSystems
Simulink

SimDriveline
Simscape
SimPowerSystems
Simulink

Three-Phase Bridge

SimPowerSystems
Simulink

SimDriveline
Simscape
SimPowerSystems
Simulink

Heuliez HYVIRA 350

Heuliez HYVIRA 350

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Heuliez HYVIRA 350
Simscape

- Extension of Simulink® designed to model multidomain physical systems
- Eases process of modeling physical systems
  - Does not require deriving and programming the equations of motion for the system
- Used by system engineers and control engineers to build a model representing the physical structure of the system
Electrical System in SimPowerSystems

- Permanent Magnet Synchronous Motor Drive
  - Speed controller
  - Vector controller
  - Inverter
  - Permanent magnet synchronous motor
  - Braking chopper
- Implemented through SimPowerSystems in the Simulink environment
Mechanical System in SimDriveline

- Transmission System
  - Input Torque
  - Transmission
  - Vehicle Inertia
- Implemented in SimDriveline within the Simulink environment
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**Situation:**

Problem: Matching design to specification is difficult.

Solution: Use **Simulink Verification and Validation** to directly link the design to the specification.
Comparing Specification and Design

Situation:

HEV Requirements
1. Drivetrain System
  Wheel Speed
  5% Setting Time in 0.5 Sec

Problem: Measuring design performance relative to specification is difficult.

Solution: Use Simulink Verification and Validation to automatically compare performance to specification.
Improved Development Process

- Advantages of improved process

1) Enables quick and easy association of specification and model

2) Automatically checks design against specification

3) Supports Model-Based Design, helping you discover and solve problems earlier in the design process
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Possibilities for System Optimization

- **Linearized model**
  - Linearize system via [Simulink Control Design](#)
  - Perform linear control design with [Control System Toolbox](#) and [Simulink Response Optimization](#)
  - Retest in nonlinear system

- **Nonlinear model**
  - Specify response characteristics
  - Automatic tuning via [Simulink Response Optimization](#)
System Optimization On Linear Plant

Model:

Ref. Voltage → Controller → Car → Ref. Speed

Problem: Design and tune the two controllers in this system to meet system requirements.

Solution: Use Simulink Control Design, Control System Toolbox to design, tune, and test the controller.
System Optimization On Linear Plant

- **Steps to Design Controller**
  1. Identify control loops of interest
  2. Identify operating point
  3. Linearize model about this point
  4. Perform control design
  5. Test controller in nonlinear system

\[ A \mathbf{x} + B \mathbf{u} = 0 \]
System Optimization On Linear Plant

- Advantages of Simulink Control Design
  1) Enable easy application of linear control theory
     - Operating points from specification or simulation
     - Graphical design with interactive plots
  2) Rapid evaluation of designs with interactive analysis plots
  3) Optimize performance based on time, frequency, or root locus constraints
System Optimization On Nonlinear Plant

**Model:**

![Diagram of the system model](image)

**Problem:** Design and tune the controller in this system to meet system requirements.

**Solution:** Use Simulink Response Optimization to design, tune, and test the controller.

![Controller parameters](image)

<table>
<thead>
<tr>
<th>System</th>
<th>Voltage</th>
<th>Speed</th>
<th>Motor</th>
</tr>
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<tr>
<td>Kp</td>
<td>Ki</td>
<td>Kp</td>
<td>Ki</td>
</tr>
<tr>
<td>0.007</td>
<td>0.001</td>
<td>1.3</td>
<td>120</td>
</tr>
</tbody>
</table>
Control Design On Nonlinear Plant

- **Steps to Optimizing Response**
  1) Identify parameters to be tuned and their ranges
  2) Specify desired response
  3) Perform response optimization
Control Design On Nonlinear Plant

- Advantages of Simulink Response Optimization

  1) Simulating plant and controller in one tool allows engineers to understand and optimize performance of the entire system.

  2) Automatic tuning of parameters saves time.

  3) Graphical interface makes it easy to map specification to tests.
Summary

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MathWorks Physical Modeling Tools Booth
(HEV Example, Other Tools)

- Series-Parallel architecture using Simscape, SimDriveline, SimPowerSystems
Physical Modeling Master Class
(Wednesday, 10:30 – 12:00)

- Model and simulate multidomain physical systems all within the Simulink environment

- Optimize system performance by developing the plant and controller in one environment

- Use Model-Based Design on your entire system to improve your development process
Thank You For Your Attention!

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