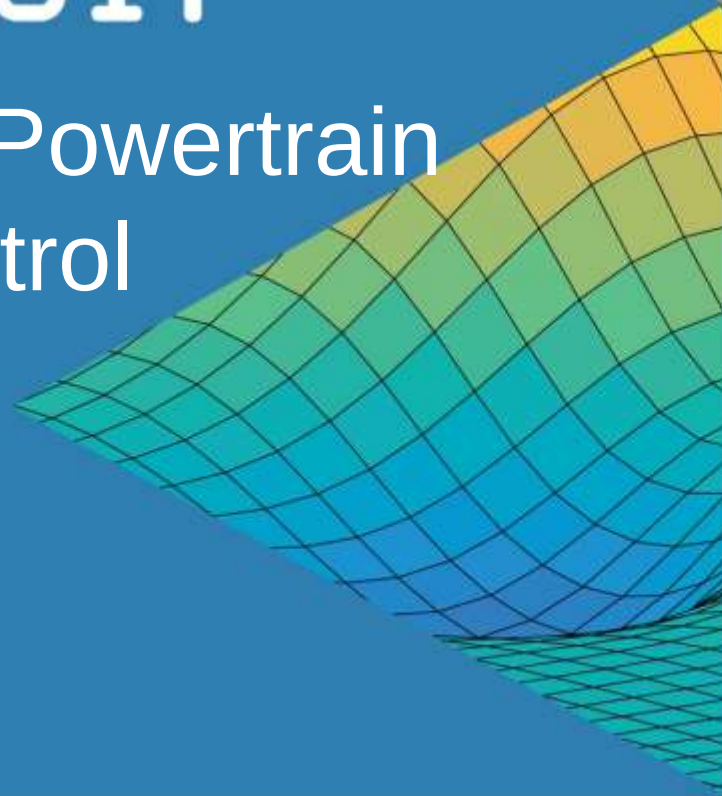


MATLAB EXPO 2017

Building Fast and Accurate Powertrain Models for System and Control Development

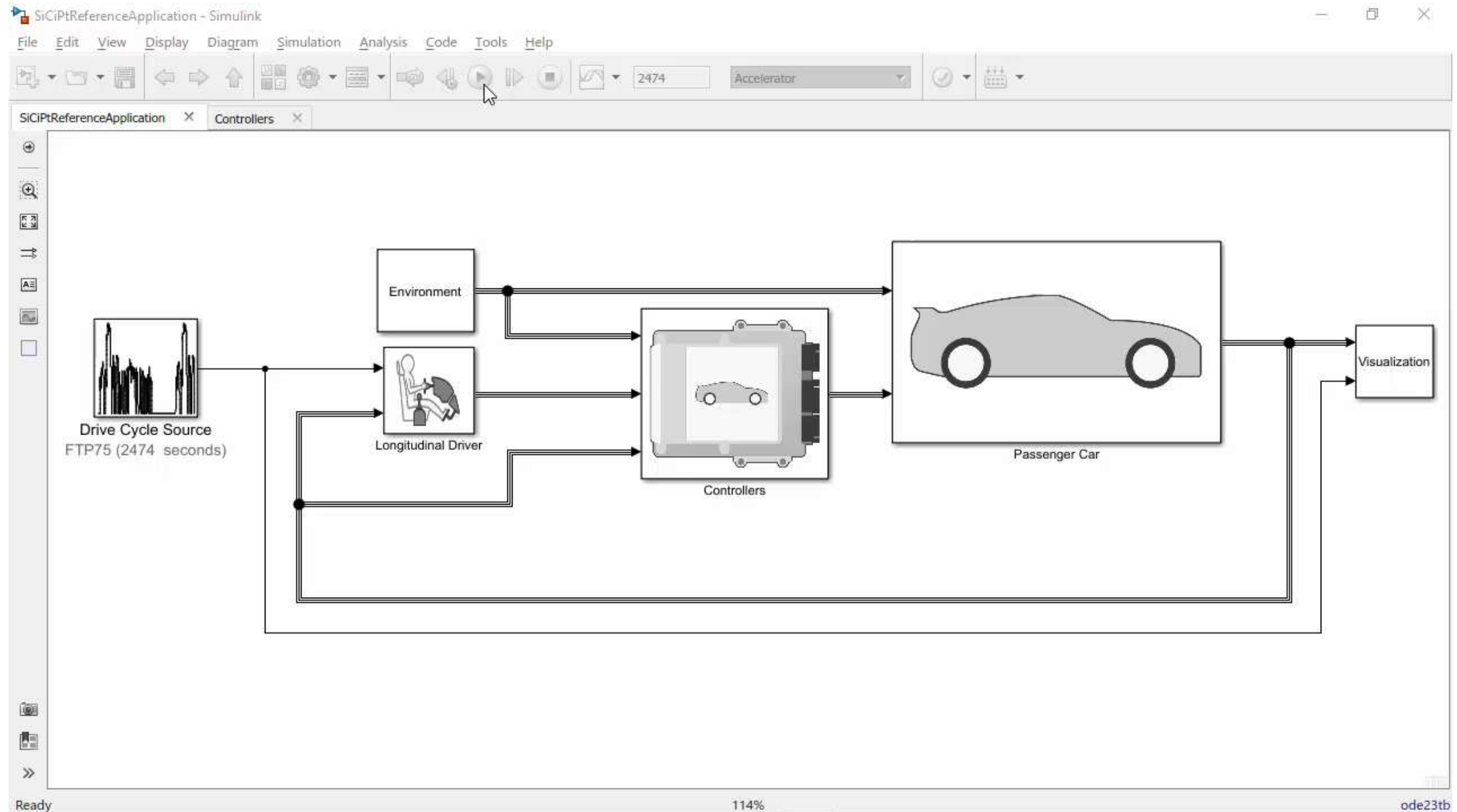
Prasanna Deshpande



Challenges for the Powertrain Engineering Teams

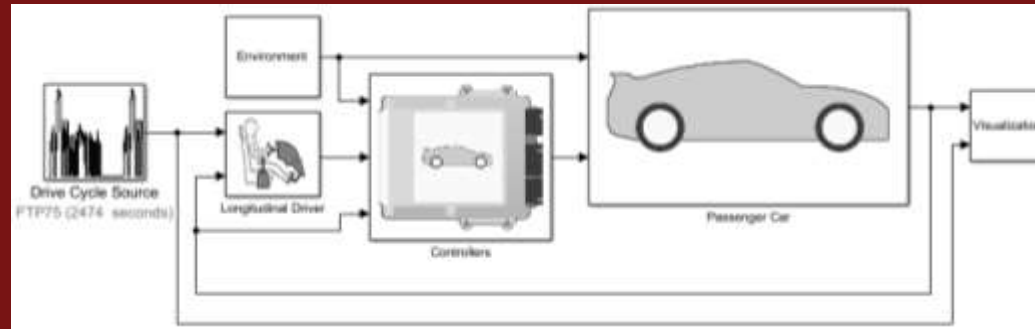
- How to design and test vehicle powertrain in a single environment?
- How to perform powertrain matching, fuel economy, performance, and emission simulations?
- How to design and verify the controller at the vehicle system level?

What Does the Solution Look Like?

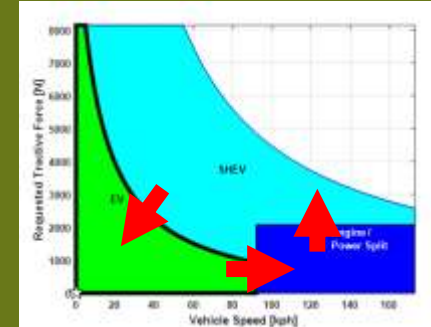
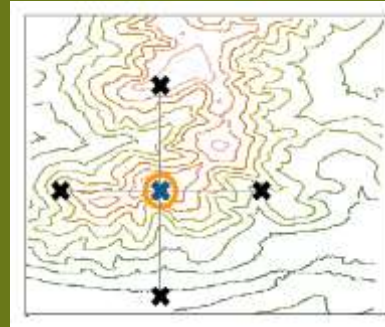


