MATLAB EXPO 2017

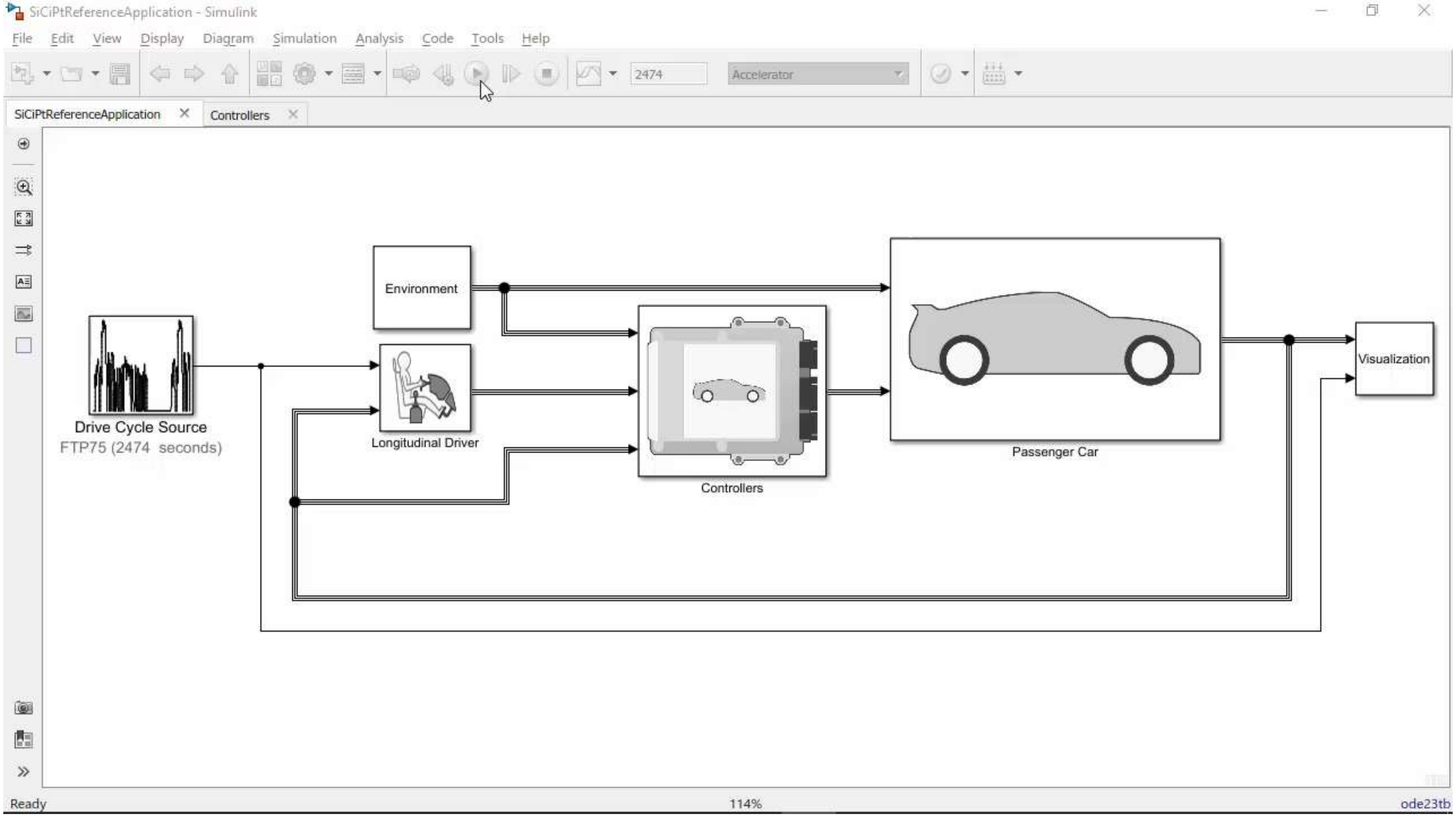
Building Fast and Accurate Powertrain Models for System and Control Development

Prasanna Deshpande

Challenges for the Powertrain Engineering Teams

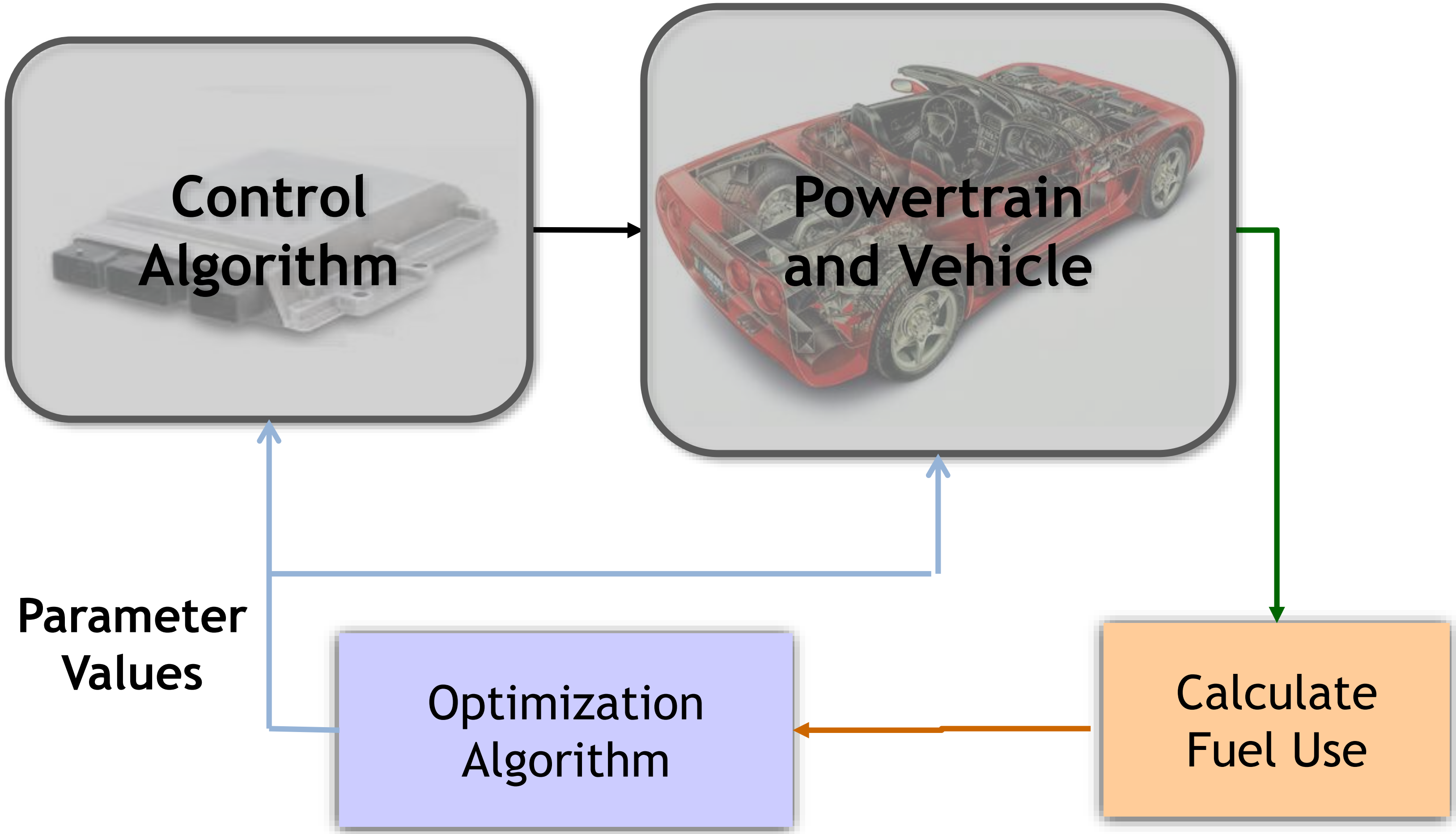
- How to design and test vehicle powertrain in a single environment?
- How to perform powertrain matching, fuel economy, performance, and emission simulations?
- How to design and verify the controller at the vehicle system level?

What Does the Solution Look Like?



Key Message

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



Agenda

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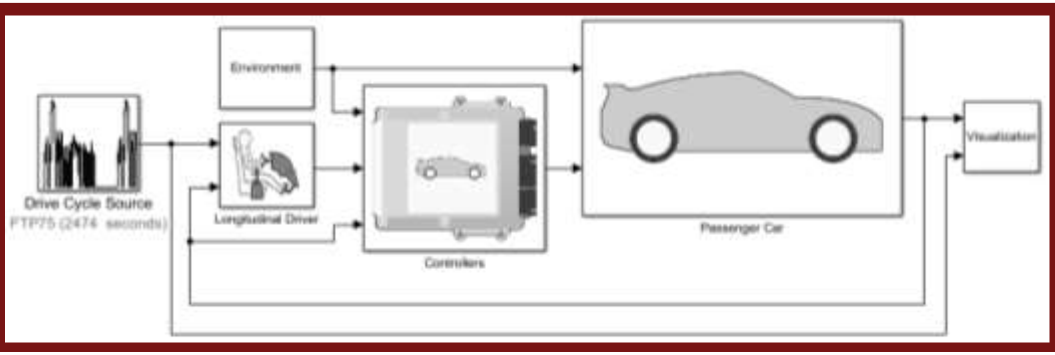
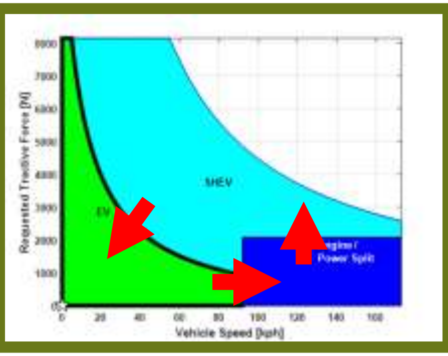


Optimize



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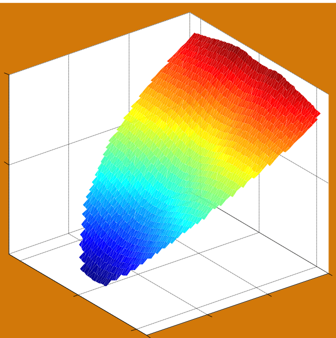

