MATLAB EXPO 2017
Building Fast and Accurate Powertrain Models for System and Control Development
Prasanna Deshpande
Challenges for the Powertrain Engineering Teams

- How to design and test vehicle powertrain in a single environment?
- How to perform powertrain matching, fuel economy, performance, and emission simulations?
- How to design and verify the controller at the vehicle system level?
What Does the Solution Look Like?
Key Message

Model-Based Design uses simulation to address the challenges of system design and optimization.

- Control Algorithm
- Powertrain and Vehicle
- Parameter Values
- Optimization Algorithm
- Calculate Fuel Use
Agenda

Create

Optimize

Verify
Agenda

Create

Optimize

Verify
Structure of a System Level Simulation Model

- Control Strategy Model
  - POWERTRAIN CONTROLLER MODEL
- Dynamic System Model
  - AUTOMOTIVE POWERTRAIN MODEL
Modeling Dynamic Systems in the Simulink Environment

Modeling Approaches

First Principles Modeling
- Code (MATLAB)
- Block Diagram (Simulink)
- Modeling Language (Simscape language)
- Symbolic Methods (Symbolic Math Toolbox)

Physical Networks (Simscape and other Physical Modeling products)

Data-Driven Modeling
- Neural Networks (Neural Network Toolbox)
- System Identification (System Identification Toolbox)
- Statistical Methods (Model Based Calibration Toolbox)
- Parameter Optimization (Simulink Design Optimization)
Structure of a System Level Simulation Model

Control Strategy Model

POWERTRAIN CONTROLLER MODEL

Dynamic System Model

AUTOMOTIVE POWERTRAIN MODEL
Control System Design in Simulink

- **Linear Control Theory**
  - Linearize system and perform linear control design with Control System Toolbox™ and Simulink® Control Design
  - Retest controller in nonlinear system

- **Specify System Response**
  - Specify response characteristics
  - Automatic tuning using Simulink® Response Optimization™
Structure of a System Level Simulation Model
Model-Based Design Challenges

*It’s hard to do good Model-Based Design without good models*

- Insufficient expertise / resources to build right kinds of models
- Limited adoption of HIL
- Significant impact on development time and cost
MathWorks’ Response

Lower the barrier to entry

- Provide starting point for engineers to build good plant / controller models
- Provide open and documented models
- Provide very fast-running models that work with popular HIL systems
Powertrain Blockset

- New product: R2016b+ web release (October 2016)
- Goal: Provide pre-built, configurable and accurate models for real-time needs
Demo – HEV system level model
Powertrain Blockset

Library of blocks

Pre-built reference applications
Agenda

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Challenges for the System Engineer

- How do I know if my powertrain configuration will meet my requirements?

- How can I squeeze a little more performance out of my existing architecture without violating any design constraints?
Multi-Mode HEV Review

Development of a New Two-Motor Plug-In Hybrid System
Naritomo Higochi, Yoshihiro Sunaga, Masashi Tanaka and Hiroo Shimada
Honda R&D Co., Ltd.

![Diagram of a two-motor plug-in hybrid system with Battery, Mot, Gen, Clutch, and Front Tires. The diagram illustrates the EV Mode.]
Multi-Mode HEV Review

Development of a New Two-Motor Plug-In Hybrid System

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Battery

Mot

Gen

Clutch

Front Tires

SHEV Mode

Requested Traction Force [N] vs. Vehicle Speed [kph]

0 1000 2000 3000 4000 5000 6000 7000 8000

0 20 40 60 80 100 120 140 160

EV

SHEV

Engine / Power Split

MathWorks

Define Requirements

System-Level Specification

Subsystem Design

Smoke Test Model Validation and Code

Subsystem Integration and Test

Complete Integration and Test

System-Level Testing and Integration
Multi-Mode HEV Review

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Engine Mode
Powertrain Blockset:
Four use cases. One framework.