Agenda

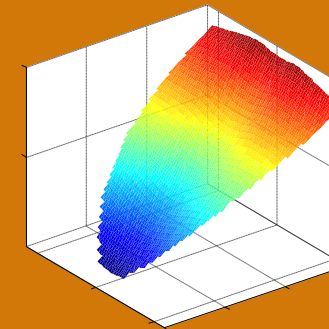
Create



Optimize

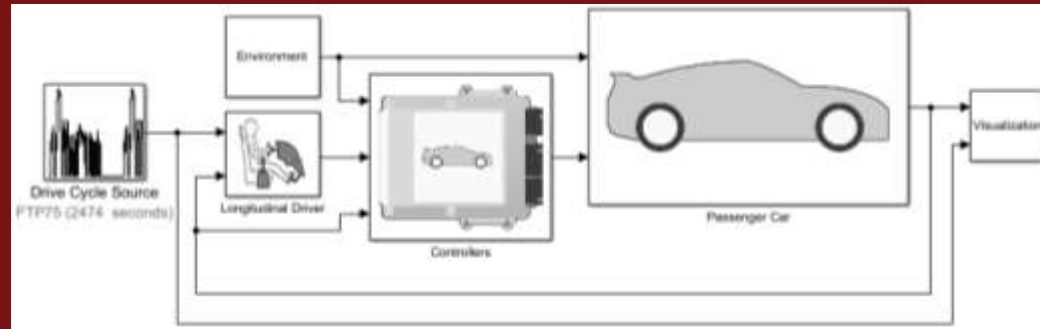


Verify

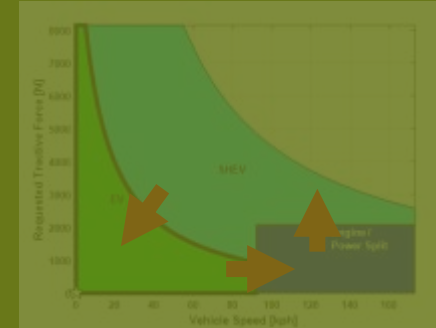


Agenda

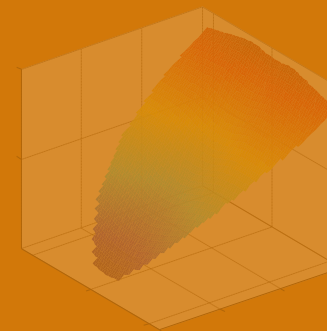
Create



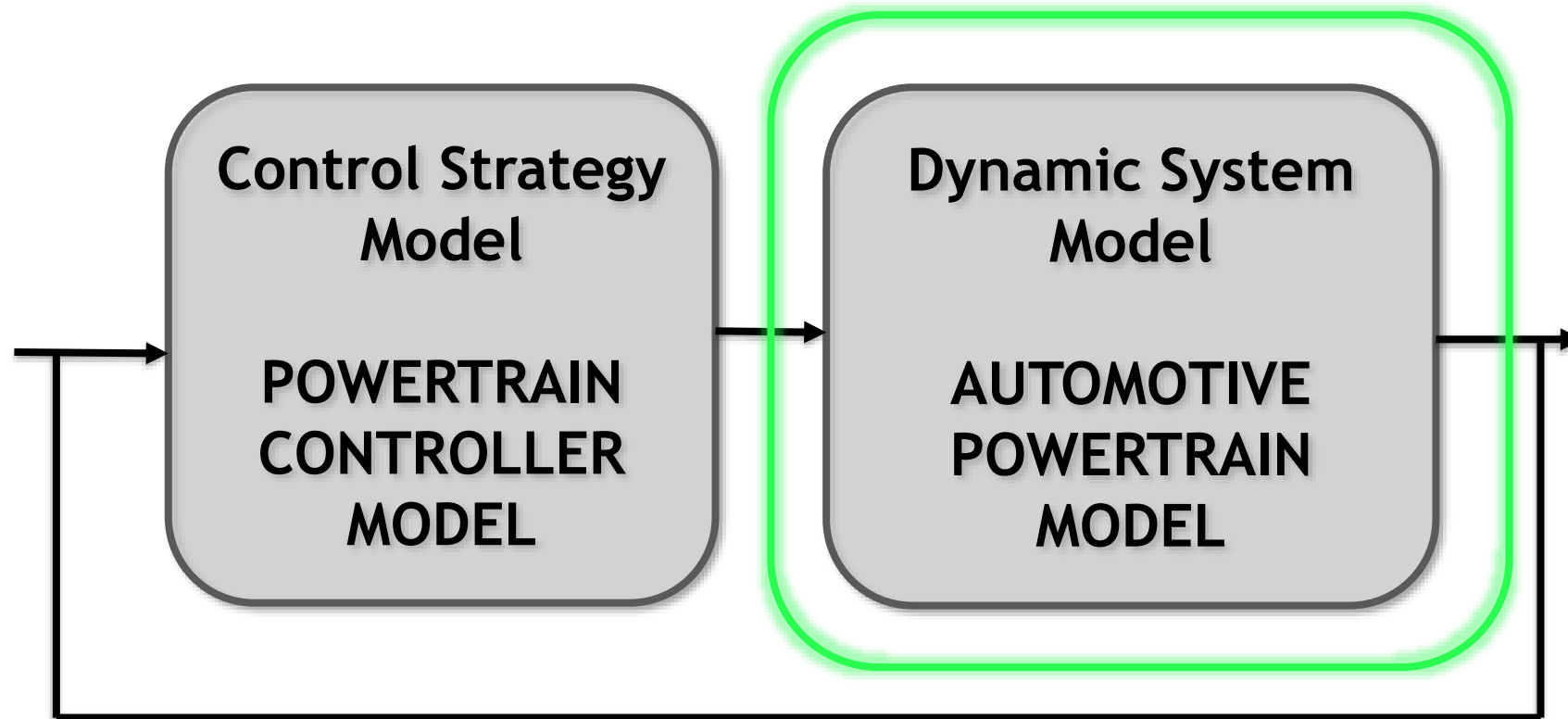
Optimize



Verify

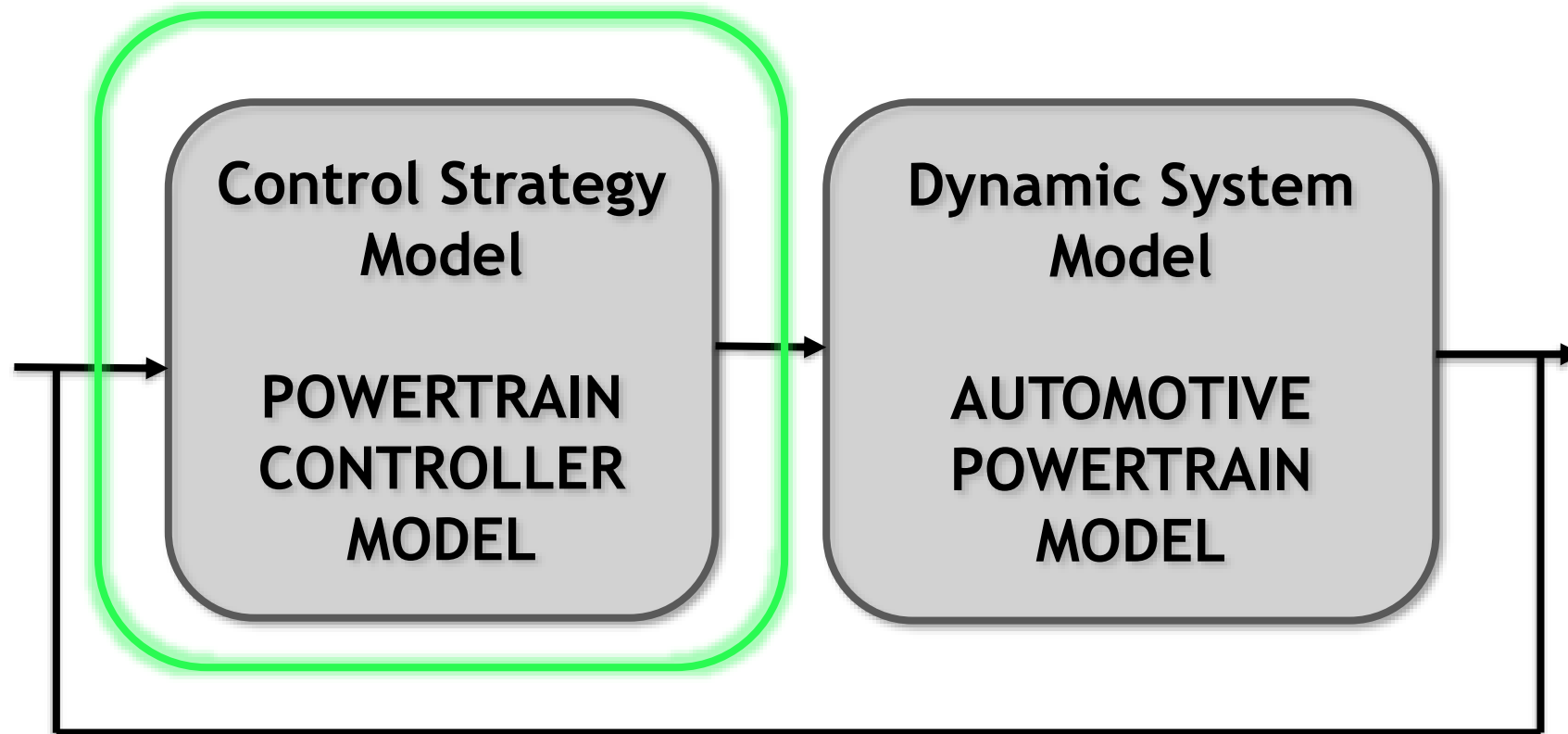


Structure of a System Level Simulation Model





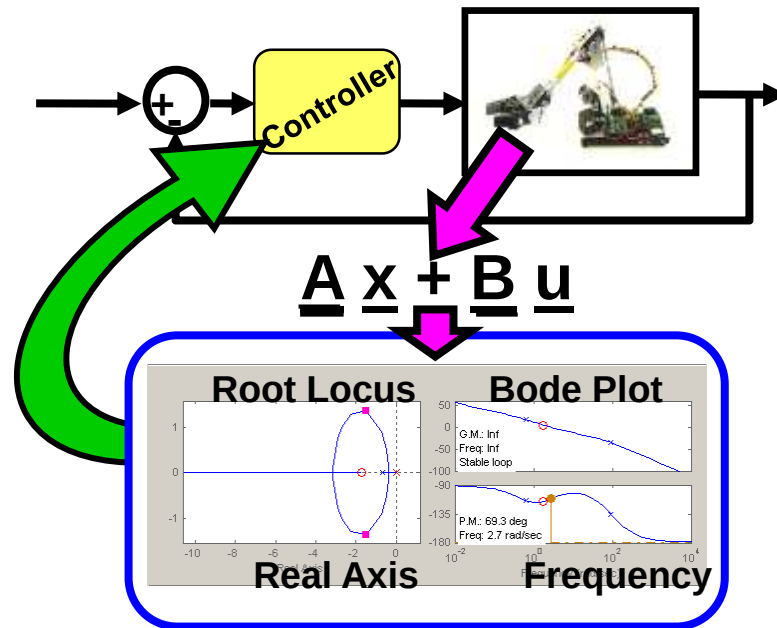
Structure of a System Level Simulation Model



Control System Design in Simulink

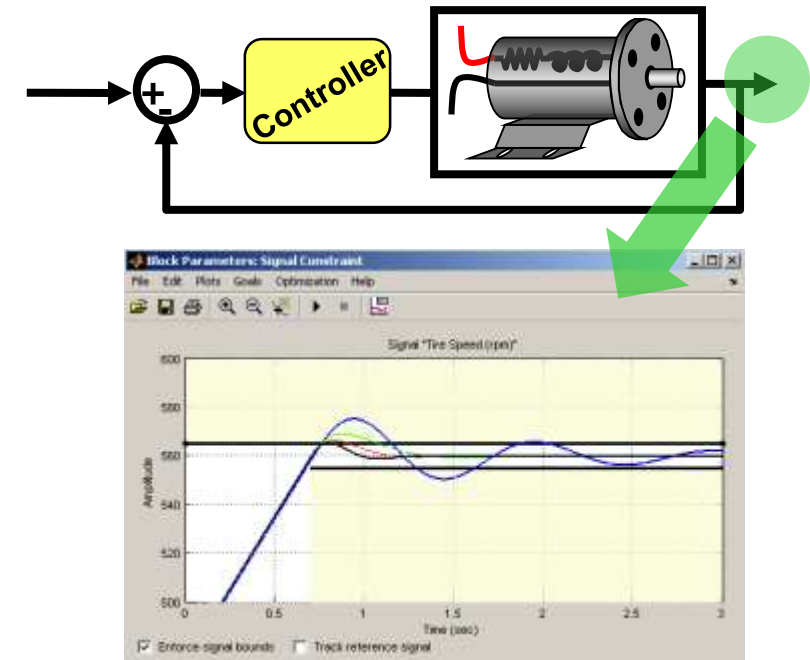
Linear Control Theory

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

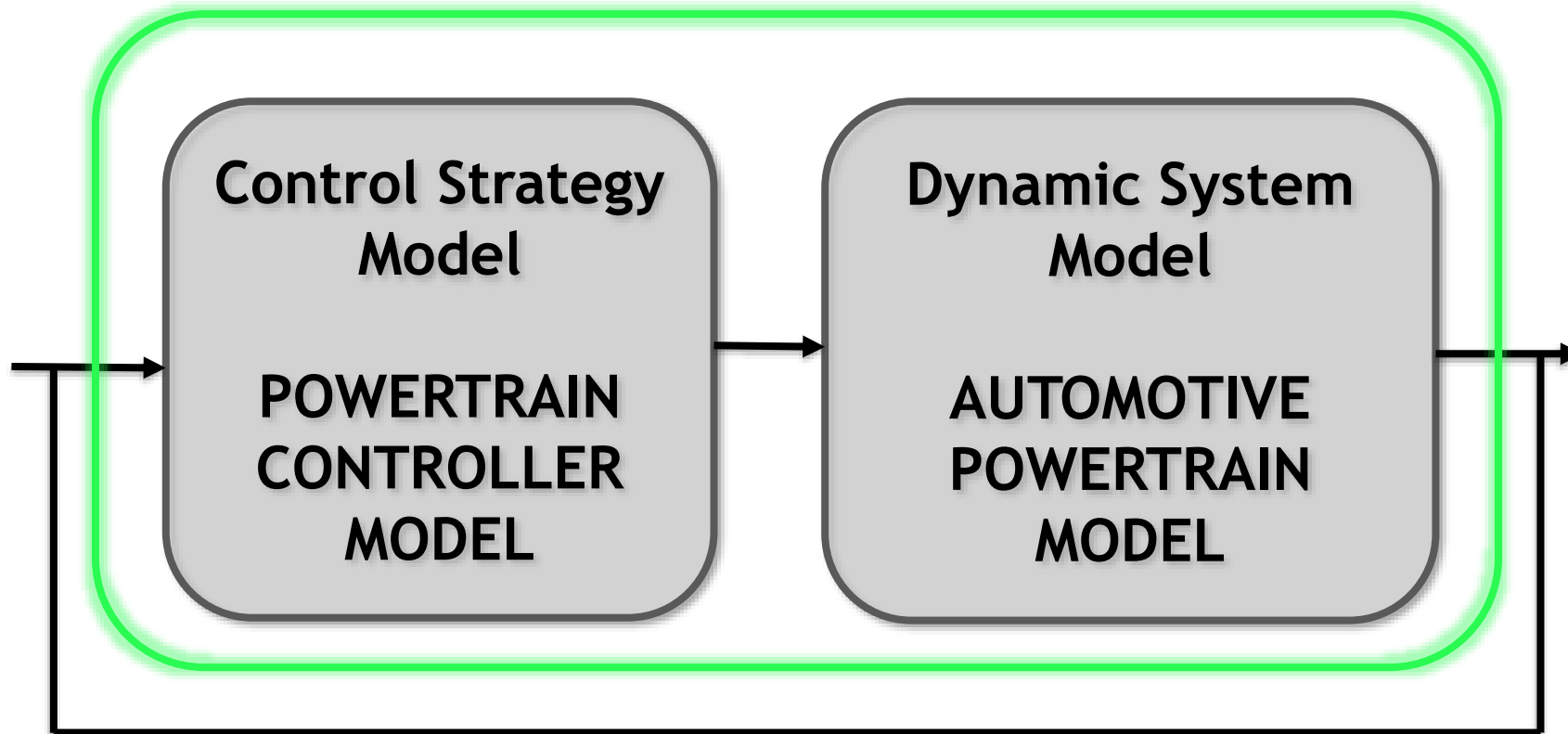


Specify System Response

- 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

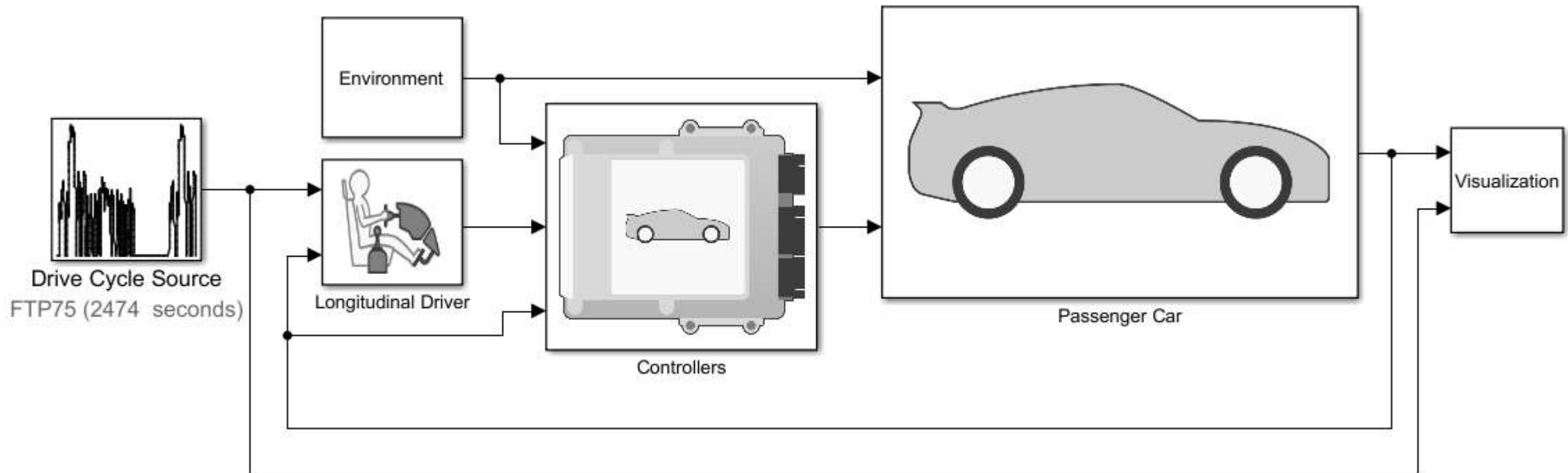
MathWorks' Response

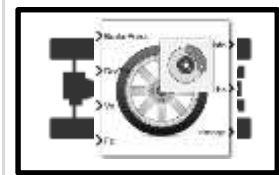
Lower the barrier to entry

- 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

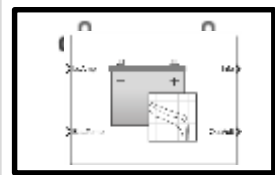
Powertrain Blockset

- New product: R2016b+ web release (October 2016)
- Goal: Provide pre-built, configurable and accurate models for real-time needs

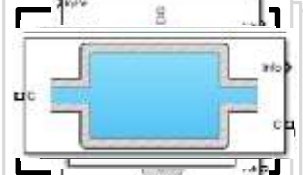




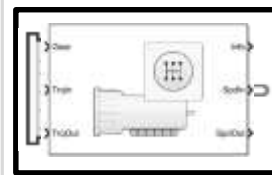
Drivetrain



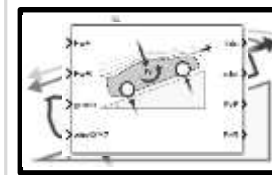
Energy Storage
and Auxiliary Drive



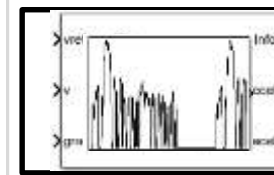
Propulsion



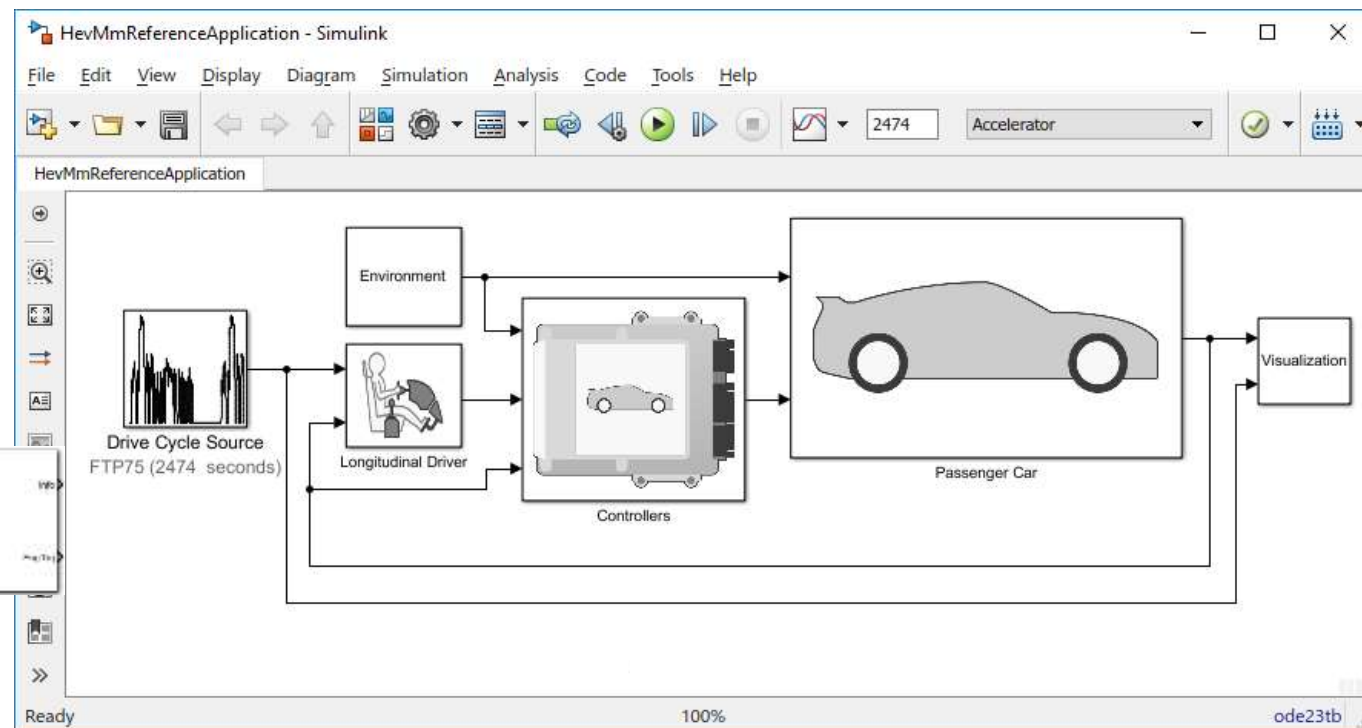
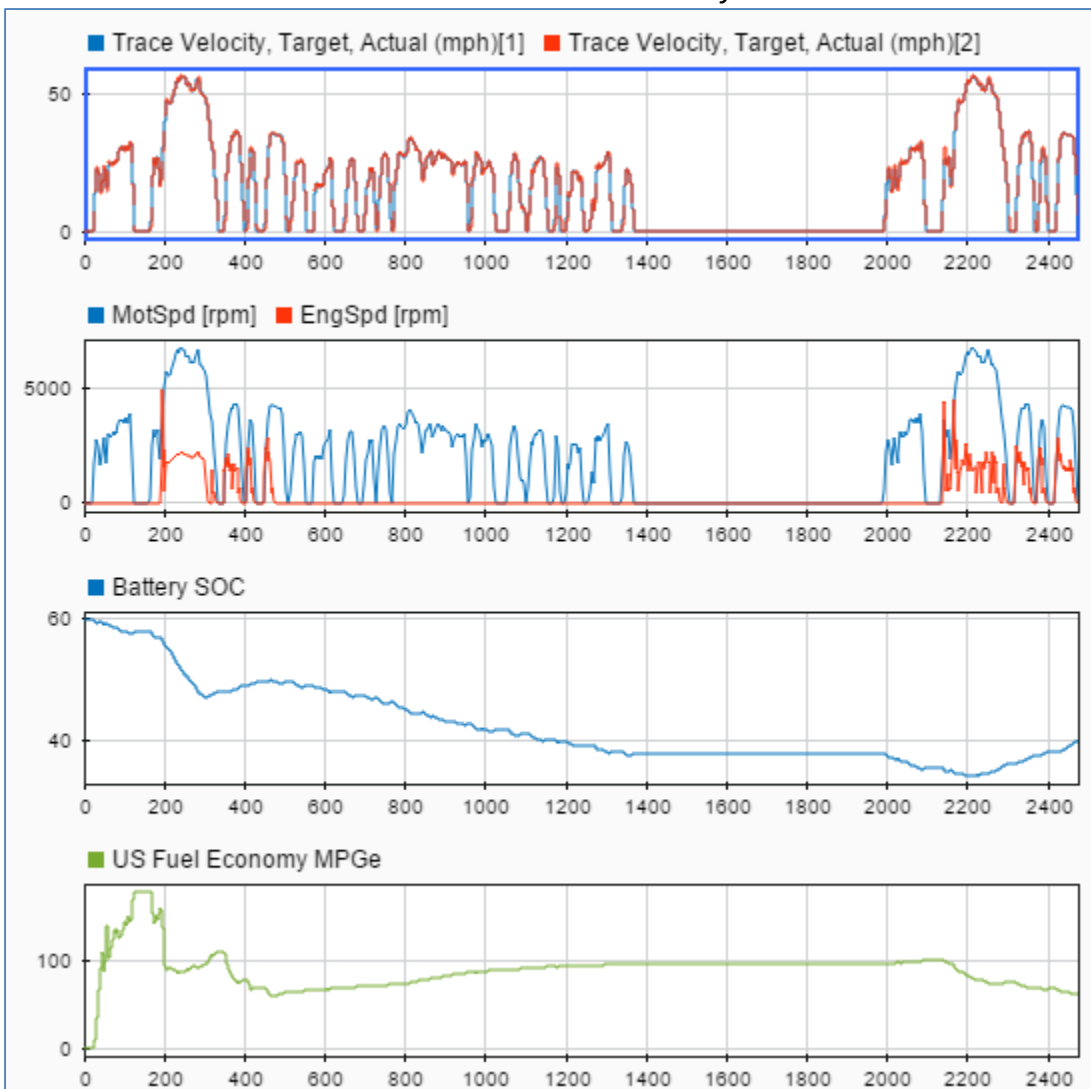
Transmission