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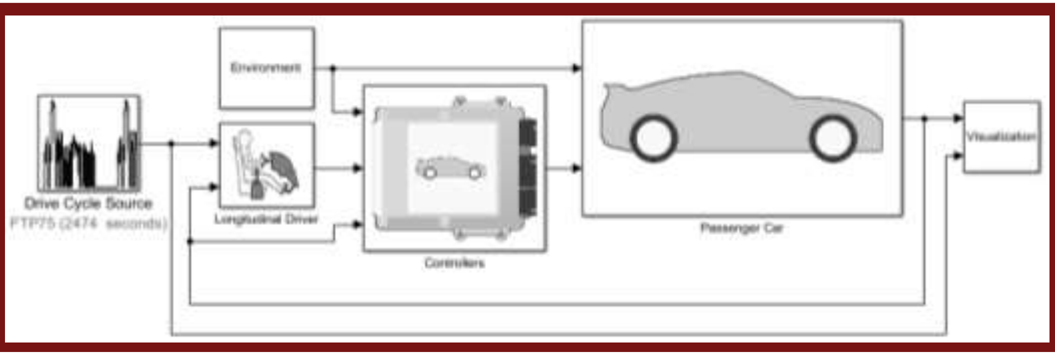

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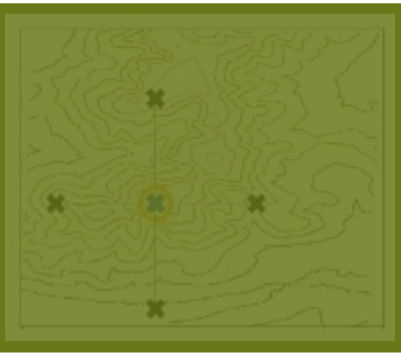

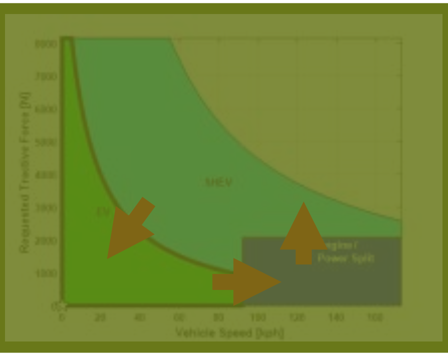

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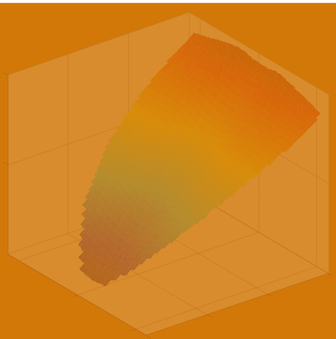
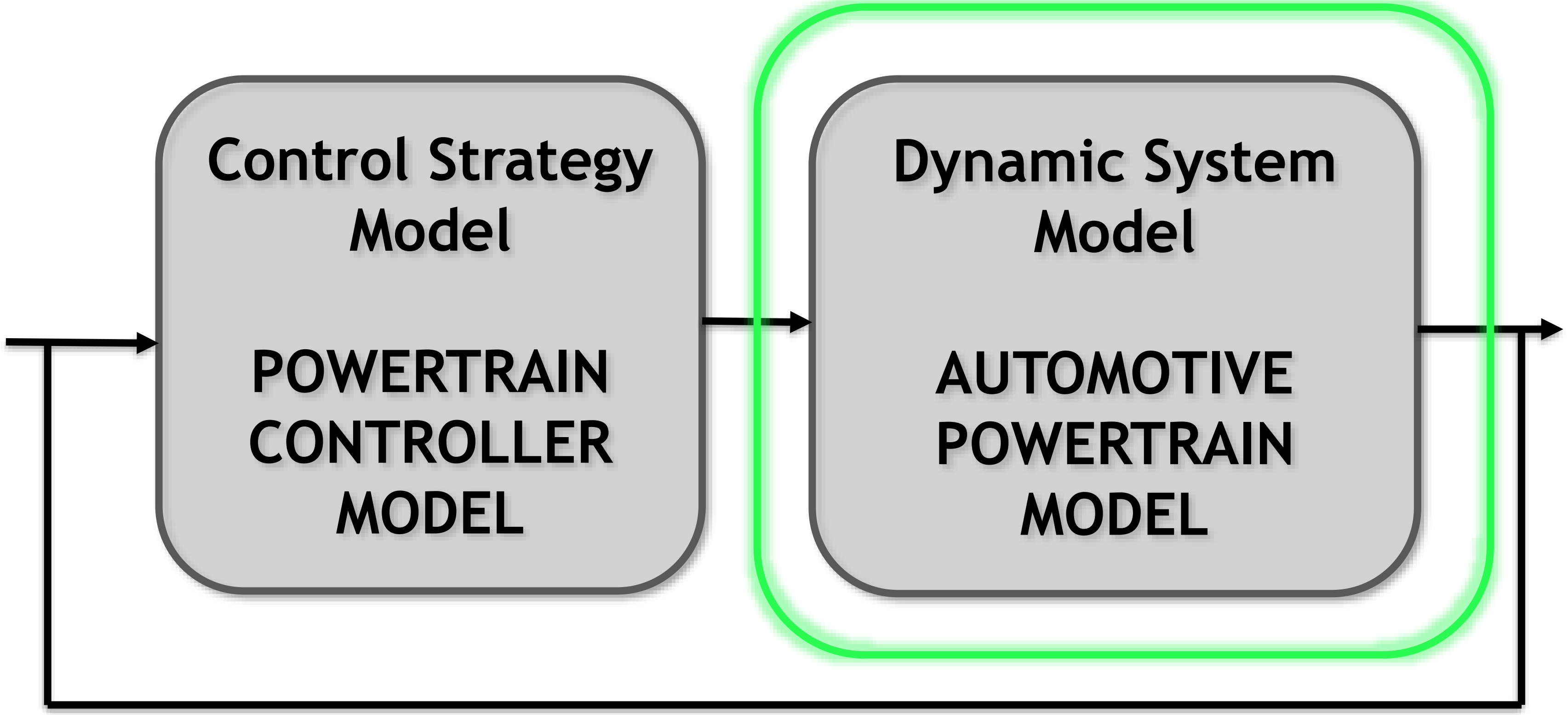


Structure of a System Level Simulation Model



Modeling Dynamic Systems in the Simulink Environment

Modeling Approaches

First Principles Modeling ⟷ **Data-Driven Modeling**

Code
(MATLAB)

Block Diagram
(Simulink)

Modeling Language
(Simscape language)

Symbolic Methods
(Symbolic Math Toolbox)

Physical Networks
(Simscape and other Physical Modeling products)

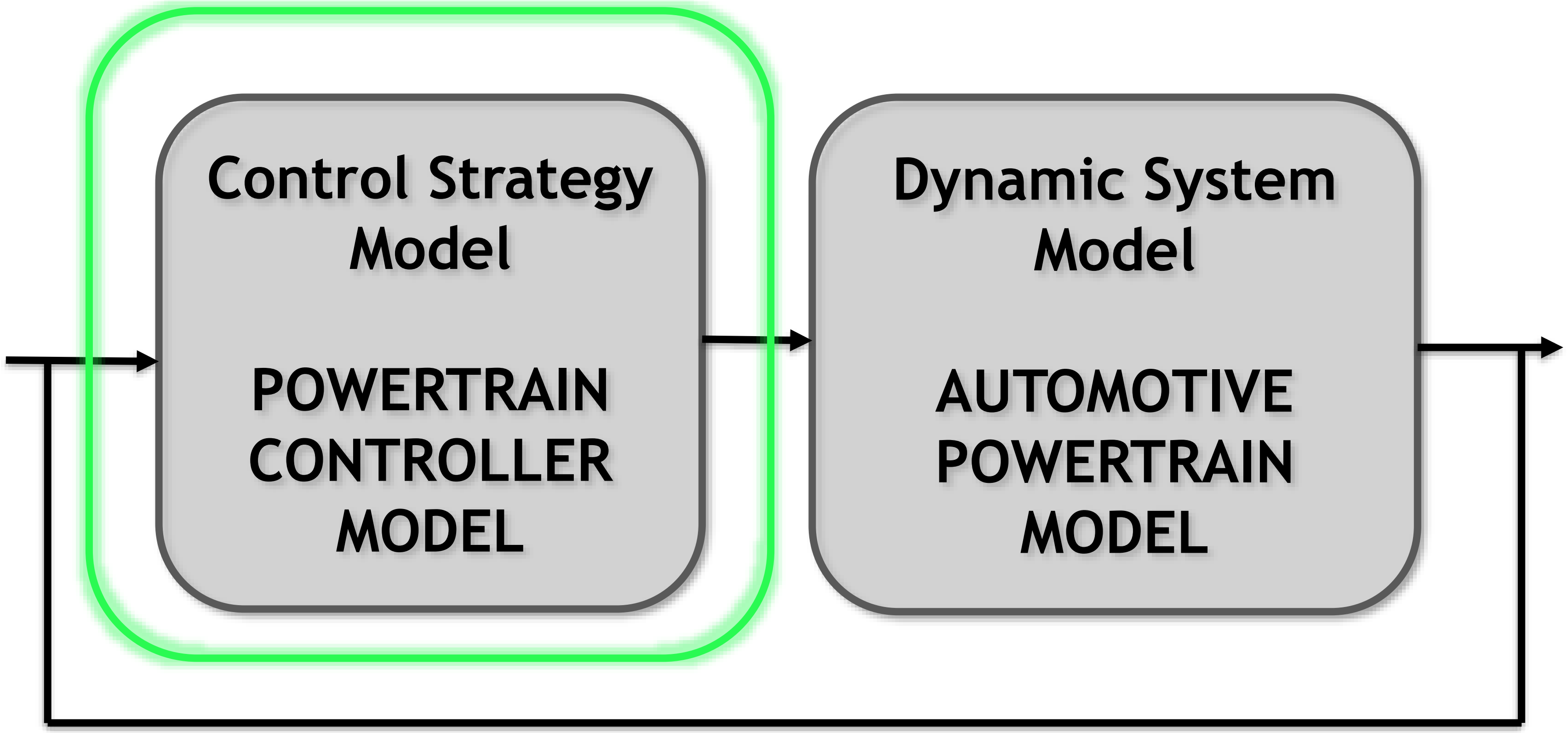
Parameter Optimization
(Simulink Design Optimization)

Neural Networks
(Neural Network Toolbox)

System Identification
(System Identification Toolbox)