- Use Cases:
  1. System design and optimization
  2. Controller parameter optimization
  3. Software integration test
  4. Software-hardware integration test (HIL)
Powertrain Blockset Enables Accessible Optimization Capabilities

**Speedup Ratio**
- 50 to 100X

  - Simulation Time / Real-Time
  - HEV Reference Application

**Efficient Optimization**
- More drive cycles and design parameters
- Using fewer resources

**PC, UI**
- Easier implementation
- Simulink Design Optimization UI
Design Optimization Problem Statement

- Maximize MPGe
  - FTP75 and HWFET
  - Weighted MPGe = 0.55(FTP75) + 0.45(HWFET)

- Optimize Parameters:
  - 5 control parameters
    - EV, SHEV, Engine mode boundaries
  - 1 hardware parameter
    - Final differential ratio

- Use PC
  - Simulink Design Optimization (SDO)
  - Parallel Computing Toolbox (PCT)
Simulink Design Optimization

- Speed Up Best practices
  - Accelerator mode
  - Fast Restart

- Use Parallel Computing Toolbox

- Specify Simulation timeout
Optimization Results – Iteration Plot
Optimization Results

Simulink Design Optimization → Response Optimization

+ 2% MPGe

~ 12 Hours

3.42:1

2.92:1
How Can the Problem be Expanded?

- Different Initial SOC Points

- Battery Capacity or Cell Configuration
  - Ah rating
  - Number cells (or modules) in series / parallel
  - Affects vehicle mass

- Road Grade Profiles

- Utilize ‘Uncertain Variables’ in SDO
  - Optimize for Robustness
Agenda

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Challenges for the Automotive Controls Engineer

- How do I know if my motor controller will produce the desired performance?

- What will the interactions be between my motor and the rest of the vehicle systems?

- How will my motor operate under more extreme load cases?
Different Motor Models for Different Needs

### System Optimization
- **Goal:** Estimate fuel economy
- **Requirements:** fast simulation speed, simple parameterization
- **Model choice:** empirical model

### Subsystem Control Design
- **Goal:** Study controller interactions
- **Requirements:** higher accuracy, inclusion of effects like saturation
- **Model choice:** nonlinear saturation

Detail model = inverter controller + nonlinear motor model
High Fidelity Detailed Motor Model in Simscape

- FEA simulations or dynamometer data used to obtain non-linear flux table
- Simscape-based model created to capture this effect

\[
\begin{align*}
\lambda_d &= v_d \\
\lambda_q &= v_q \\
i_d &= \text{Mechanical Eqn.} \\
i_q &= \text{Mechanical Eqn.}
\end{align*}
\]
Including Detailed Subsystem Variants

- Add your own subsystem variants to the existing vehicle models
  - Simulink-based
  - Simscape-based
  - S-function
Detailed Model Variant Simulation

- Detailed variant gives comparable response
- Supervisory controller handles both motor variants
- Motor controller requires further verification
Torque Control Performance

FTP75 Drive Cycle
- Motor torque response accurately follows the commanded torque at different speeds
Torque Control Performance

US06 Drive Cycle

- Much higher power demand reveals a problem
- Motor controller becomes unstable under certain operating conditions
Controller Enhancements

- Controller robustness was improved via dynamic gain scheduling

Flux-Weakening Controller

Current Controller

Modulation

\[ \begin{align*}
\text{Trq}_{\text{cmd}} & \rightarrow \text{Speed} \\
\text{id}_{\text{cmd}} & \rightarrow \text{iq}_{\text{cmd}} \\
\text{vd}_{\text{ref}} & \rightarrow \text{vq}_{\text{ref}}
\end{align*} \]
Torque Control Performance

US06 Drive Cycle

- Even in more extreme maneuvers, improved motor controller is able to provide the commanded torque
Powertrain Blockset and Simscape

Complementary Technologies

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Simscape Assembly

Powertrain Blockset

- Torque Control
- Batt. Control
- Engine Control
- Driver
- Clutch Control
- Engine
- 2L Engine

6.7 kWh Battery

Traction Motor

Winter Tires

Clutch

Simscape Flexible Architecture

Powertrain Blockset

Pre-built Applications
System Level Verification

- Started with a fast running system model
- Incorporated a detailed subsystem model
- Ran several use cases to identify problems
- Modified subsystem controller to address problems
- Verified the updated subsystem met requirements
Key Takeaways

- Powertrain Blockset provides components and controllers for enabling rapid Model-Based Design of vehicle powertrains
- Fast simulation time enables efficient optimization using fewer resources
- Powertrain Blockset can be combined with high fidelity subsystem models to perform system level testing and verification
Thank you

Please send your questions to Mike Sasena at mike.sasena@mathworks.com