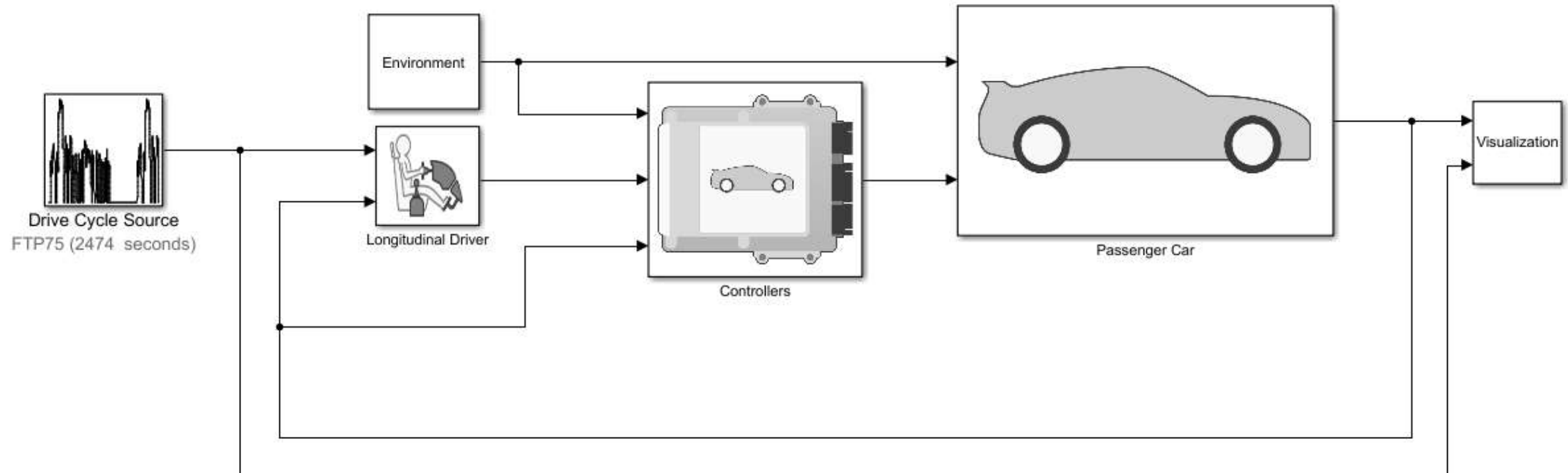
Vehicle Dynamics



Vehicle Scenario Builder

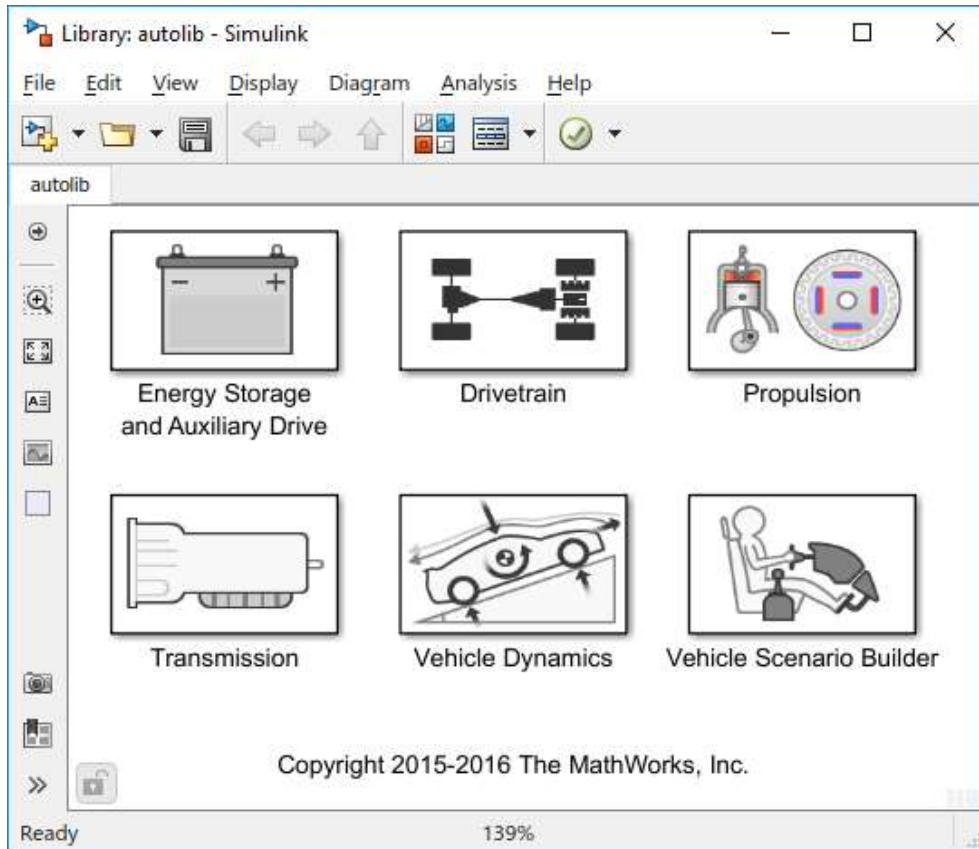


Demo – HEV system level model

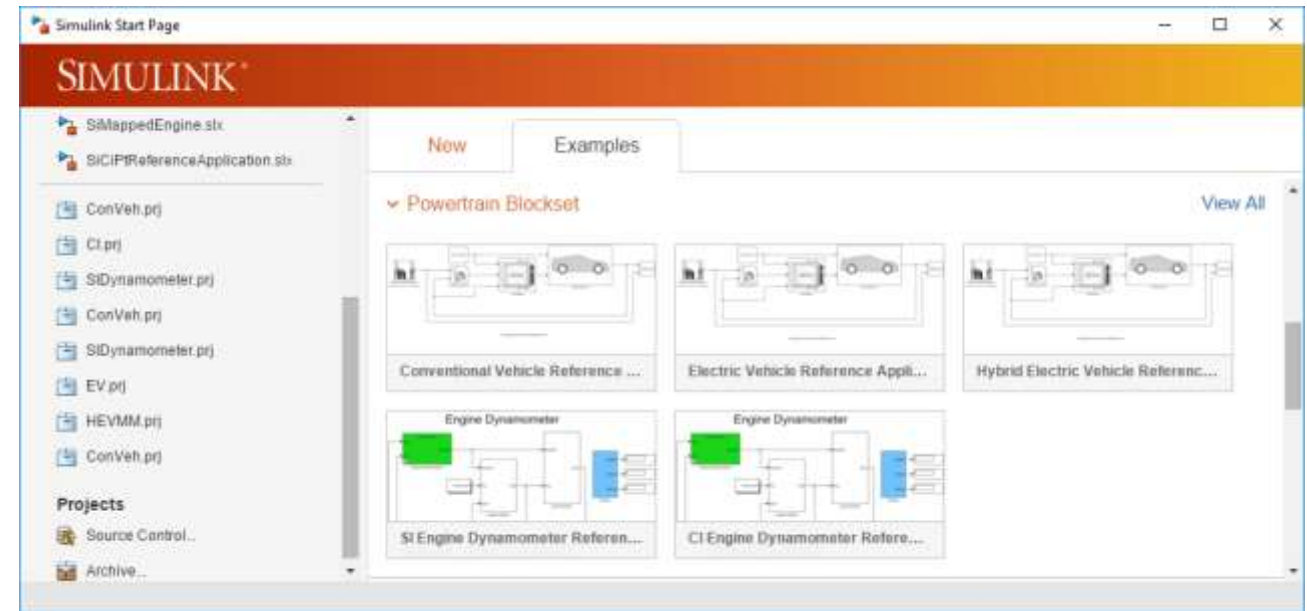


Powertrain Blockset

Library of blocks

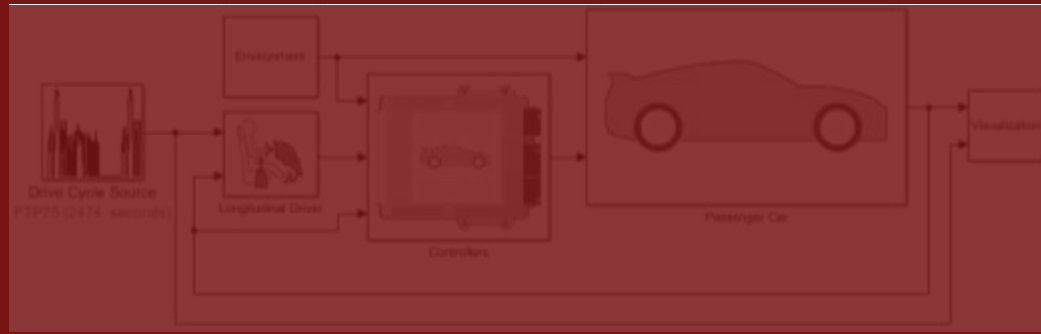


Pre-built reference applications

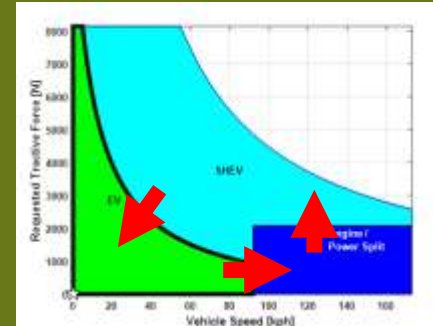
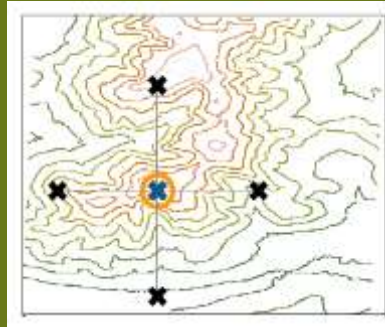


Agenda

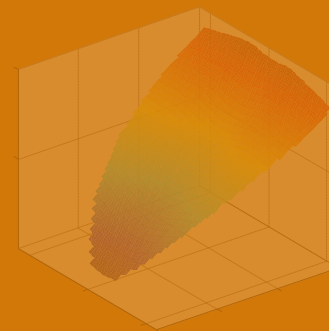
Create



Optimize



Verify



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?

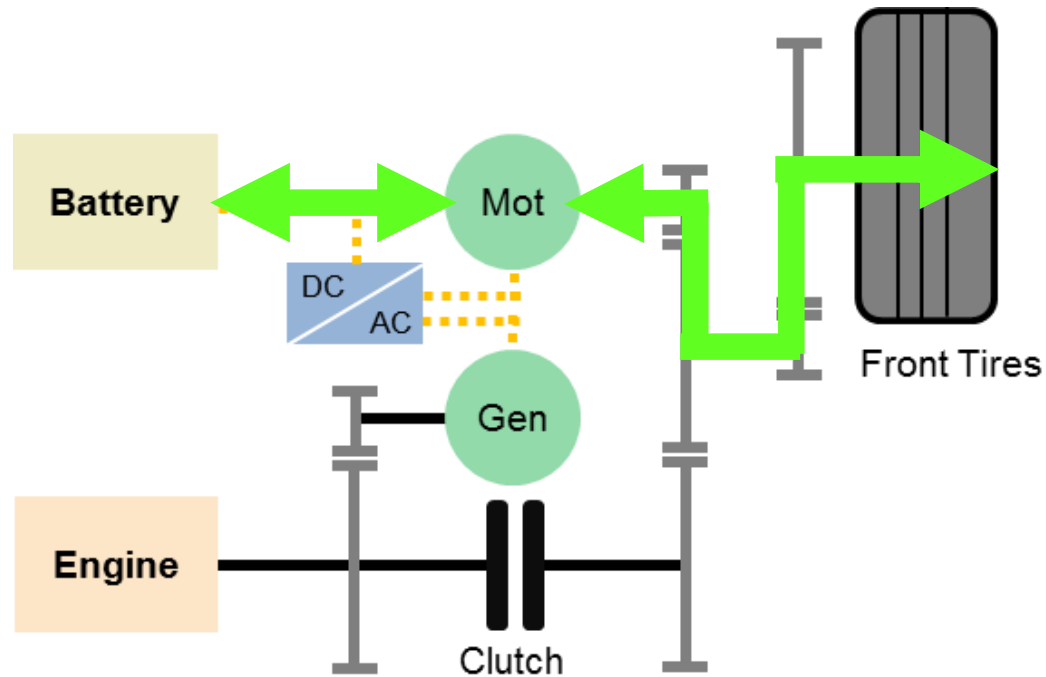
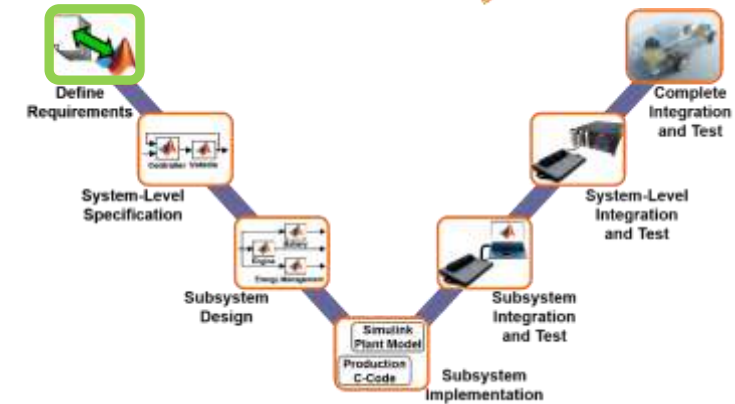
Multi-Mode HEV Review