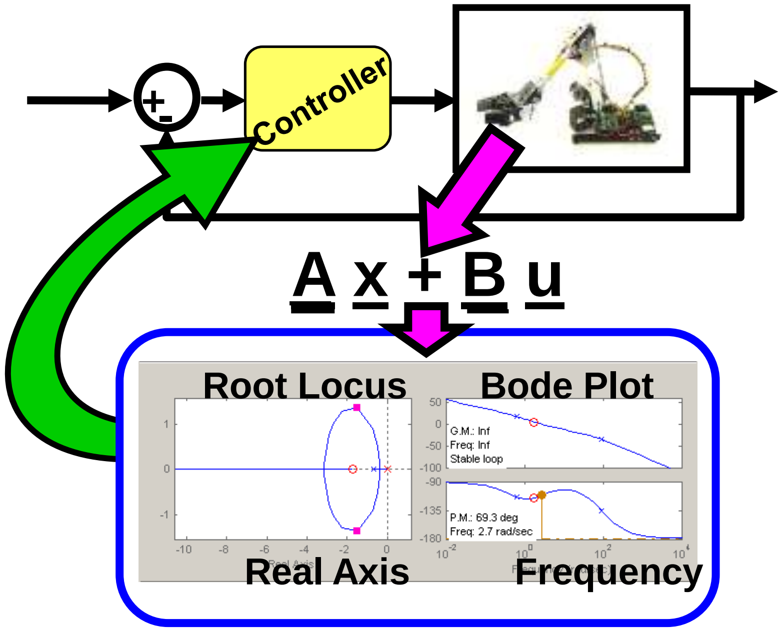
Statistical Methods
(Model Based Calibration Toolbox)

Structure of a System Level Simulation Model

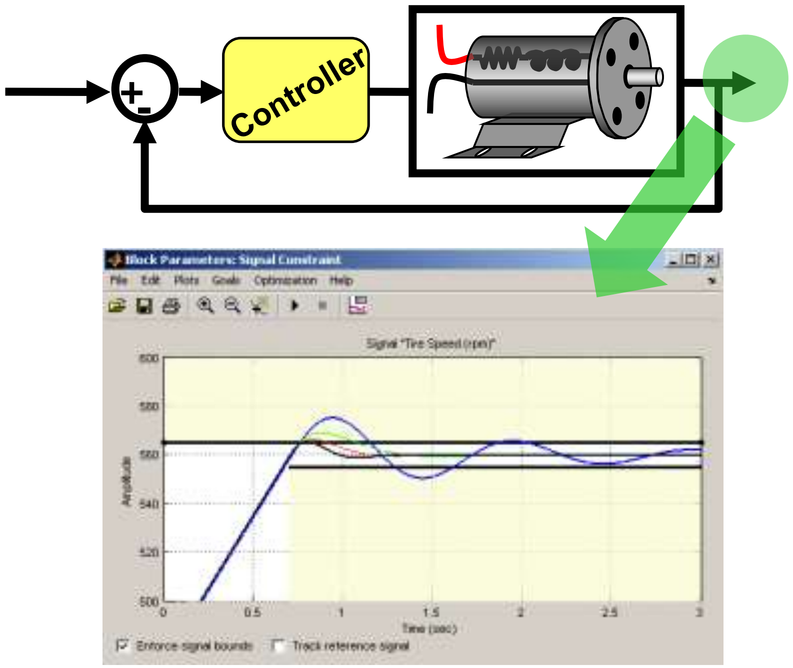


Control System Design in Simulink

- **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™**



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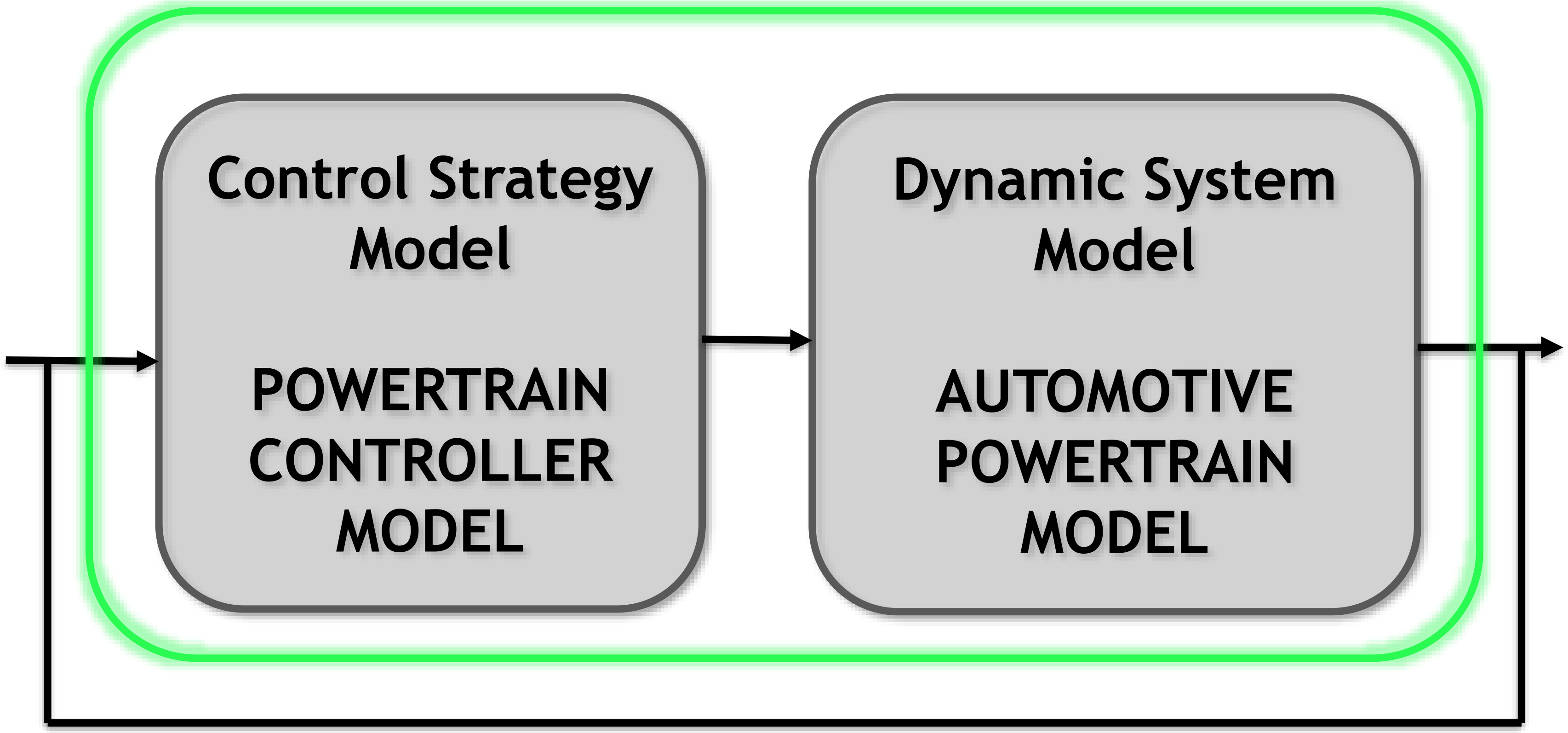