SAE International

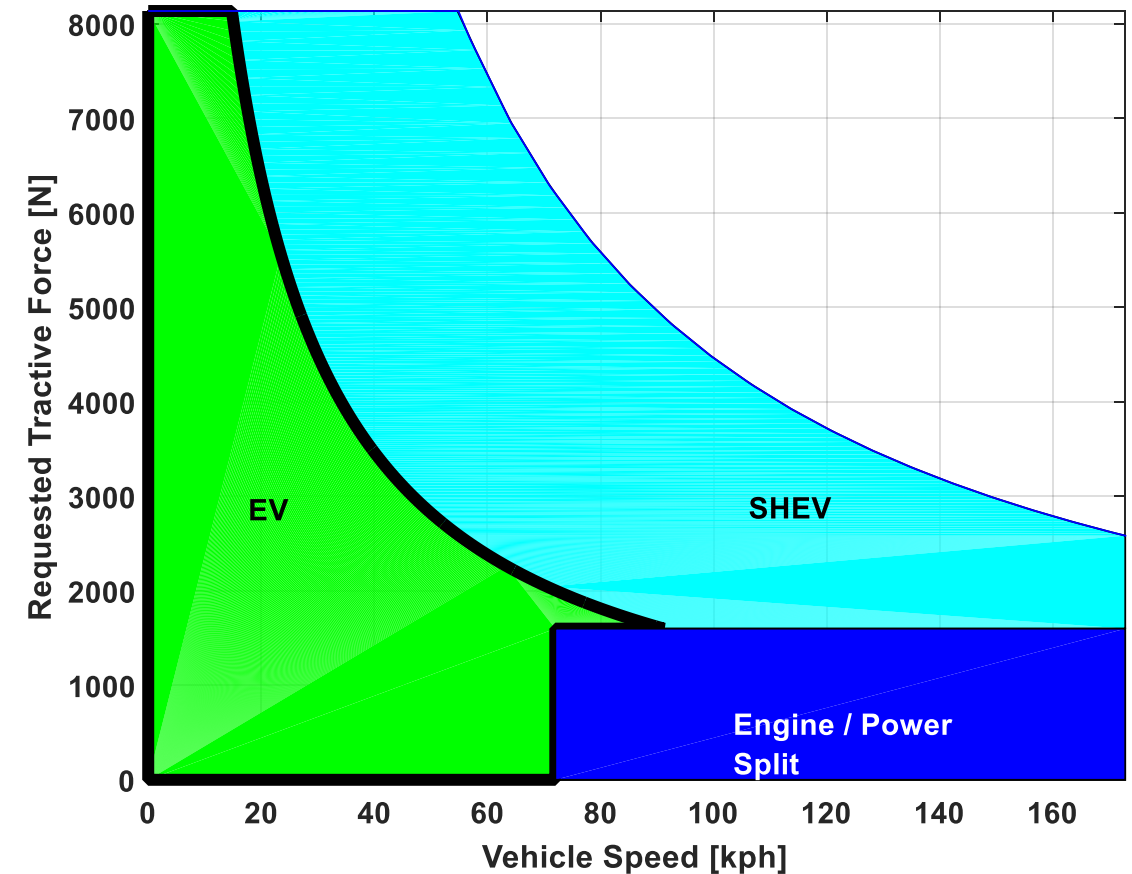
Development of a New Two-Motor Plug-In Hybrid System

Naritomo Higuchi, Yoshihiro Sunaga, Masashi Tanaka and Hiroo Shimada
Honda R&D Co., Ltd.

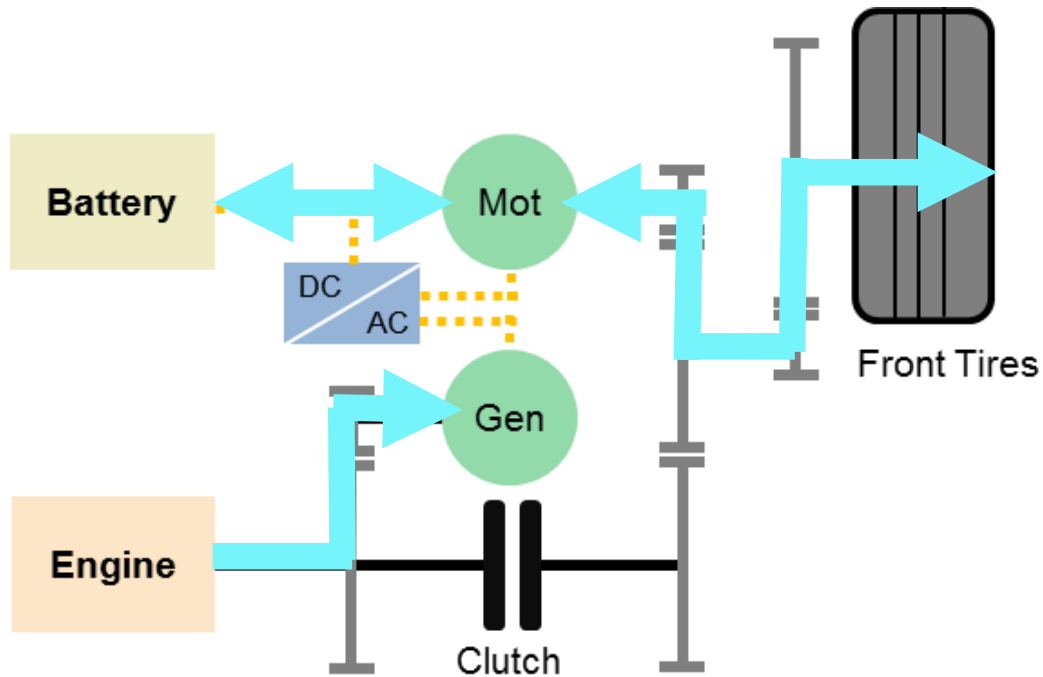
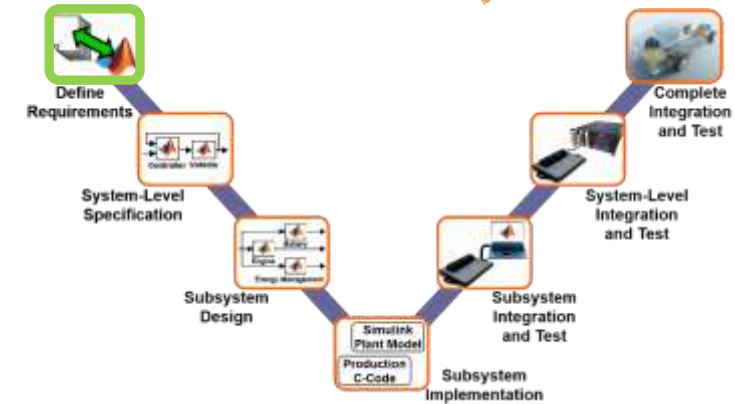
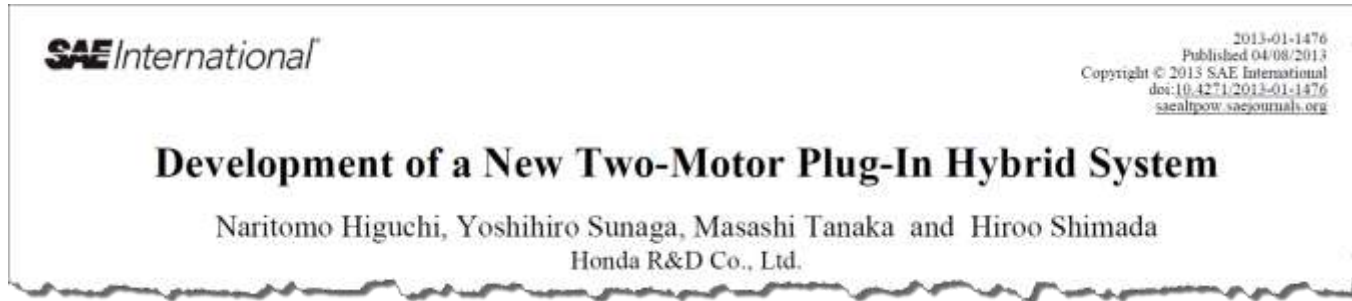
2013-01-1476
Published 04/08/2013
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doi:10.4271/2013-01-1476
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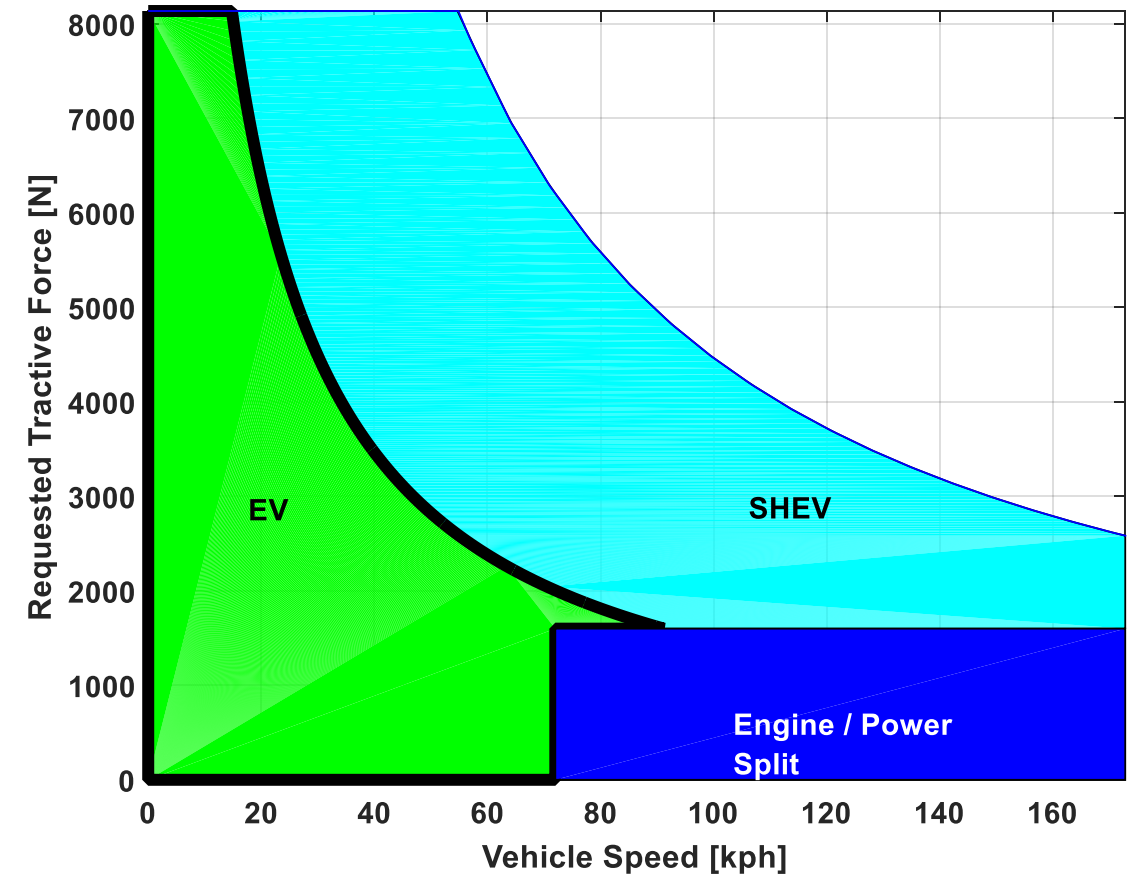
EV Mode



Multi-Mode HEV Review



SHEV Mode



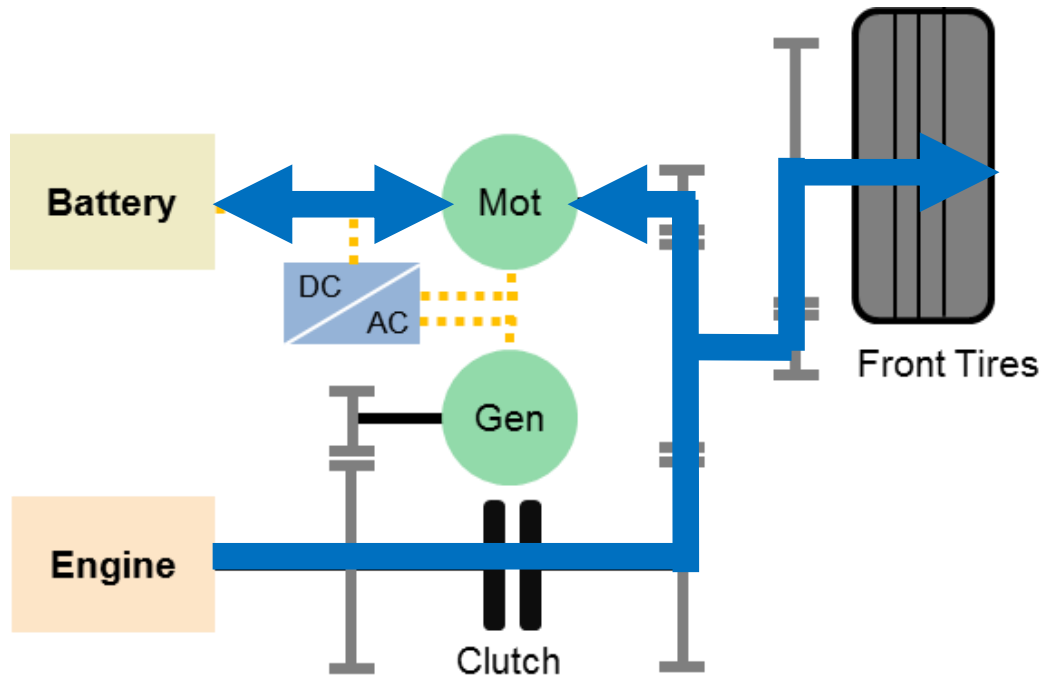
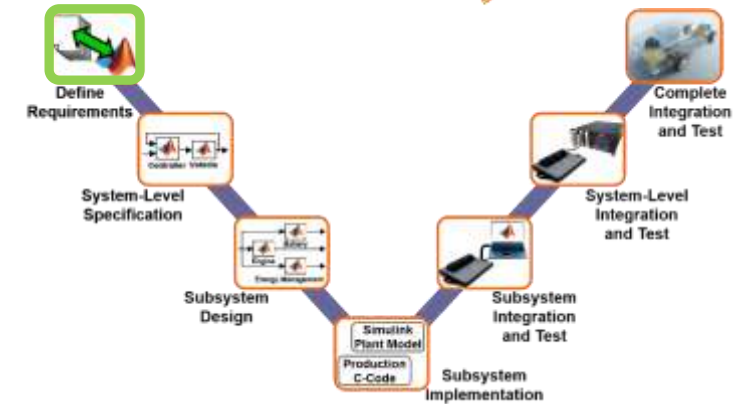
Multi-Mode HEV Review

SAE International

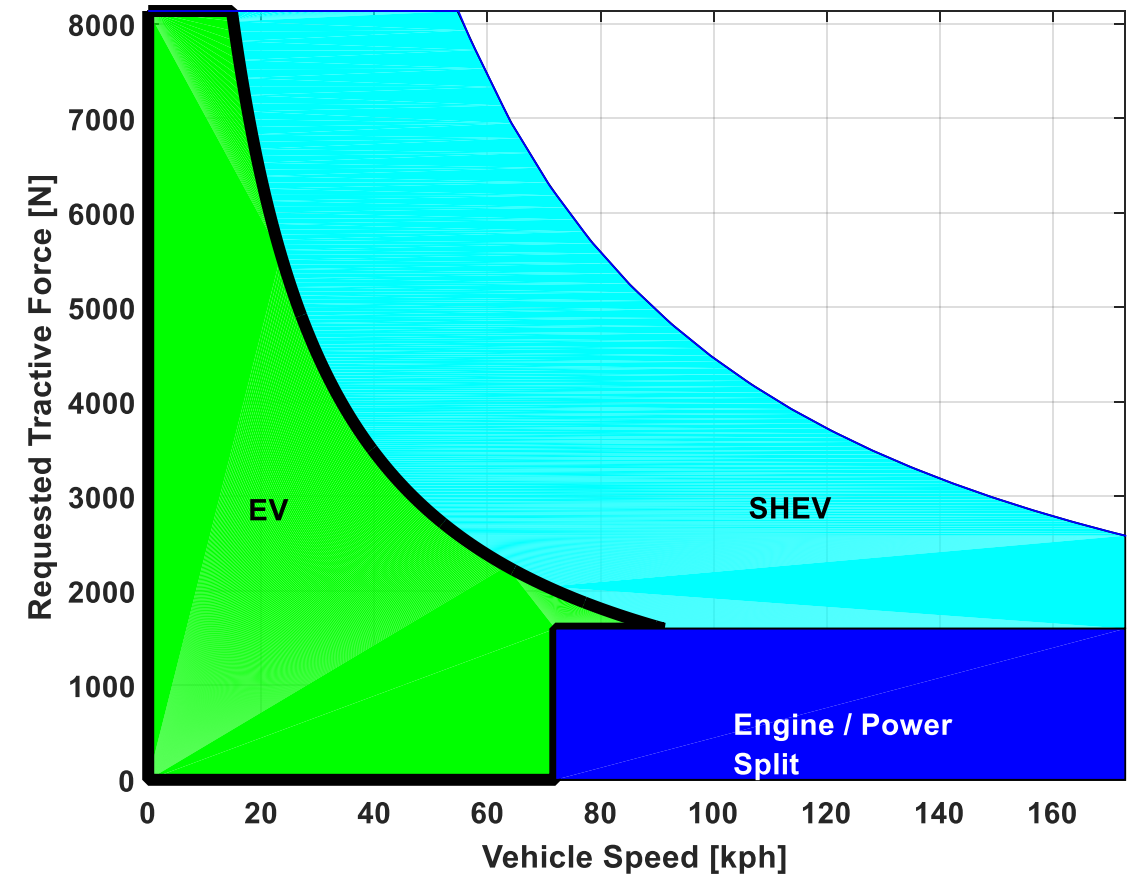
2013-01-1476
Published 04/08/2013
Copyright © 2013 SAE International
doi:10.4271/2013-01-1476
saealprow.saejournals.org

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

Naritomo Higuchi, Yoshihiro Sunaga, Masashi Tanaka and Hiroo Shimada
Honda R&D Co., Ltd.



Engine Mode

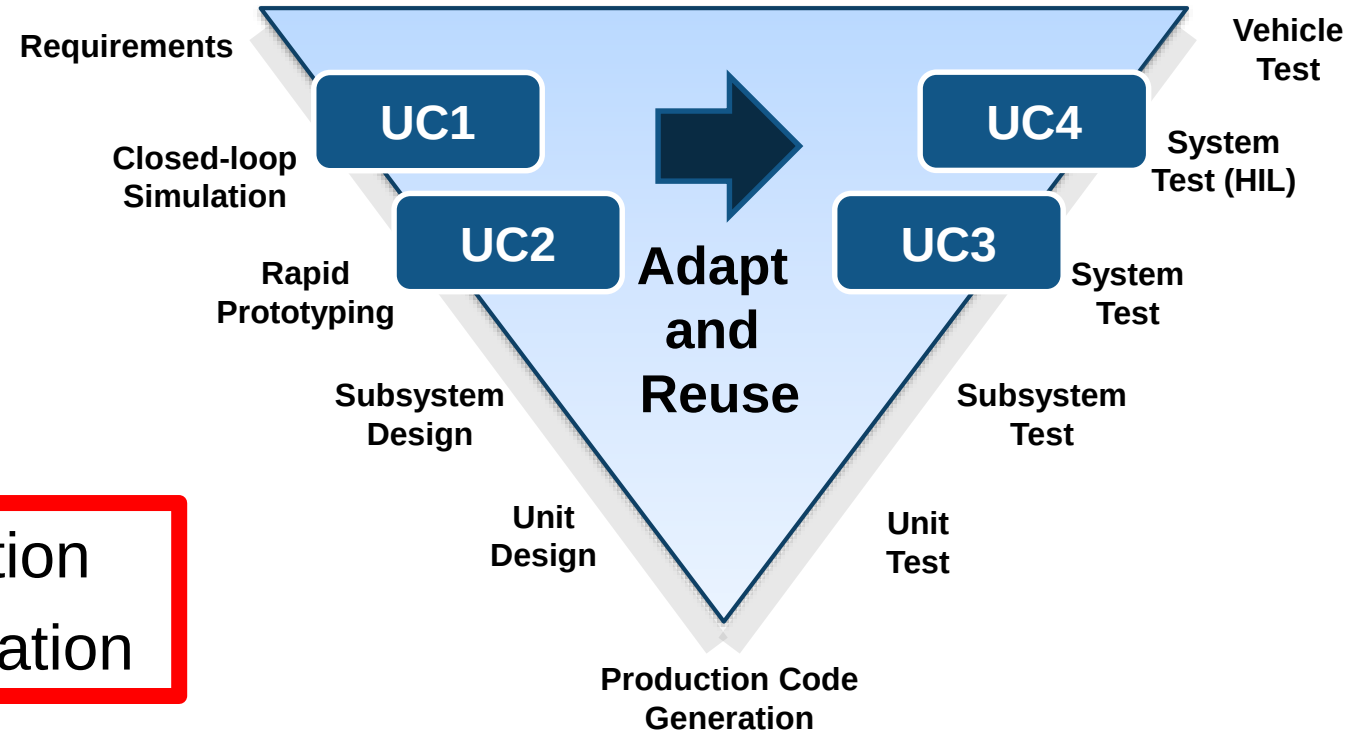


Powertrain Blockset:

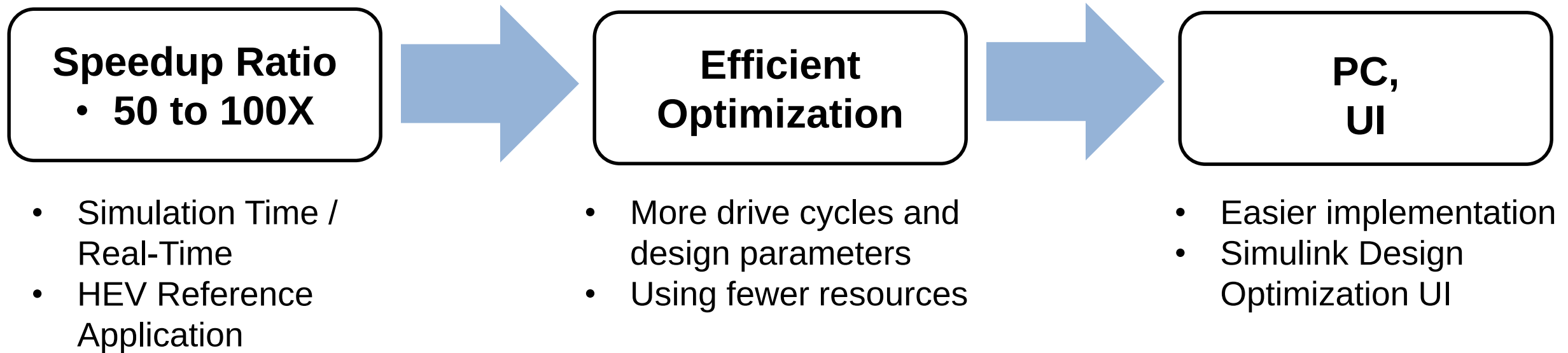
Four use cases. One framework.

- Use Cases:

1. System design and optimization
2. Controller parameter optimization
3. Software integration test
4. Software-hardware integration test (HIL)

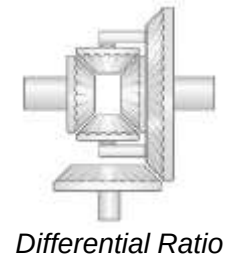
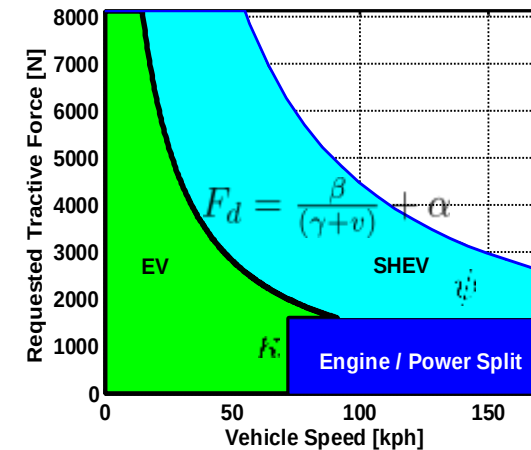
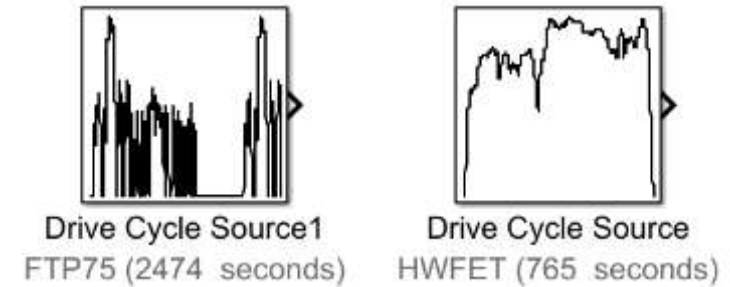


Powertrain Blockset Enables Accessible Optimization Capabilities



Design Optimization Problem Statement

- Maximize MPGe
 - FTP75 and HWFET
 - Weighted MPGe = $0.55(\text{FTP75}) + 0.45(\text{HWFET})$
- 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)



Lenovo ThinkPad T450s
Dual Core i7 2.60GHz
12 GB RAM

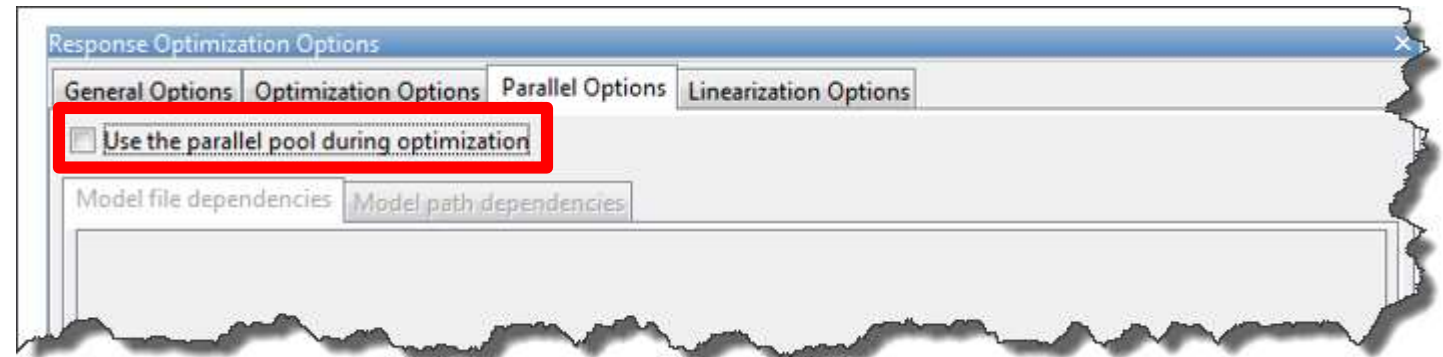
Simulink Design Optimization

- Speed Up Best practices

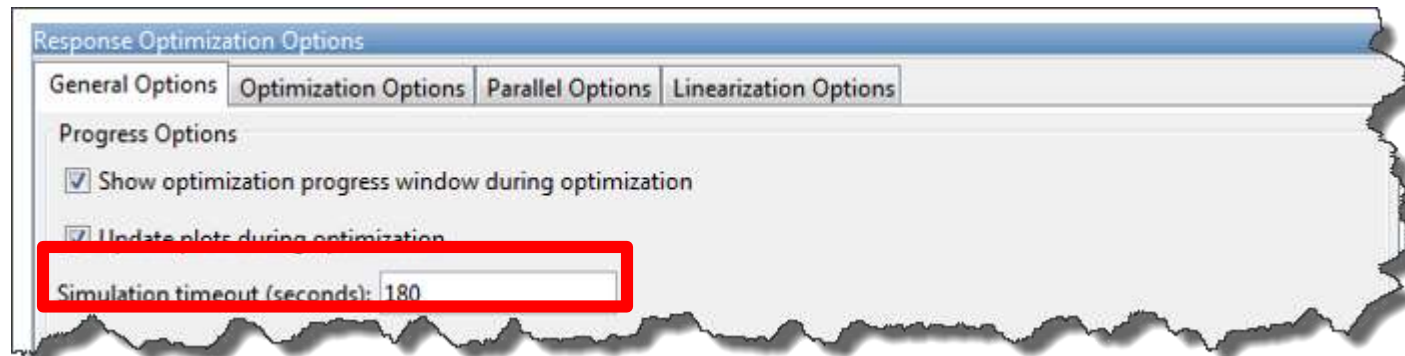
- Accelerator mode
- Fast Restart



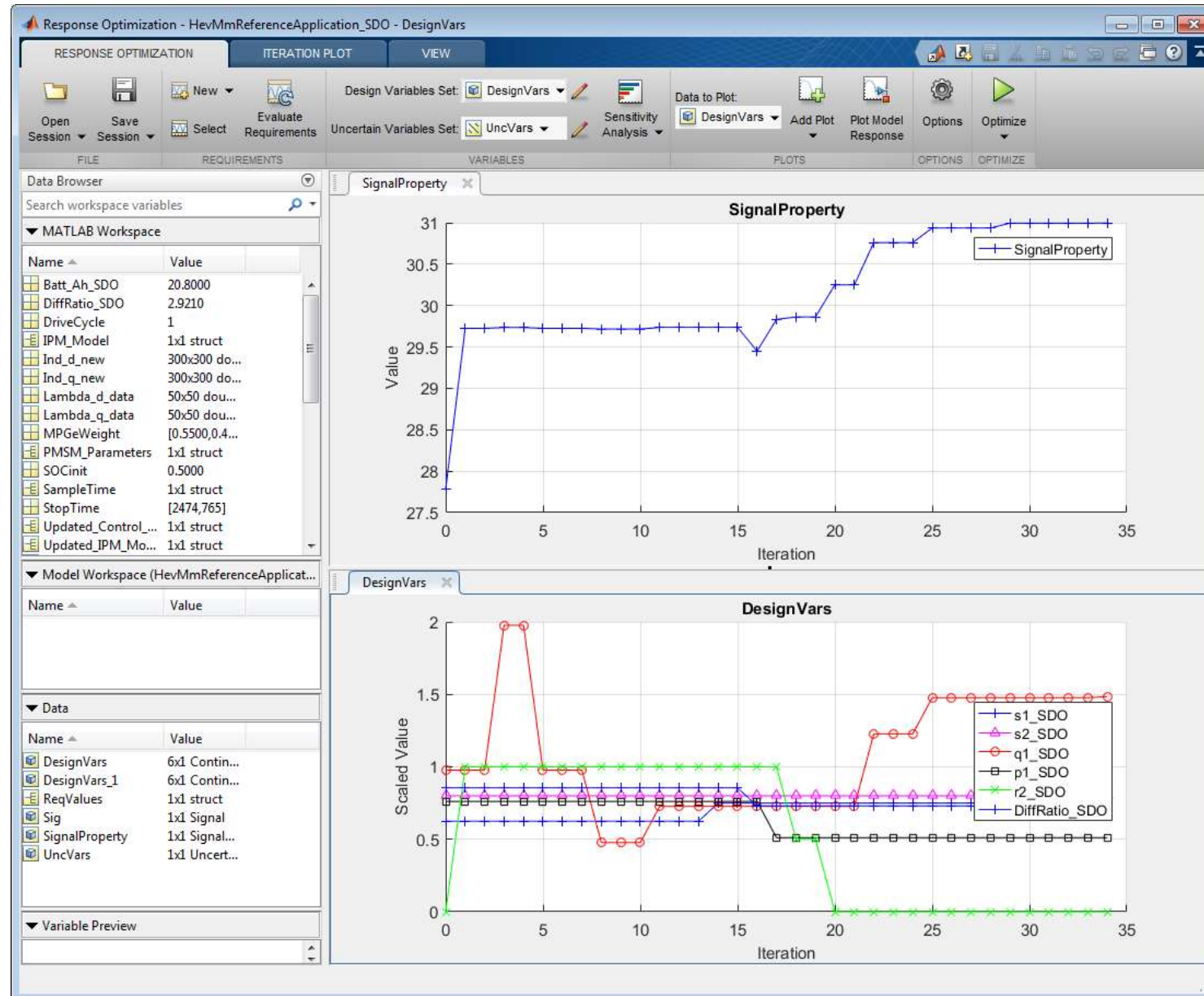
- Use Parallel Computing Toolbox



- Specify Simulation timeout

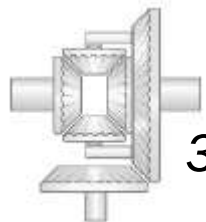
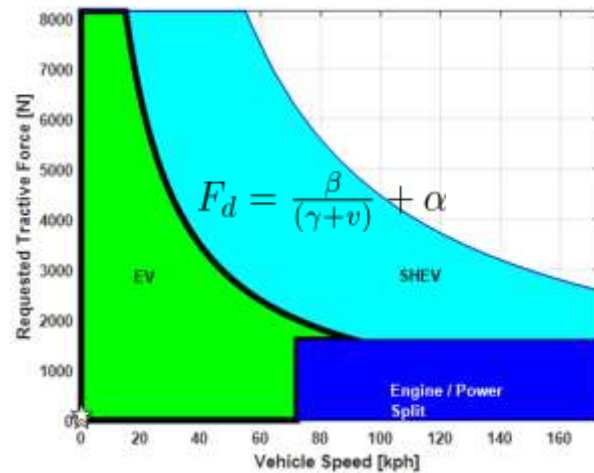