Model-Based Design Challenges

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

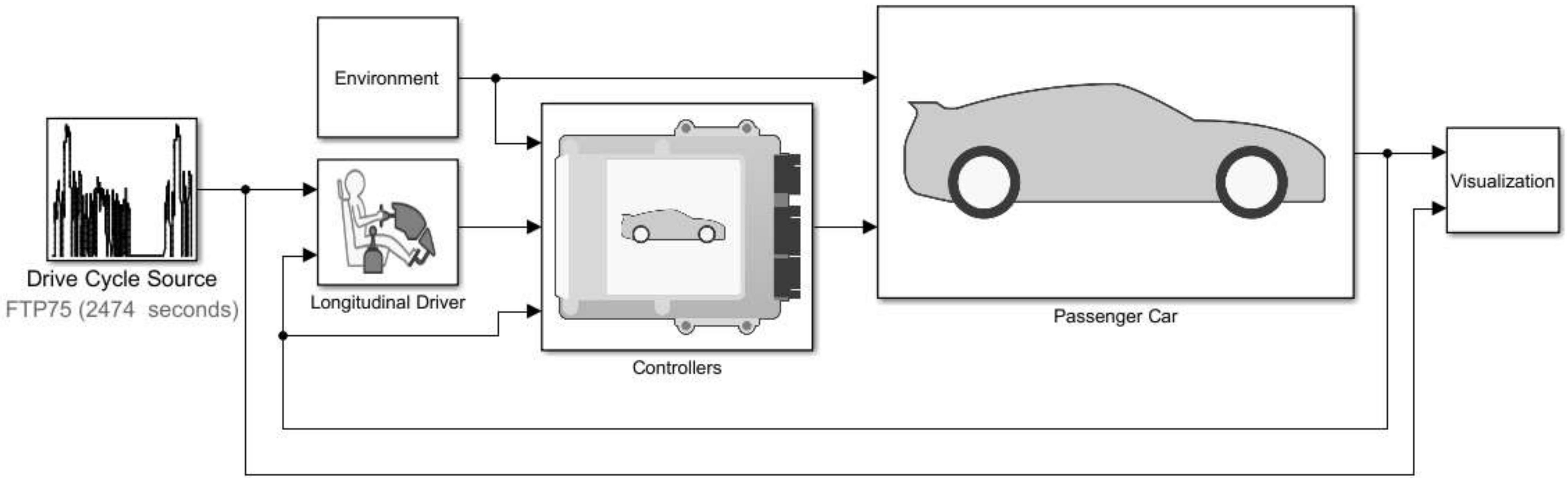
MathWorks' Response

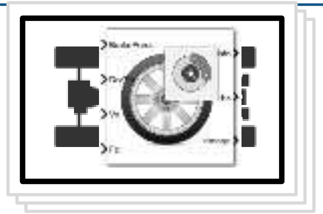
Lower the barrier to entry

- 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

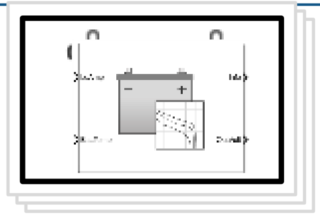
Powertrain Blockset

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

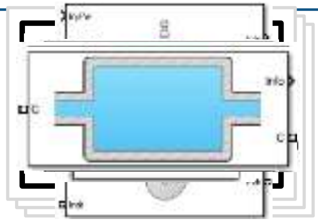




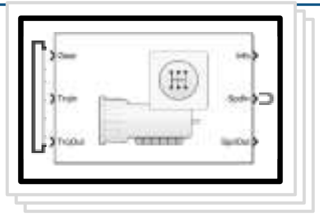
Drivetrain



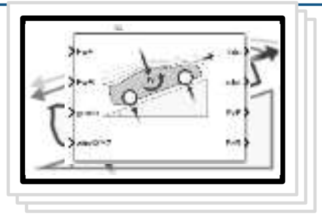
Energy Storage
and Auxiliary Drive



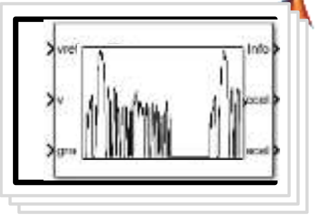
Propulsion