Optimization Results – Iteration Plot

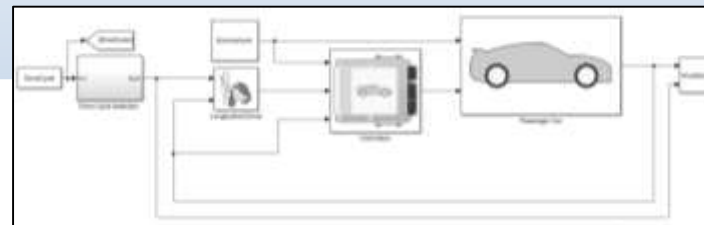
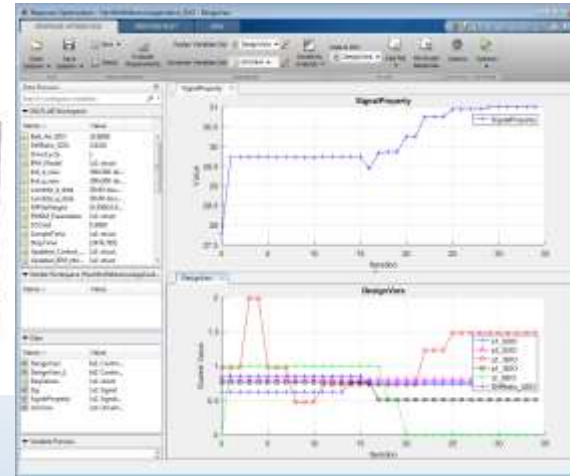


Optimization Results

Simulink Design Optimization → Response Optimization

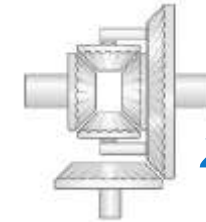
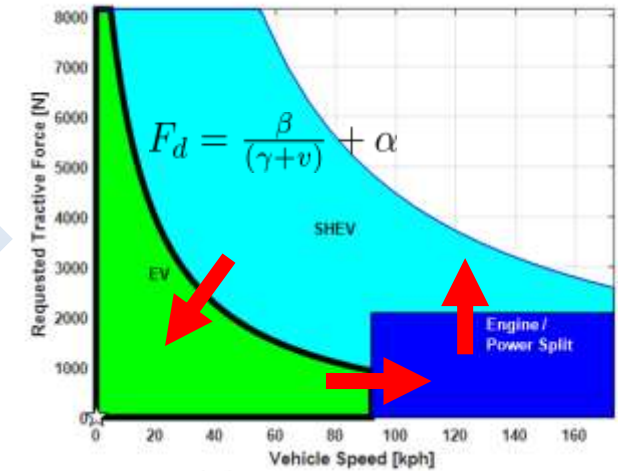


3.42:1



~ 12 Hours

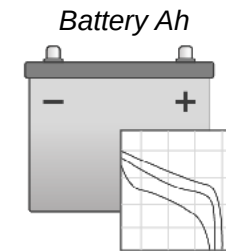
+ 2% MPGe



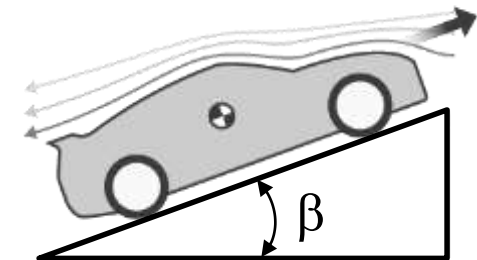
2.92:1

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

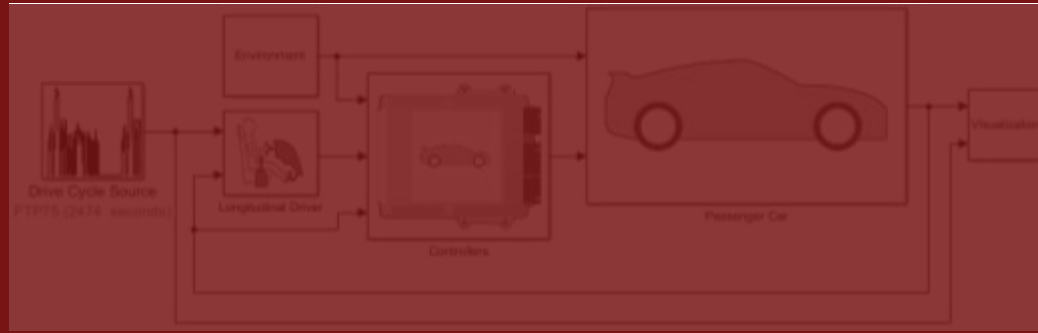


Series, # Parallel ?

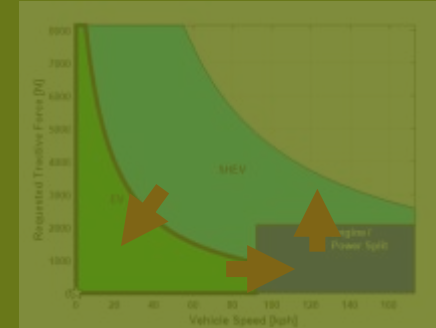


Agenda

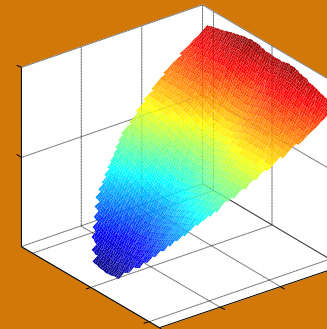
Create



Optimize



Verify

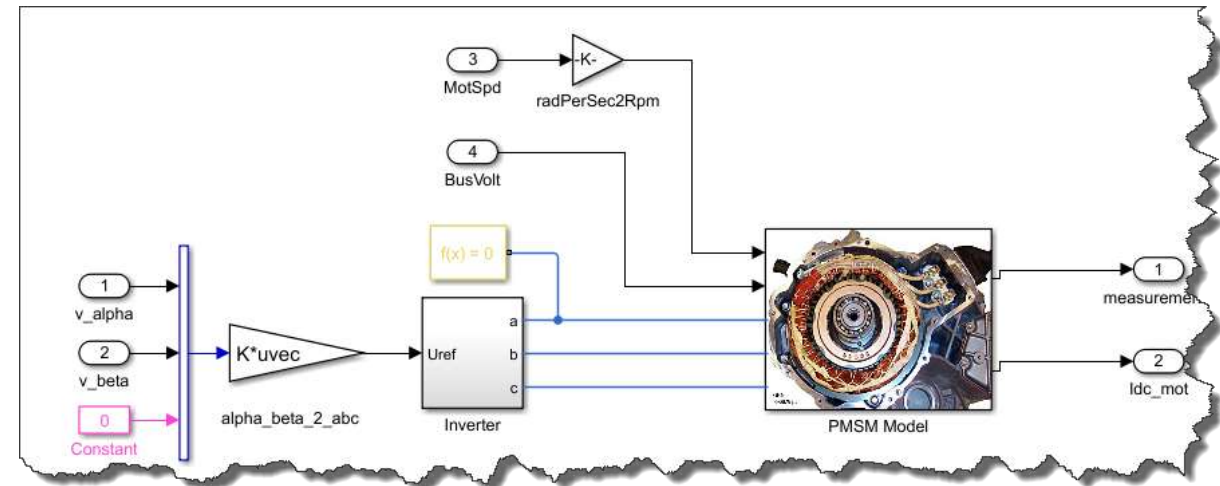
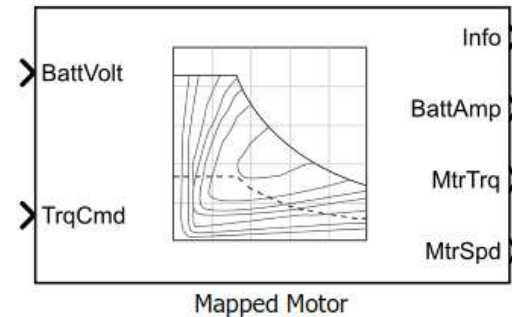
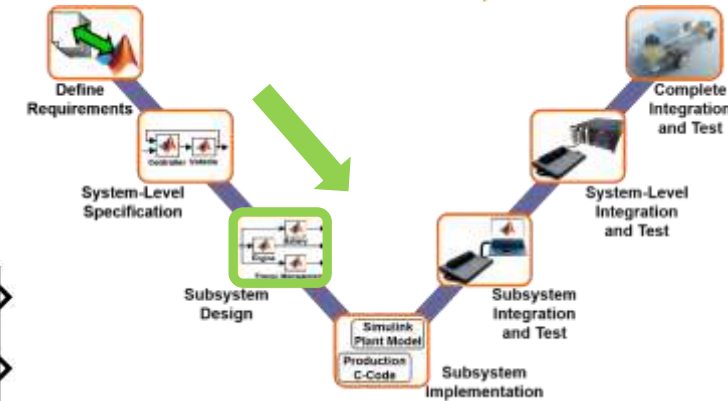


Challenges for the Automotive Controls Engineer

- 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

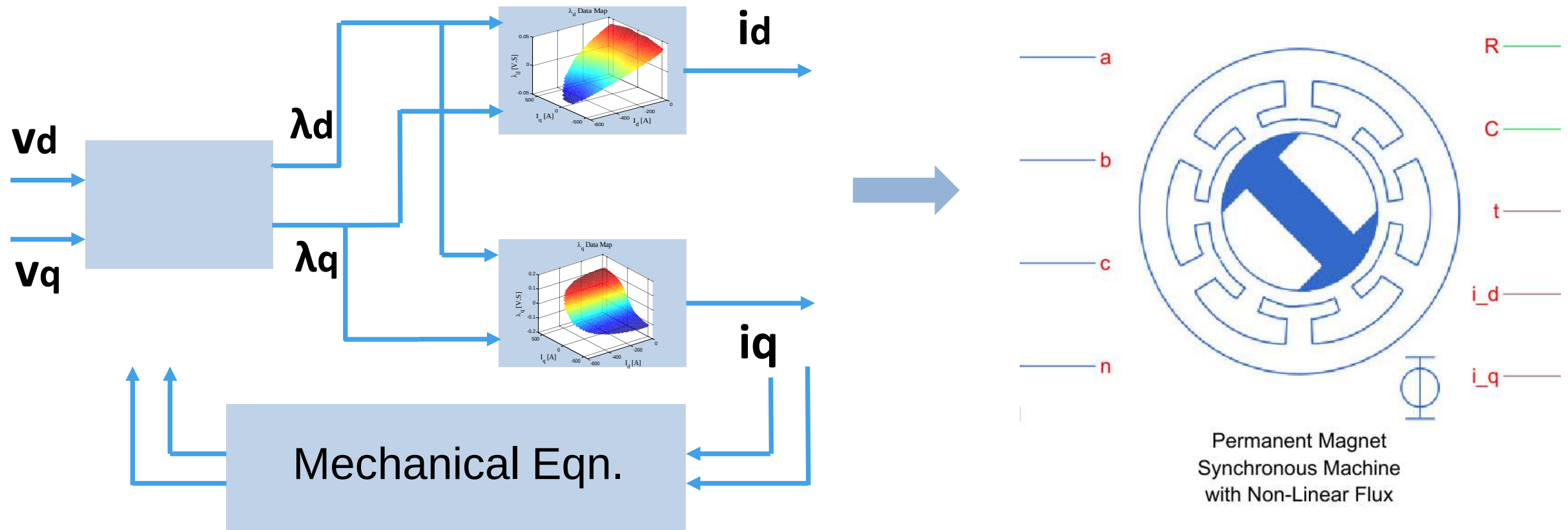
- **System Optimization**
 - Goal: Estimate fuel economy
 - Requirements: fast simulation speed, simple parameterization
 - Model choice: empirical model
- **Subsystem Control Design**
 - Goal: Study controller interactions
 - Requirements: higher accuracy, inclusion of effects like saturation
 - Model choice: nonlinear saturation



Detailed model = inverter controller + nonlinear motor model

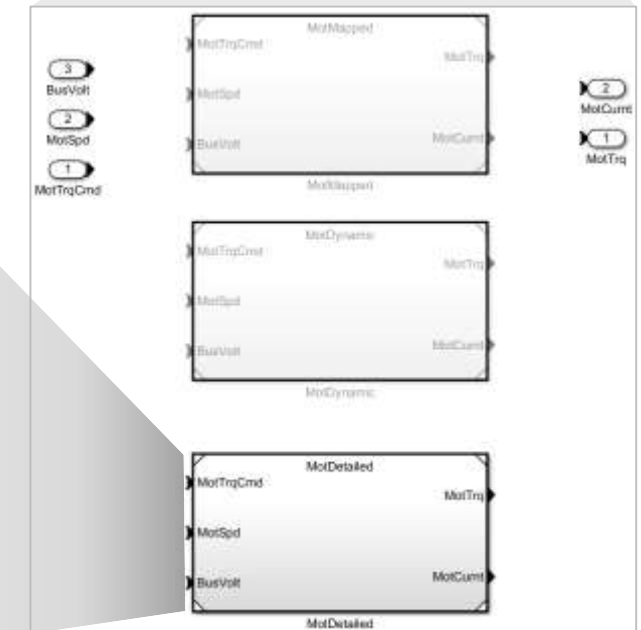
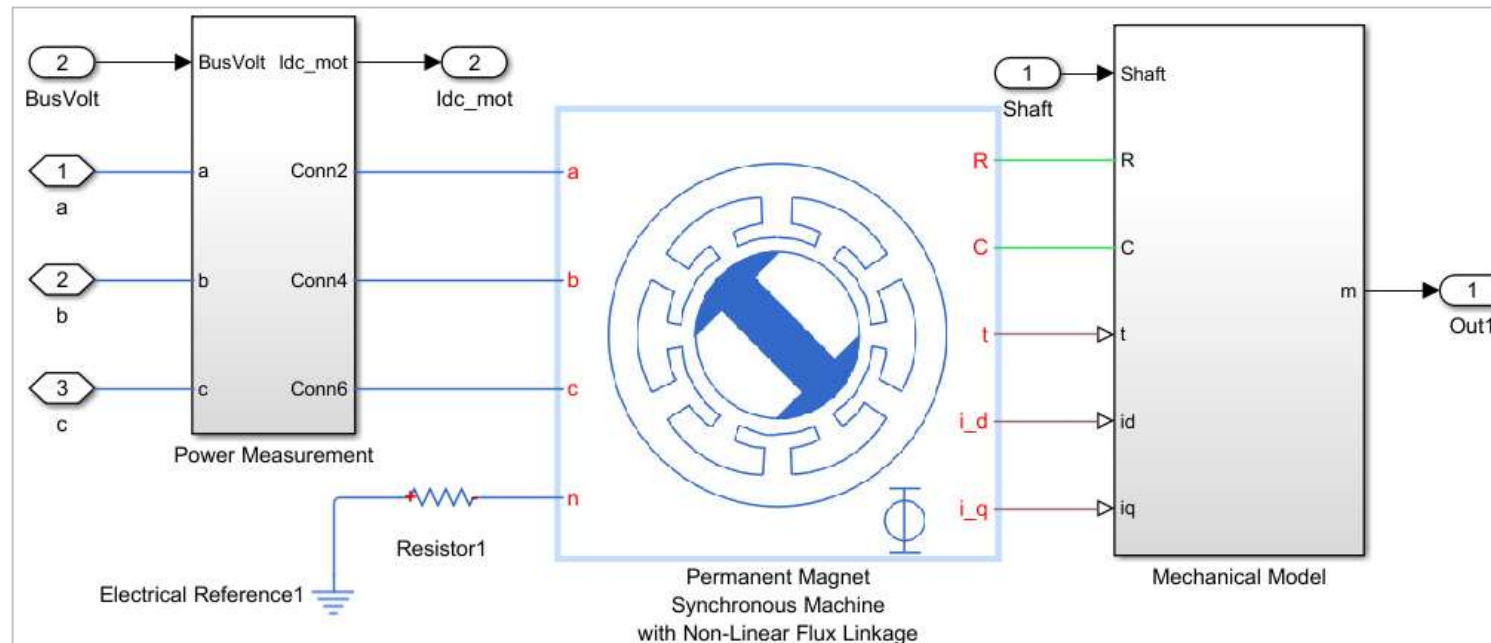
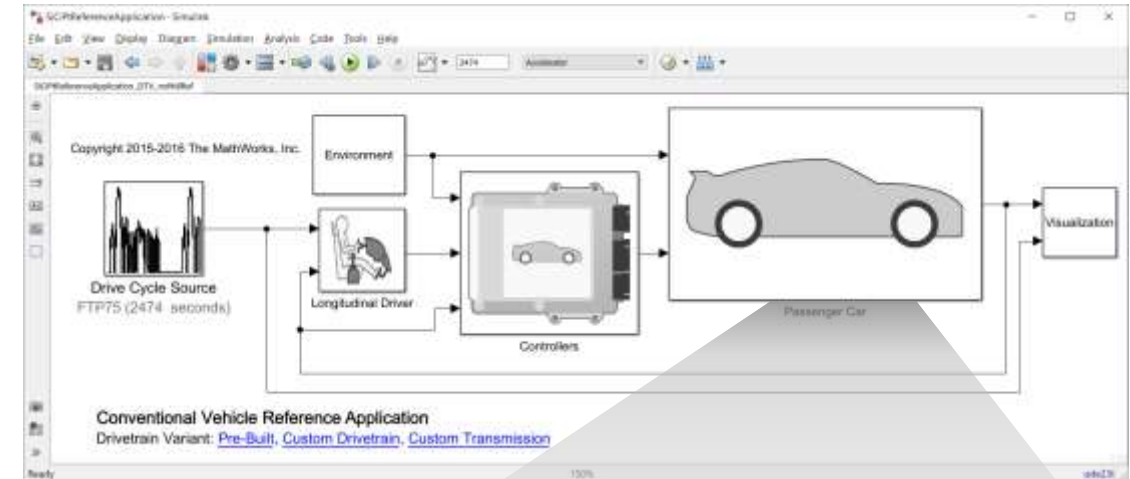
High Fidelity Detailed Motor Model in Simscape

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

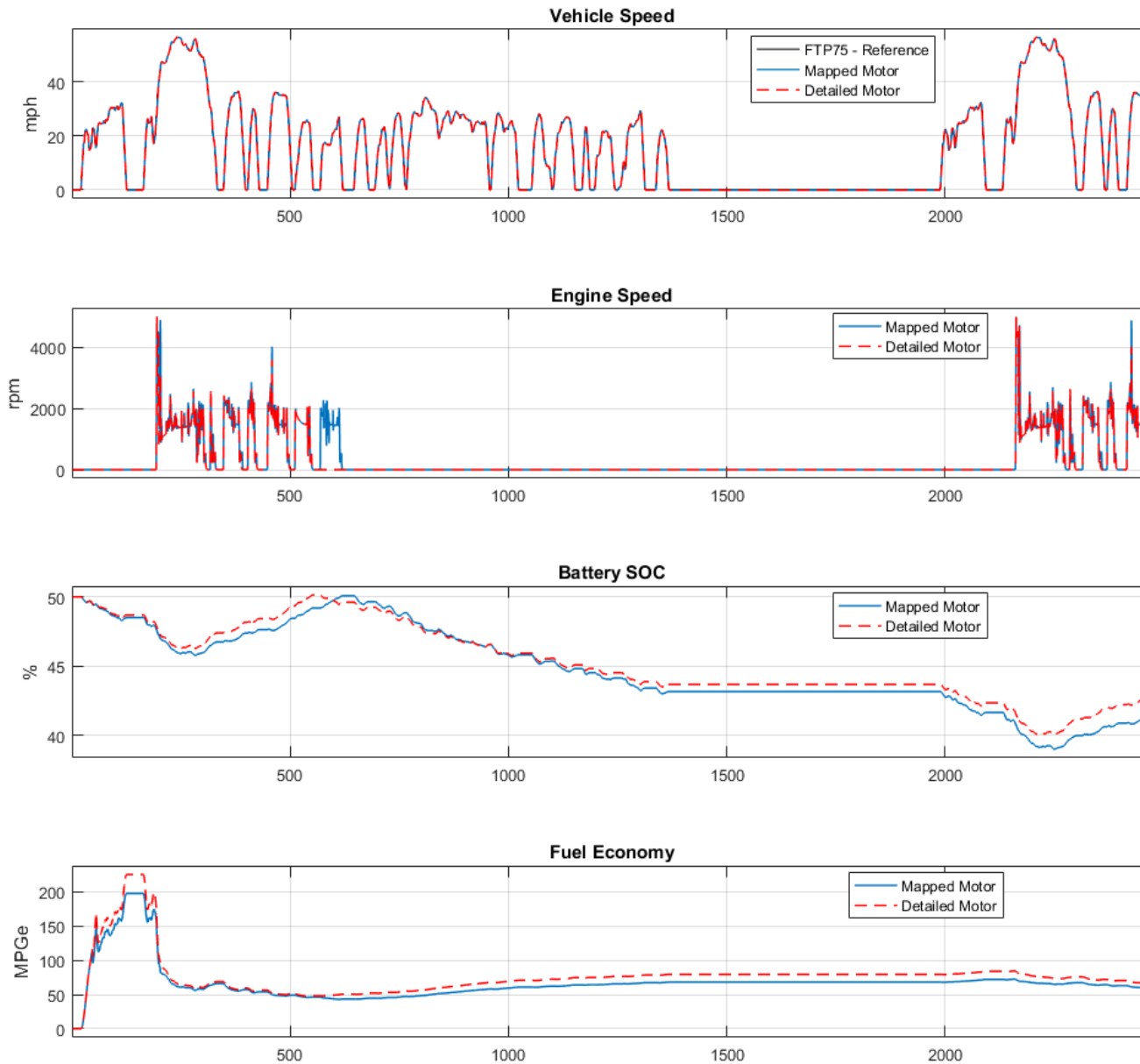


Including Detailed Subsystem Variants

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



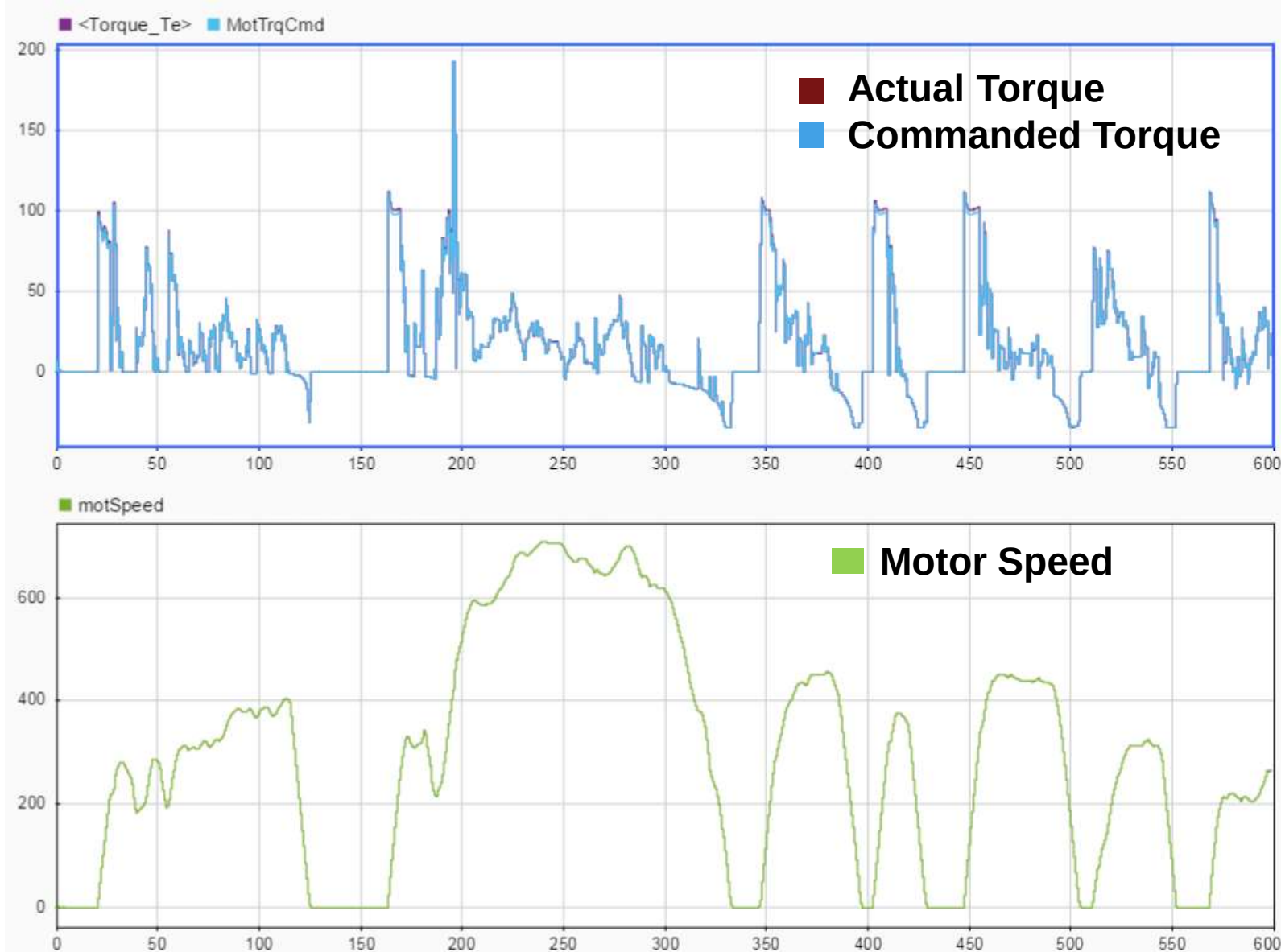
Detailed Model Variant Simulation



Cycle Name	Final SOC (%)		MPGe	
	Mapped	Detailed	Mapped	Detailed
HWFET	42	44	50.5	51.8
FTP75	41.4	42.8	59.6	66.4

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

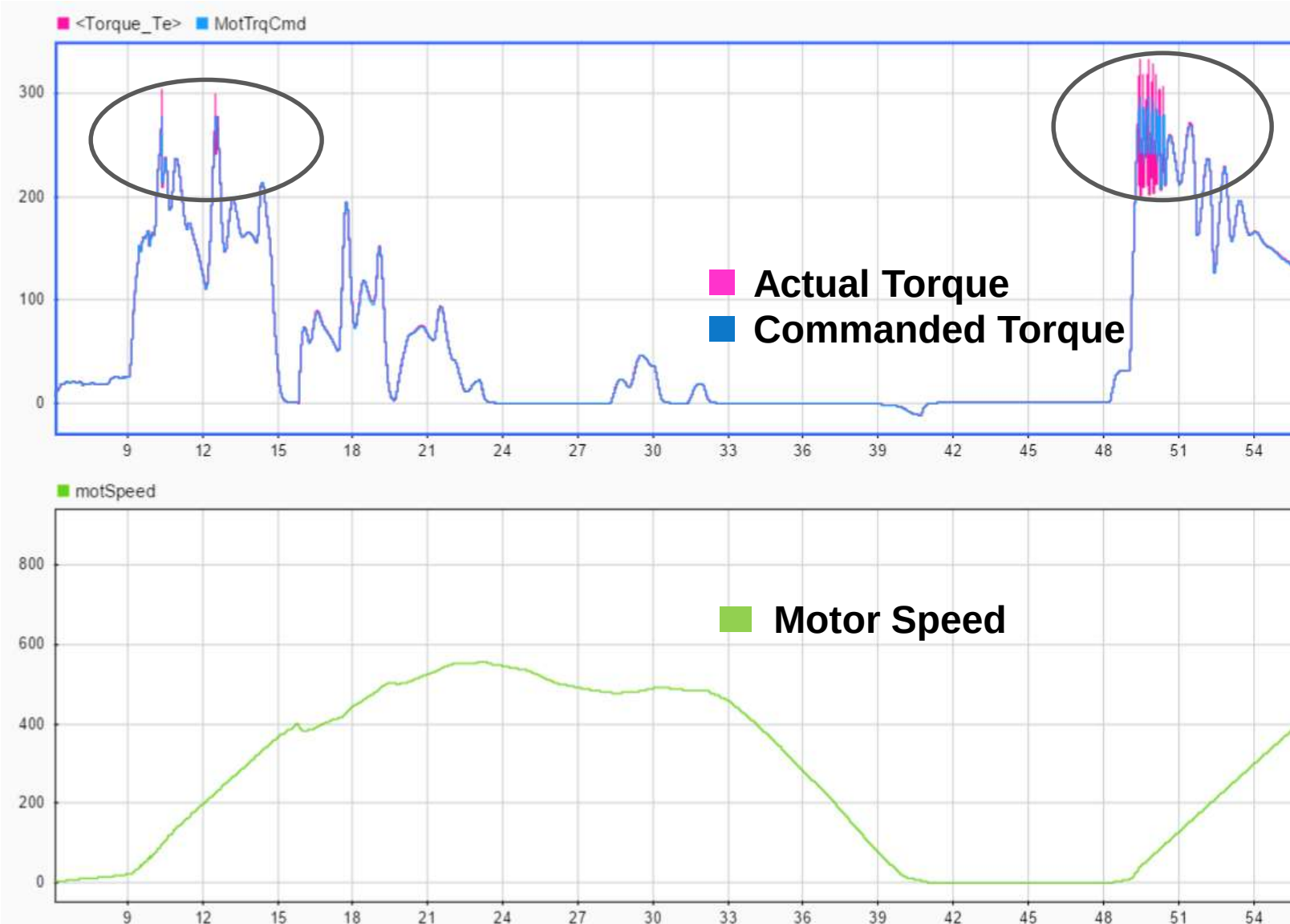
Torque Control Performance



FTP75 Drive Cycle

- Motor torque response accurately follows the commanded torque at different speeds