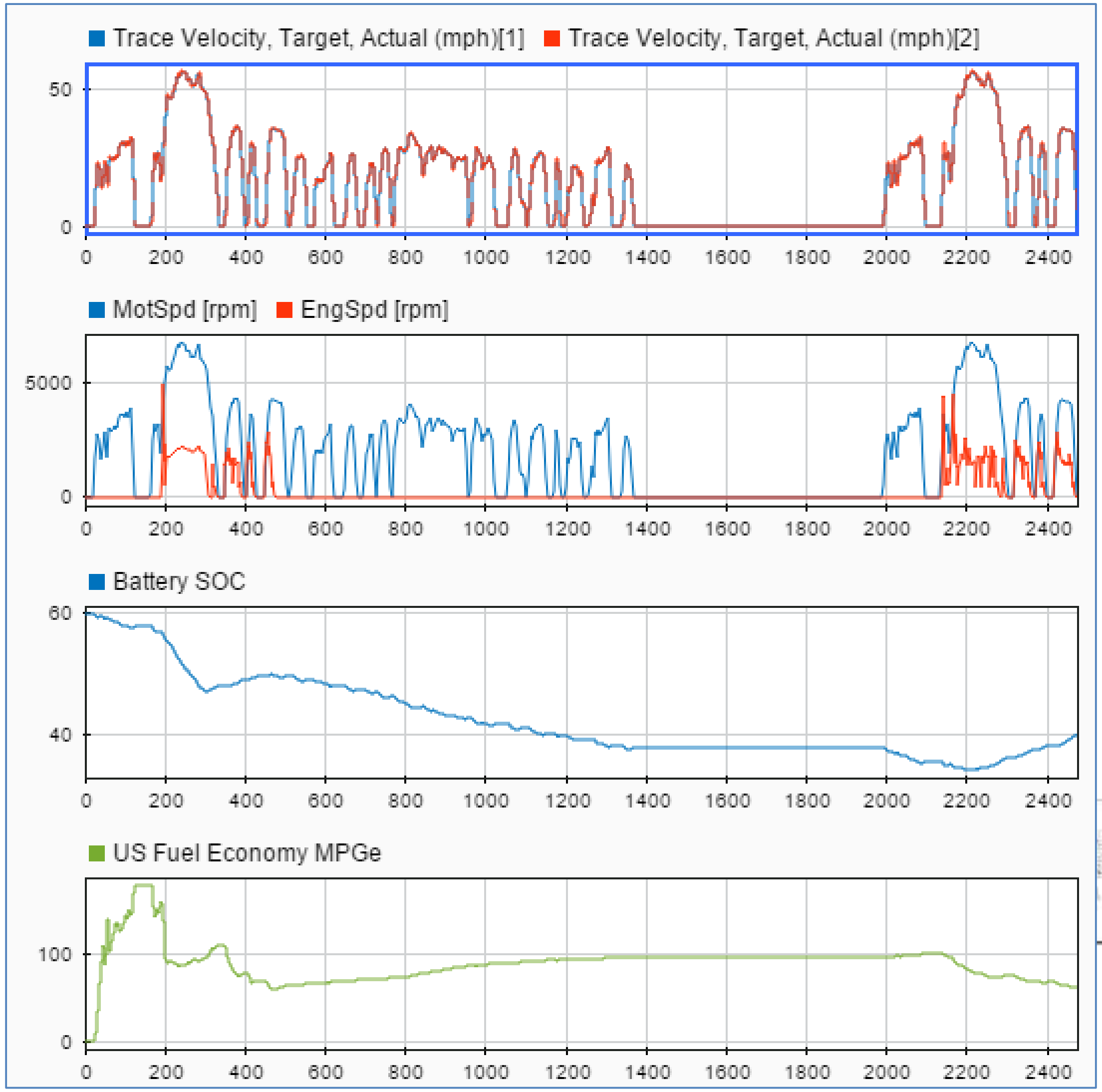
Transmission

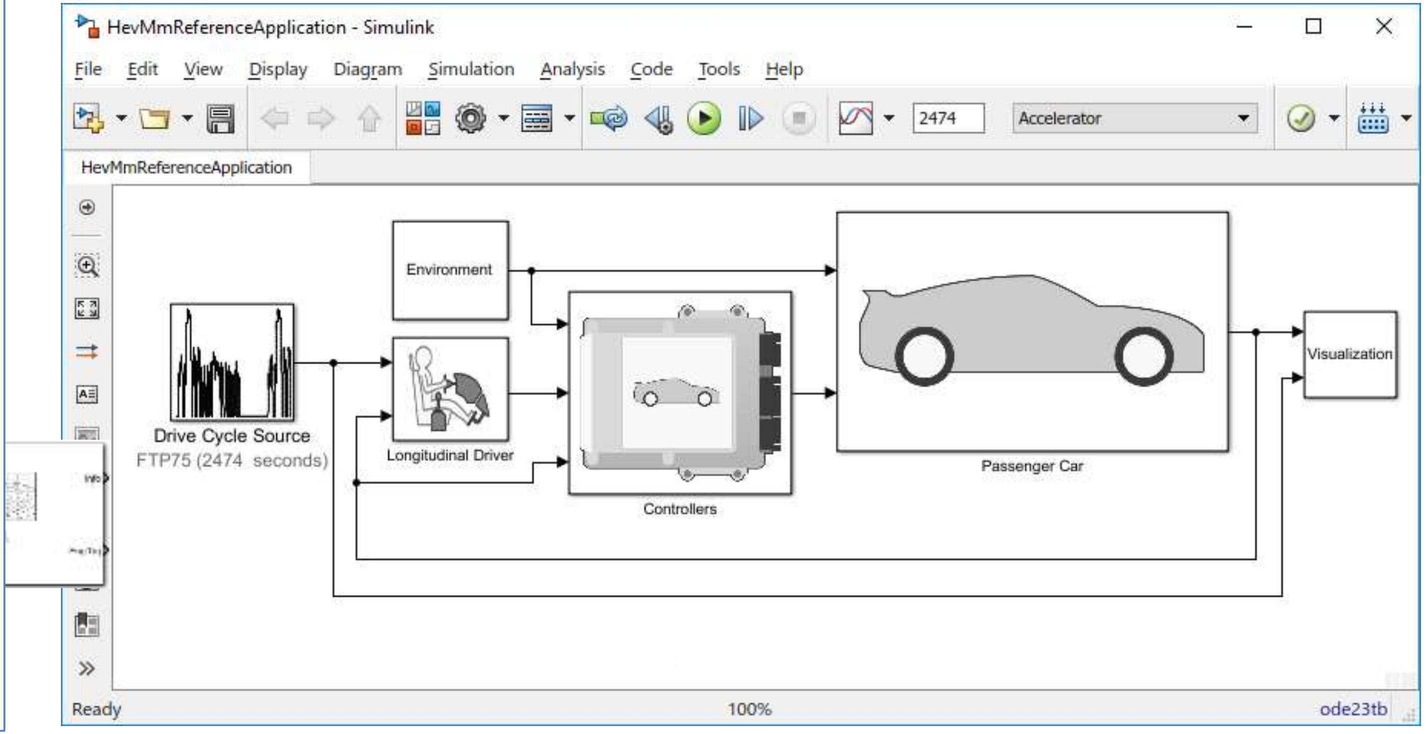


Vehicle Dynamics

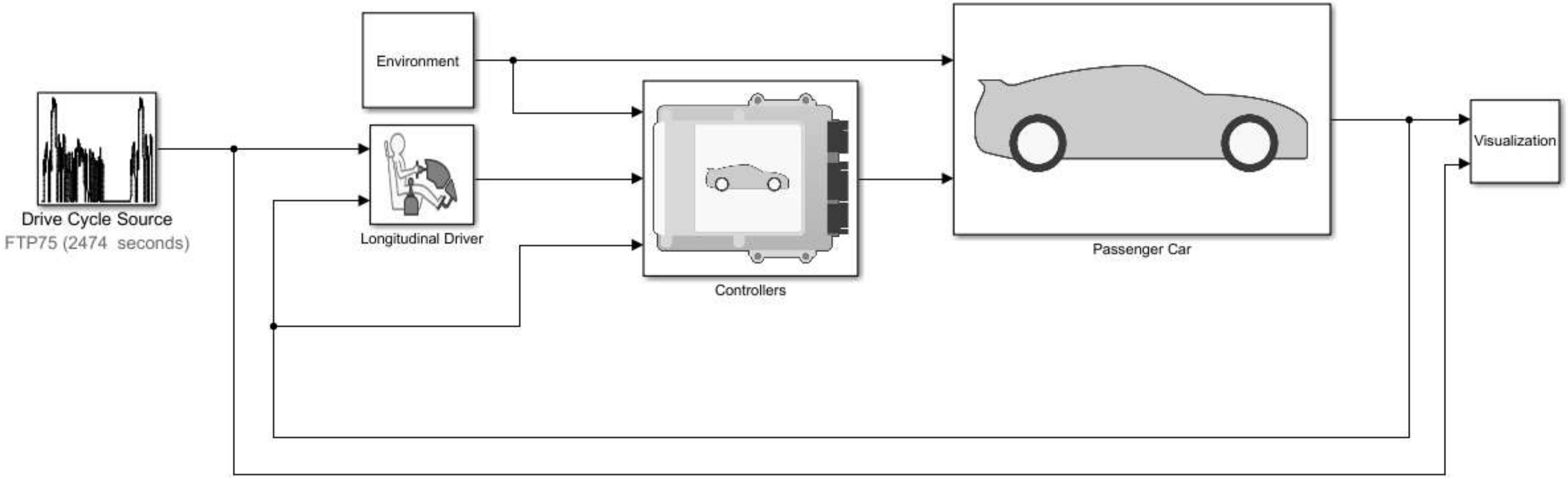


Vehicle Scenario Builder



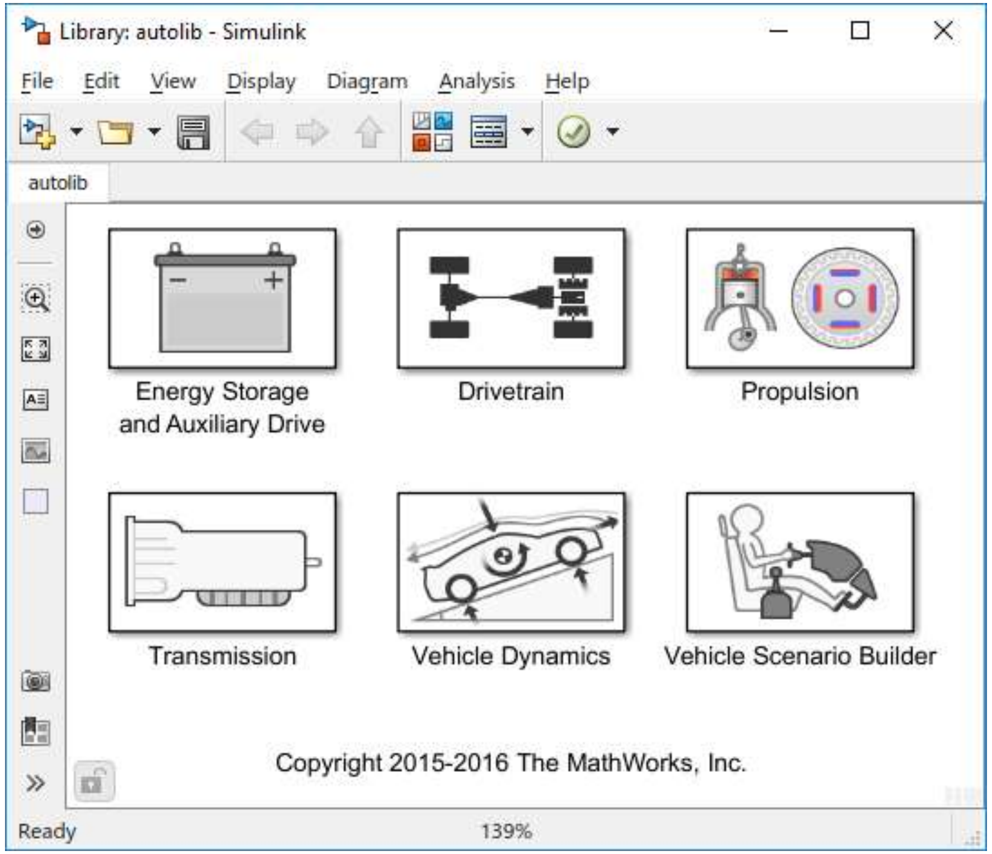


Demo – HEV system level model

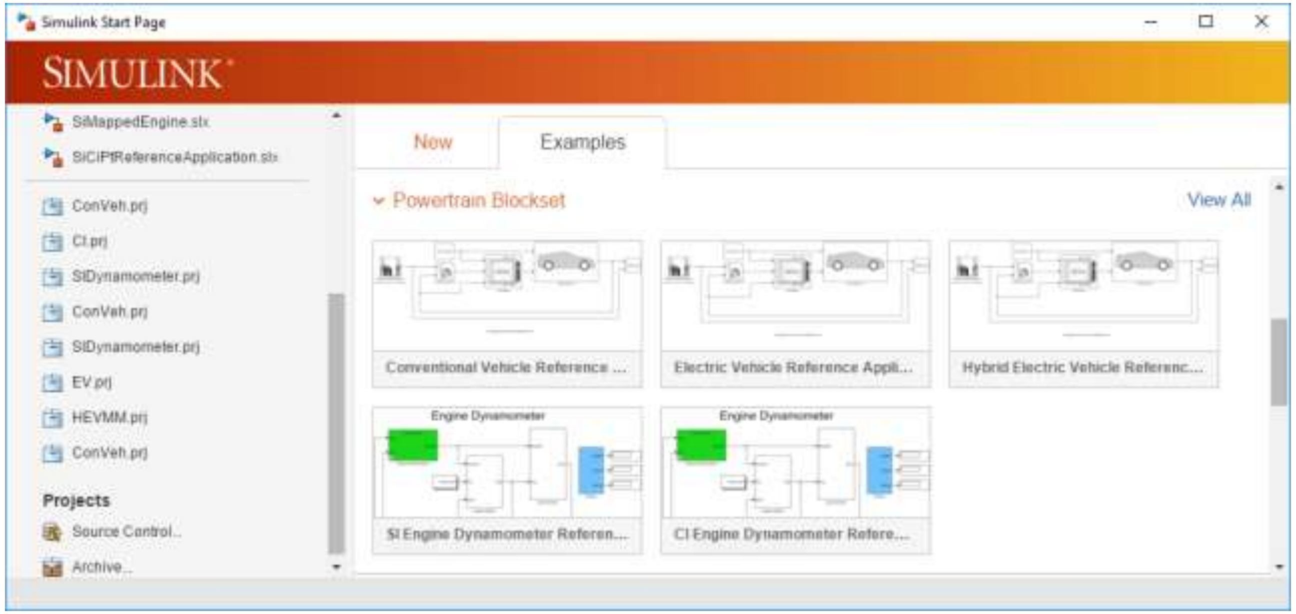


Powertrain Blockset

Library of blocks



Pre-built reference applications



Agenda

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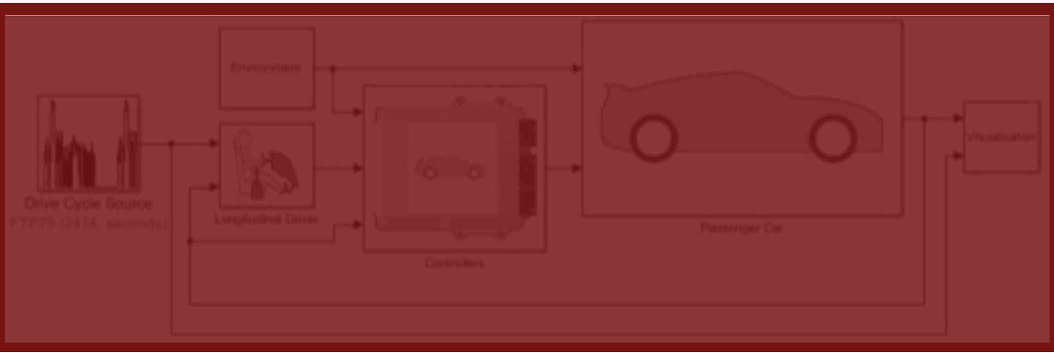
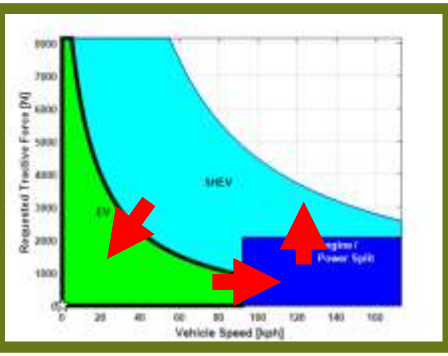


Optimize



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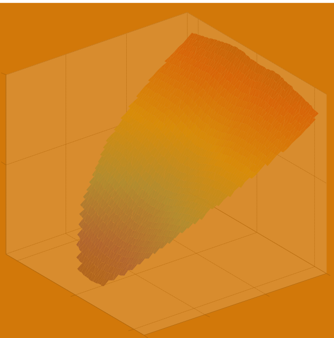

Challenges for the System Engineer

- 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

2013-01-1476
Published 04/08/2013
doi:10.4271/2013-01-1476
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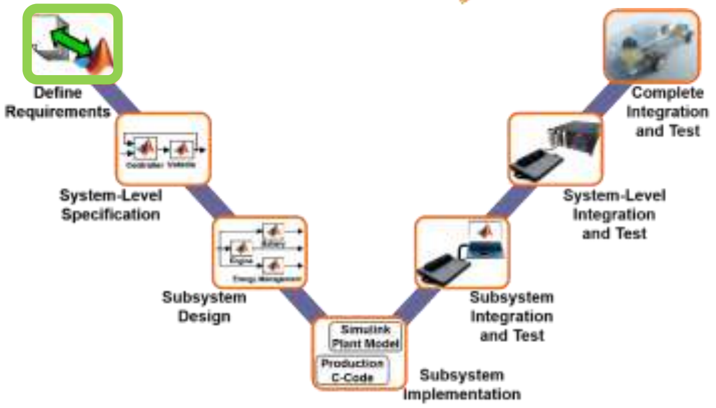
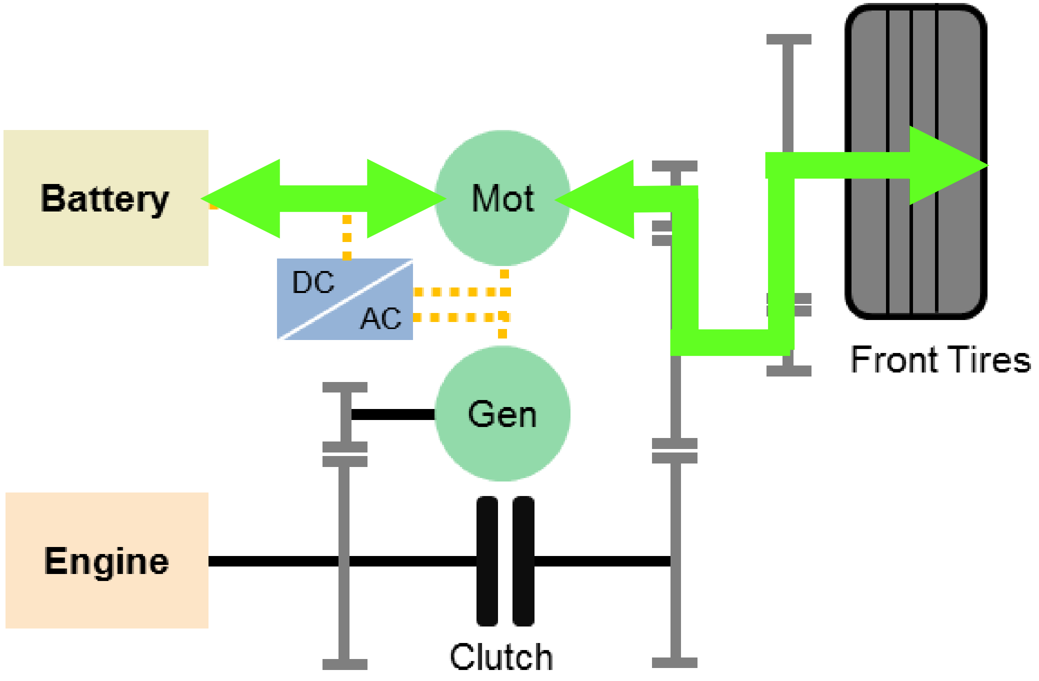
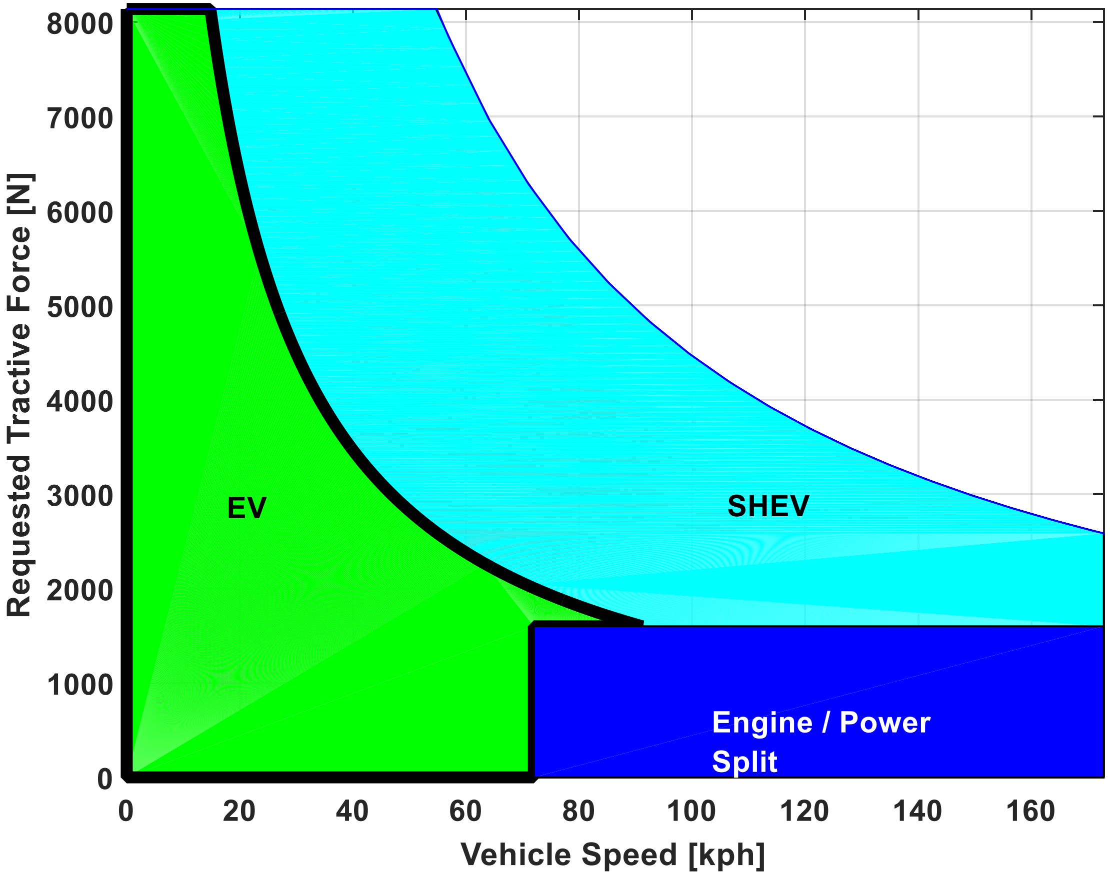
Development of a New Two-Motor Plug-In Hybrid System

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





EV Mode



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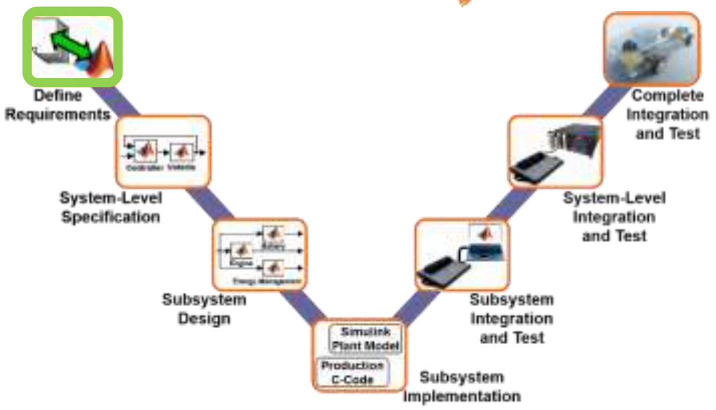
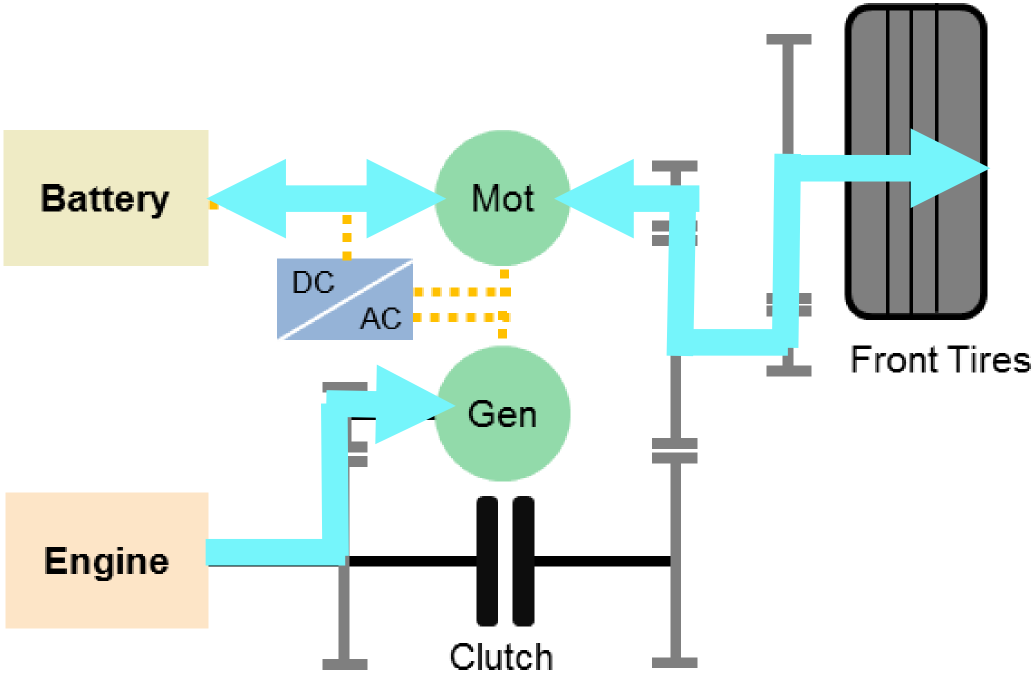
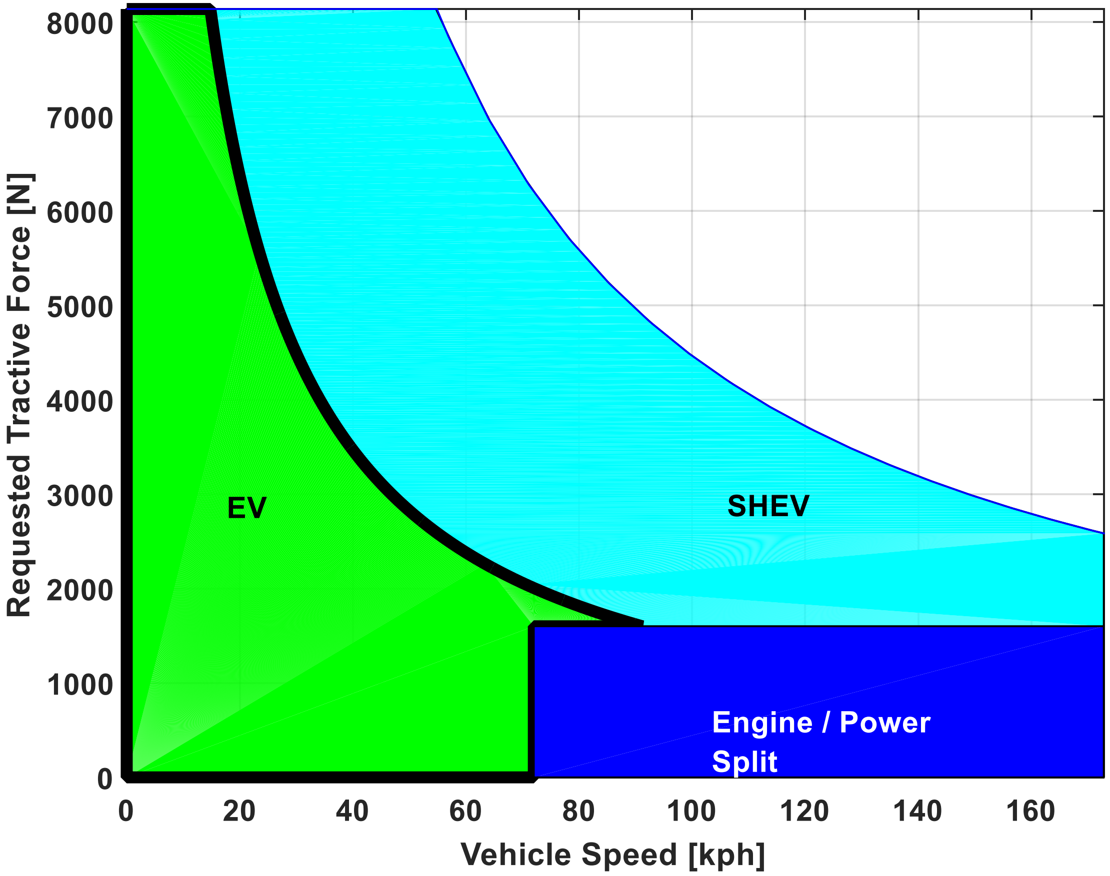