Torque Control Performance

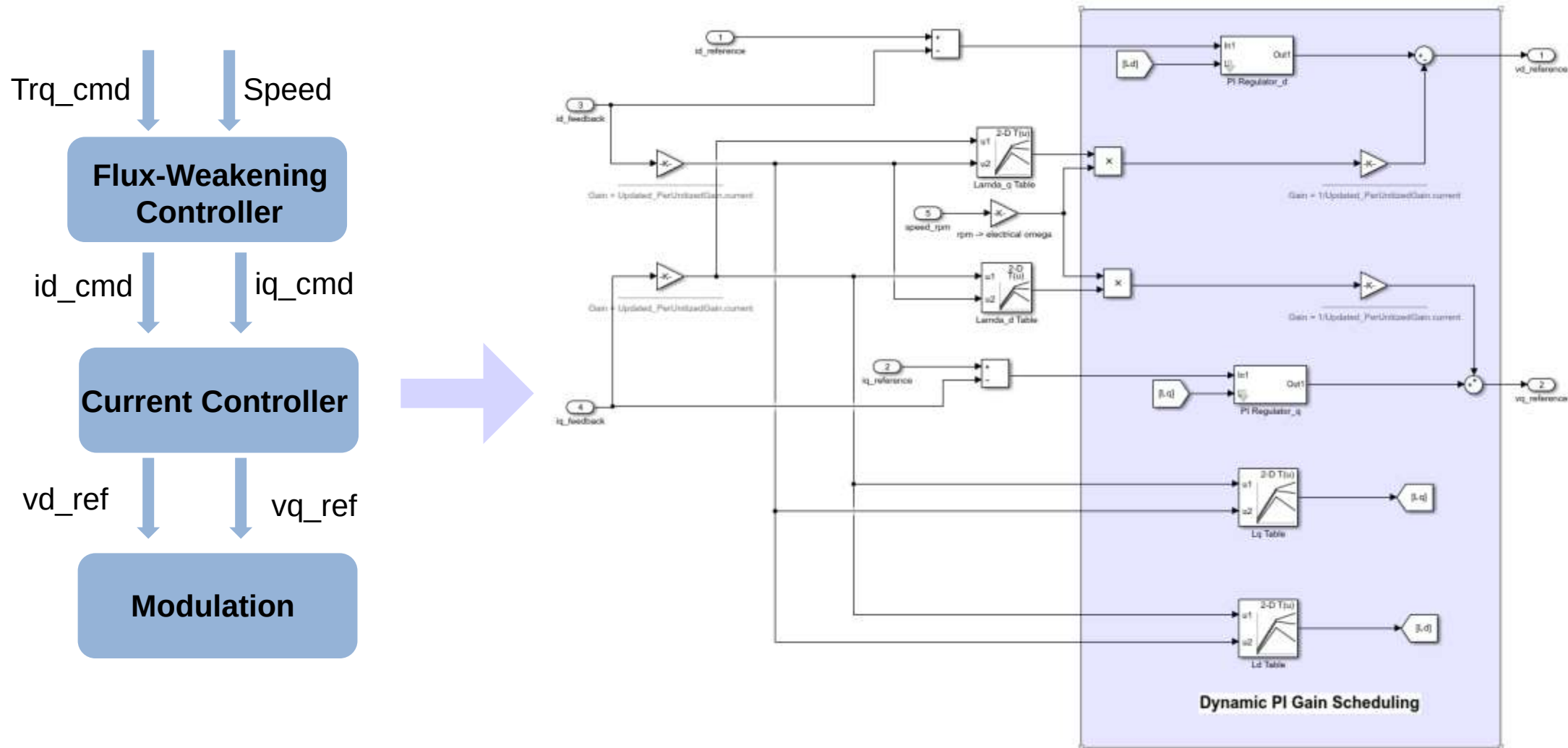


US06 Drive Cycle

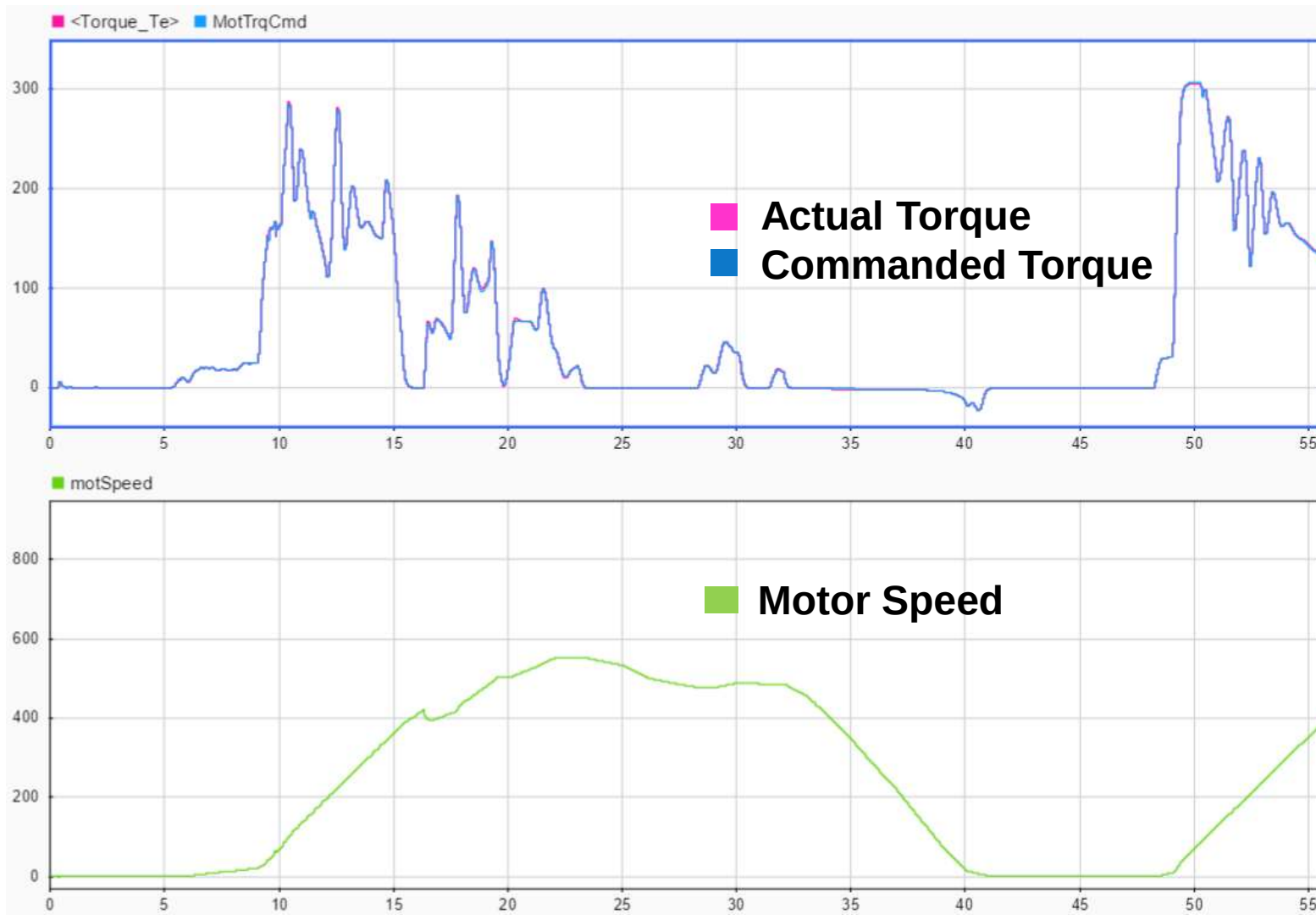
- Much higher power demand reveals a problem
- Motor controller becomes unstable under certain operating conditions

Controller Enhancements

- Controller robustness was improved via dynamic gain scheduling



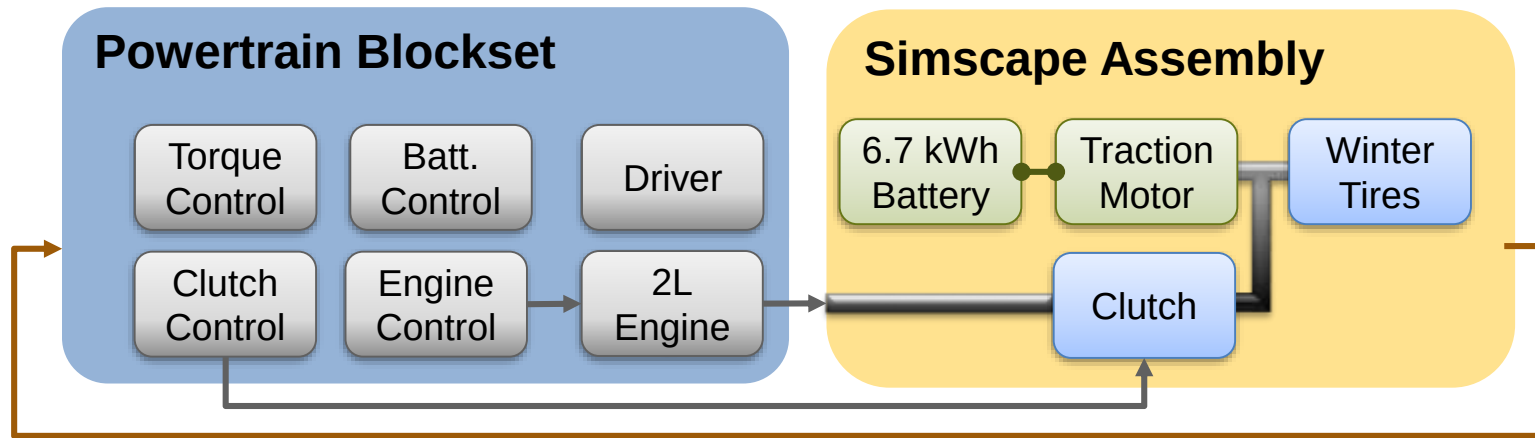
Torque Control Performance



US06 Drive Cycle

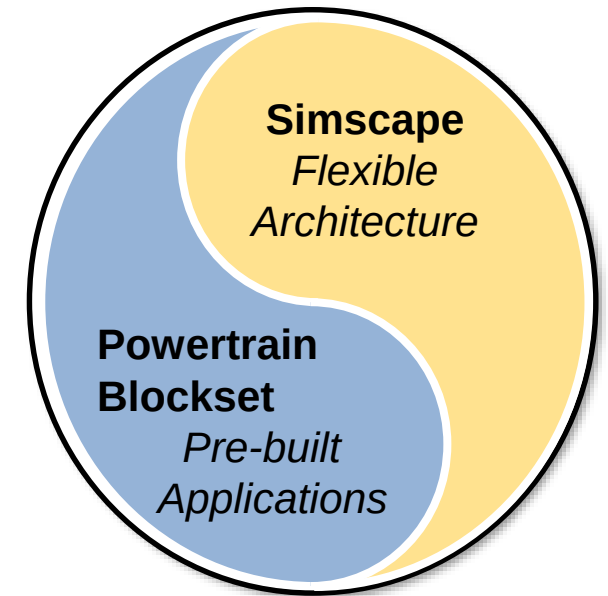
- Even in more extreme maneuvers, improved motor controller is able to provide the commanded torque

Powertrain Blockset and Simscape



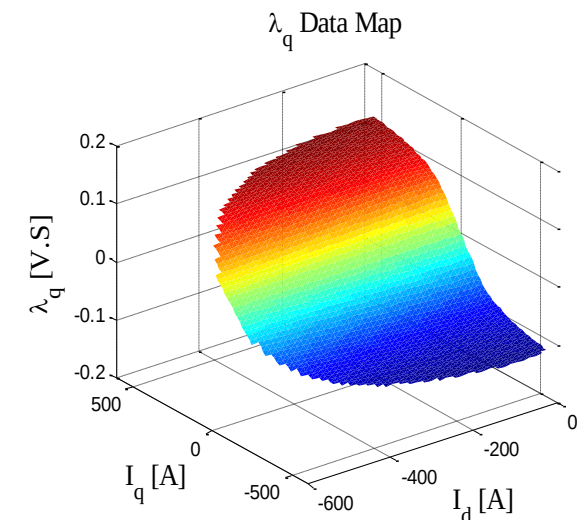
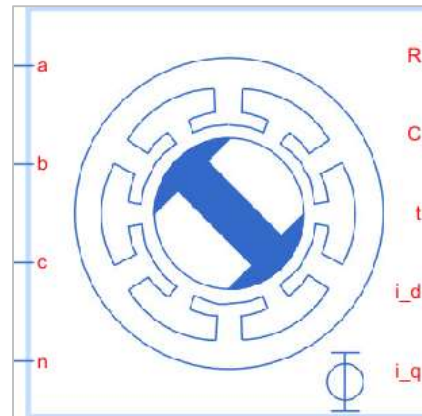
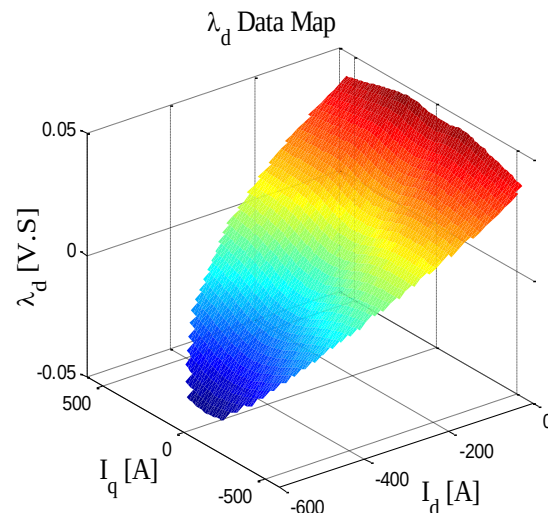
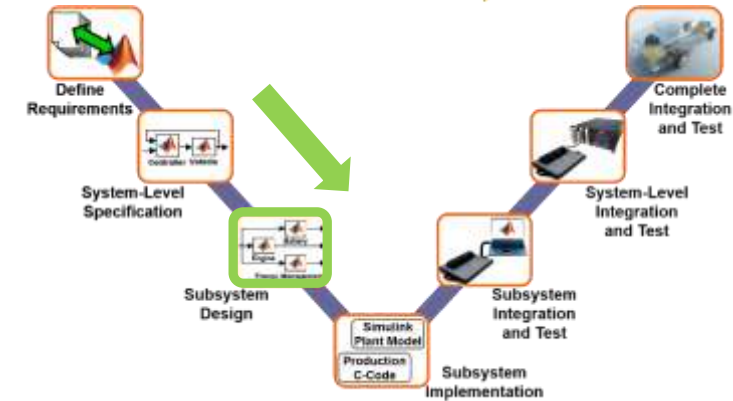
Complementary Technologies

Powertrain Blockset Focus	Simscape Focus
Empirical studies	Predictive studies
Engine modeling	Electrical, fluid system design
Engine calibration	Multi-domain modeling
Fuel economy studies	Architecture concept evaluation



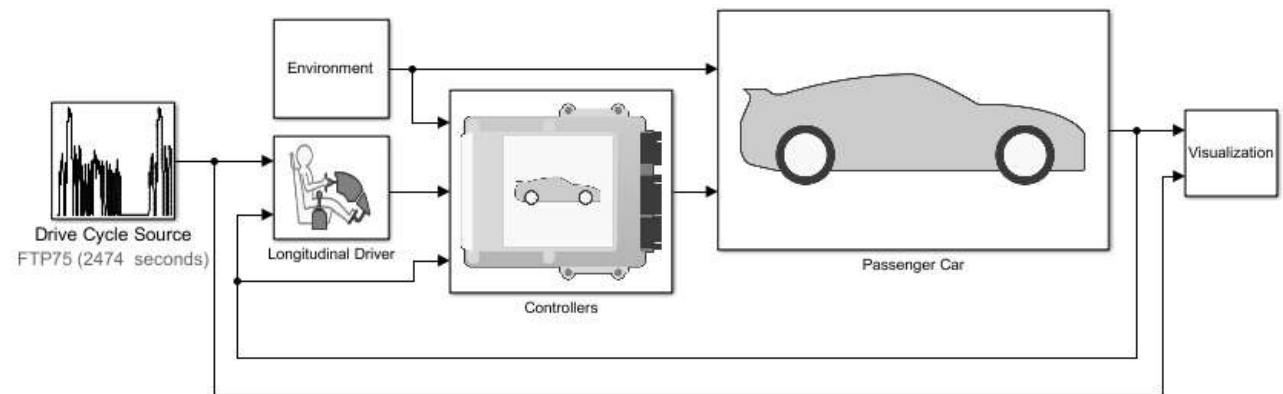
System Level Verification

- 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