SHEV Mode



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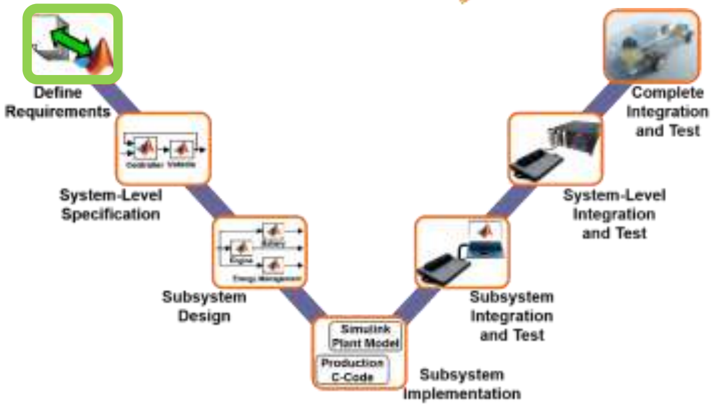
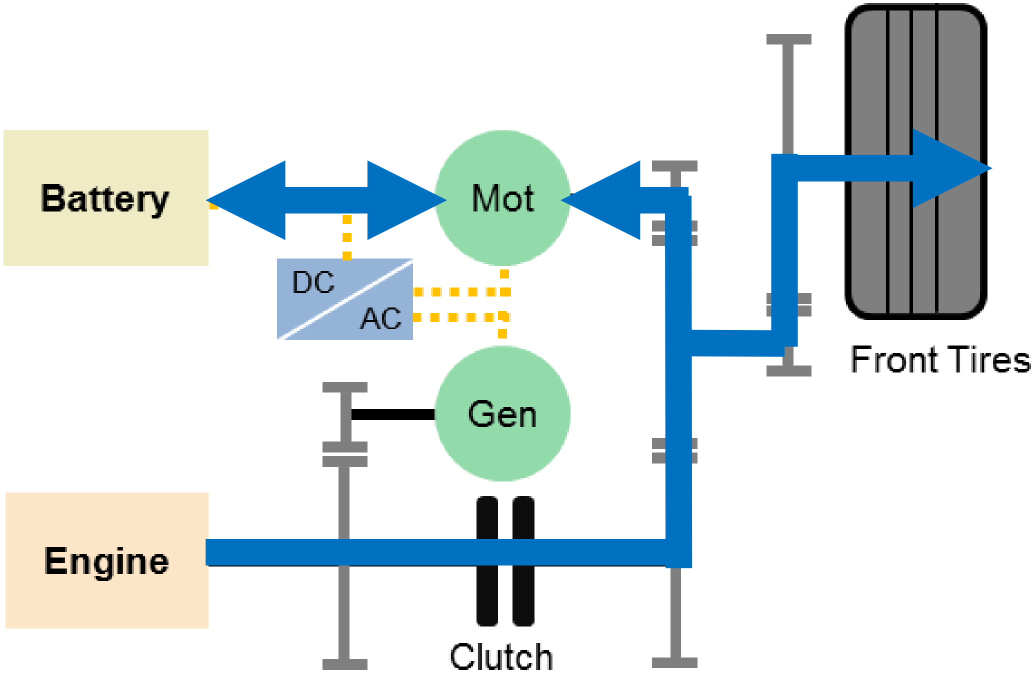
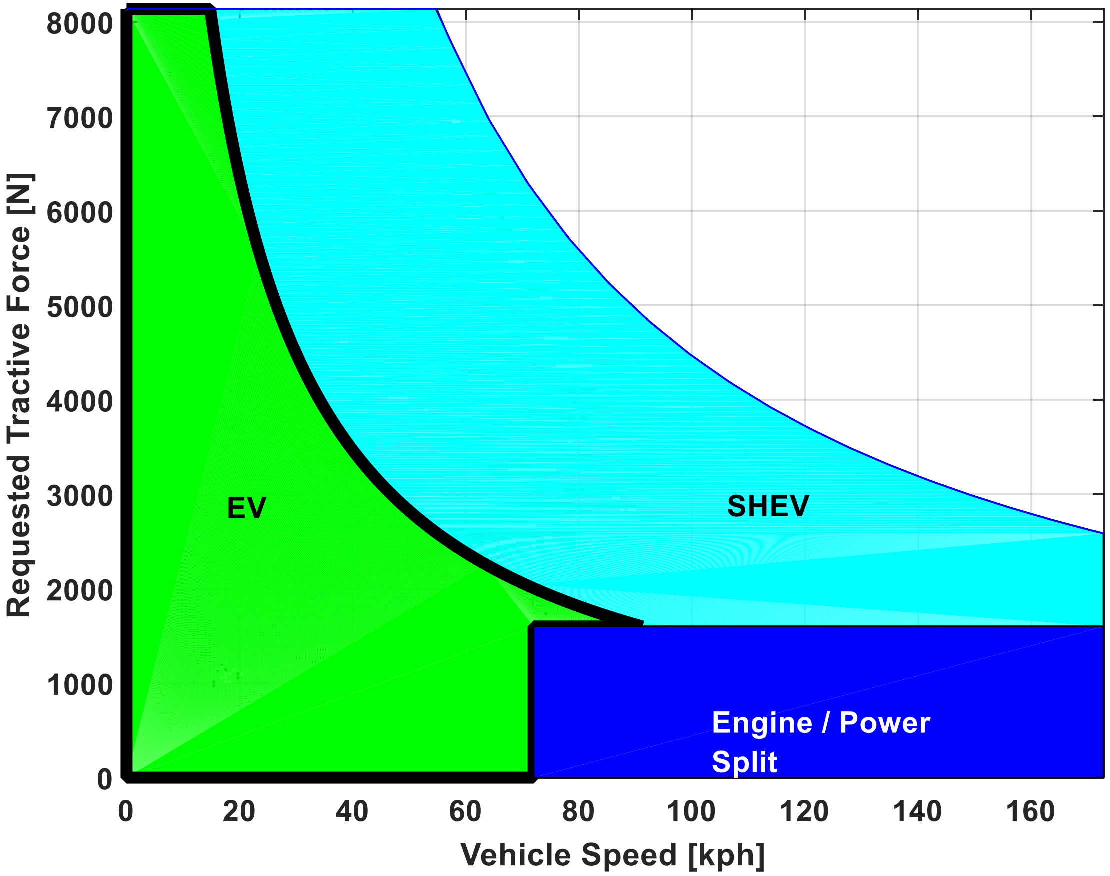
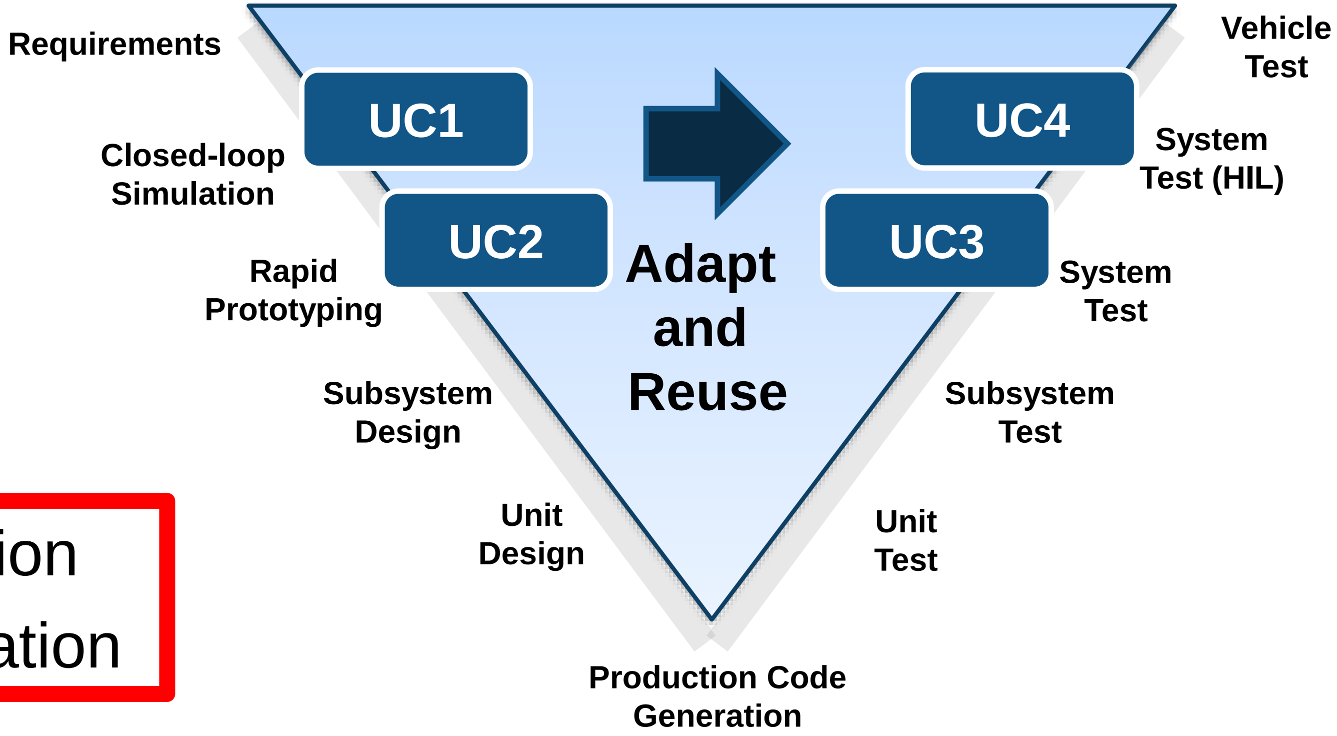




Engine Mode



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**

→

Efficient Optimization

→

PC, UI

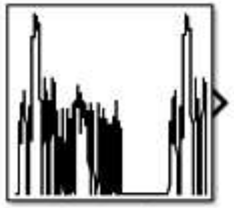
- Simulation Time / Real-Time
- HEV Reference Application

- More drive cycles and design parameters
- Using fewer resources

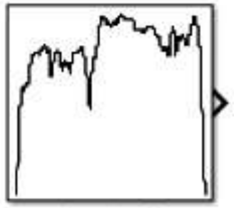
- Easier implementation
- Simulink Design Optimization UI

Design Optimization Problem Statement

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

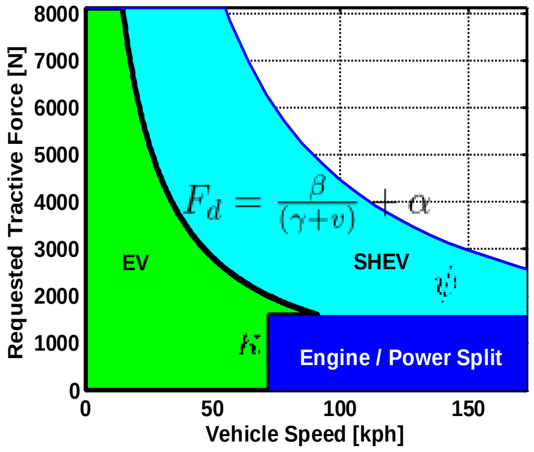


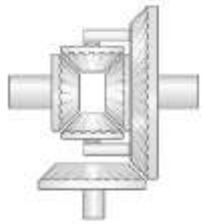
Drive Cycle Source1
FTP75 (2474 seconds)



Drive Cycle Source
HWFET (765 seconds)

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





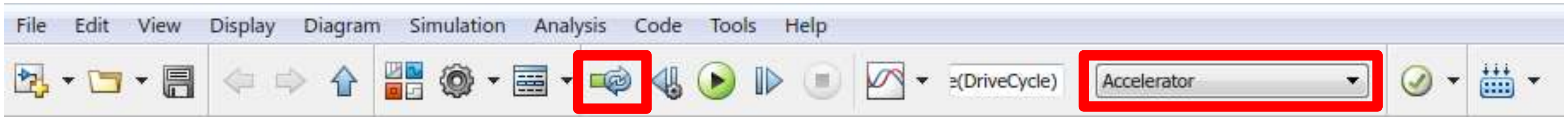
Differential Ratio

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

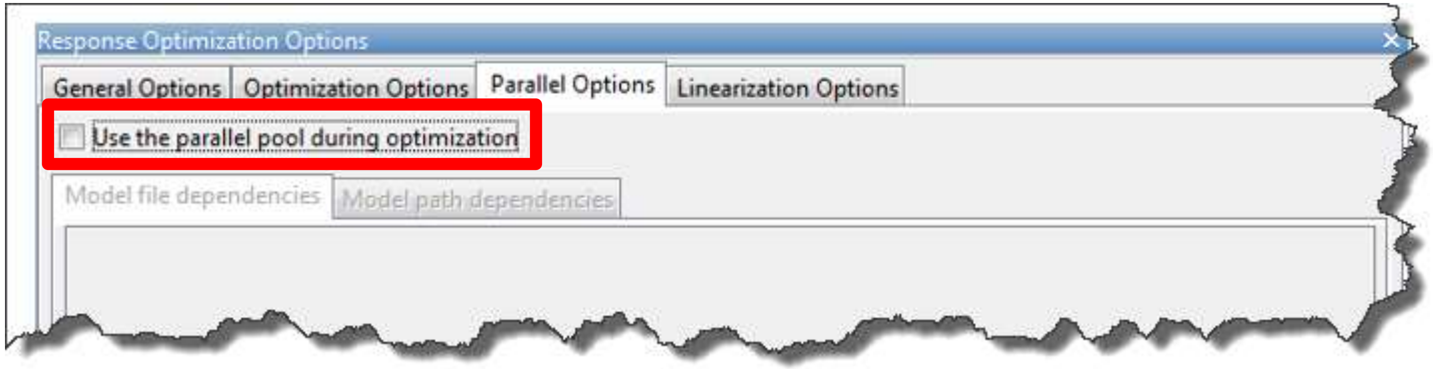
Lenovo ThinkPad T450s
Dual Core i7 2.60GHz
12 GB RAM

Simulink Design Optimization

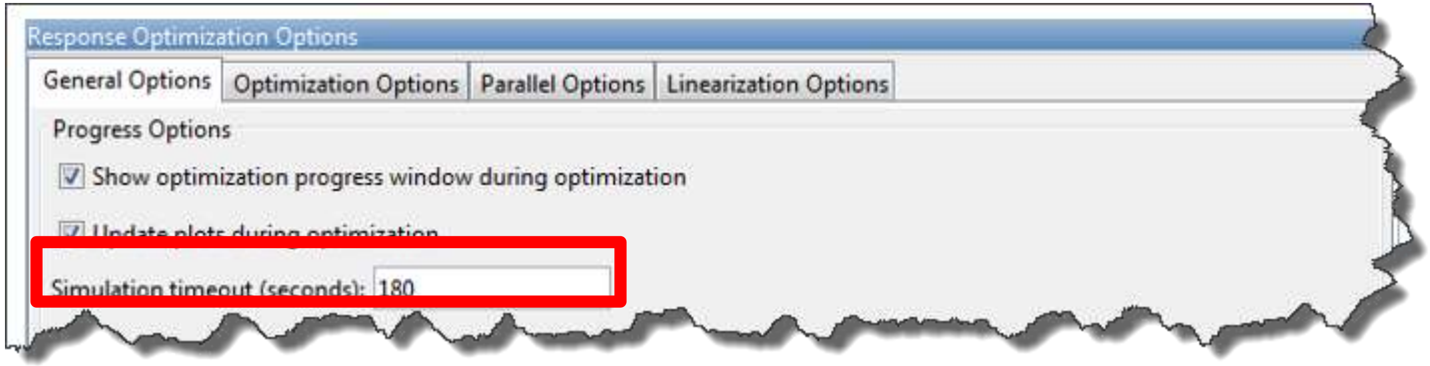
- Speed Up Best practices
  - Accelerator mode
  - Fast Restart



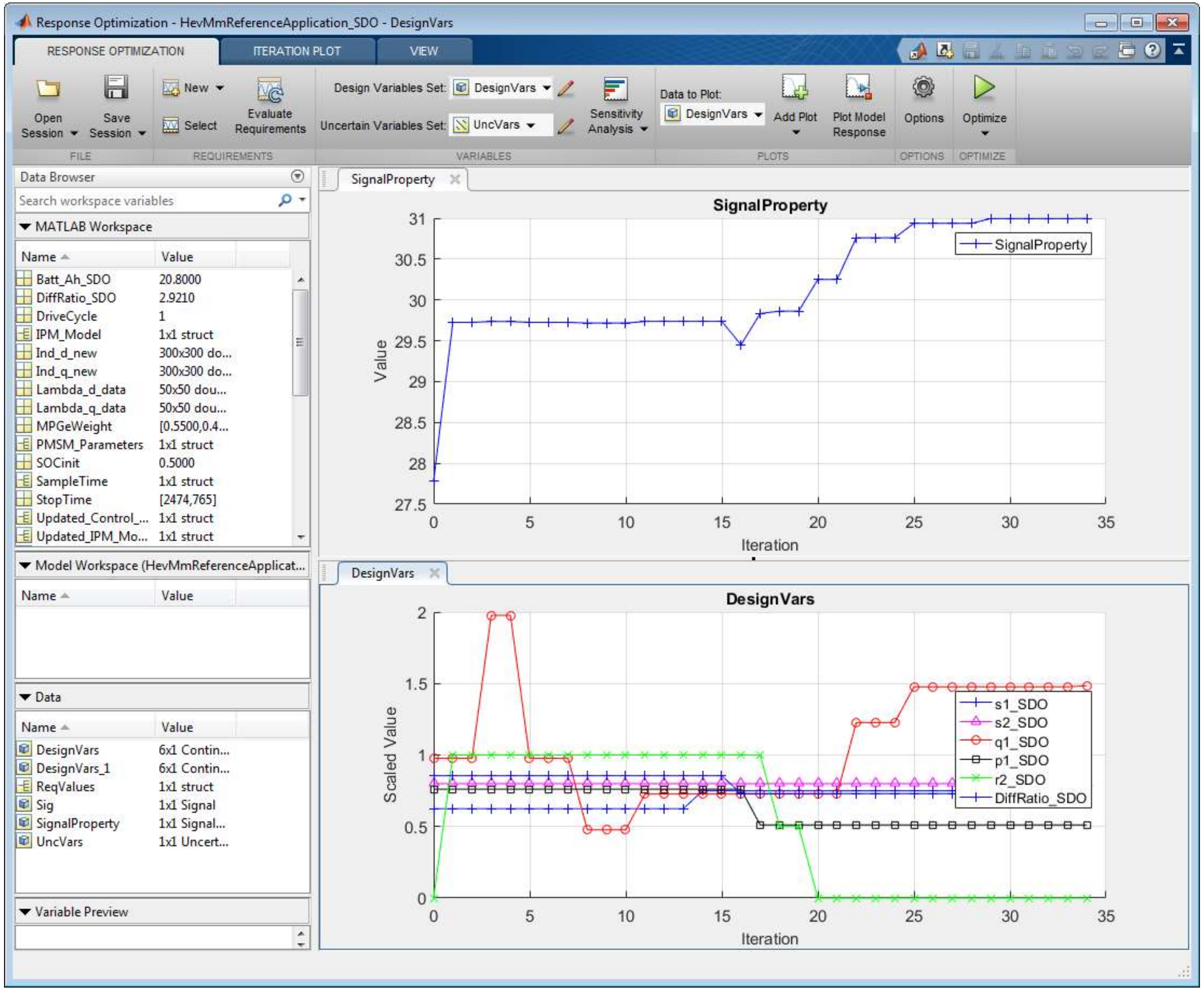
  - Use Parallel Computing Toolbox



  - Specify Simulation timeout

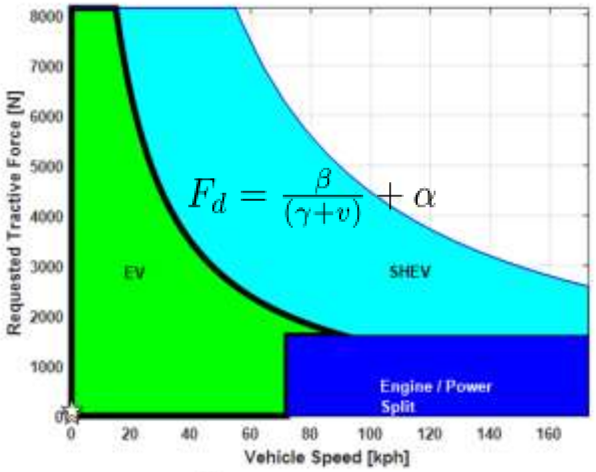


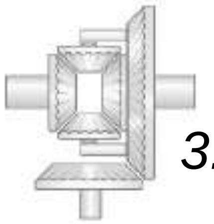
Optimization Results – Iteration Plot



Optimization Results

Simulink Design Optimization → Response Optimization





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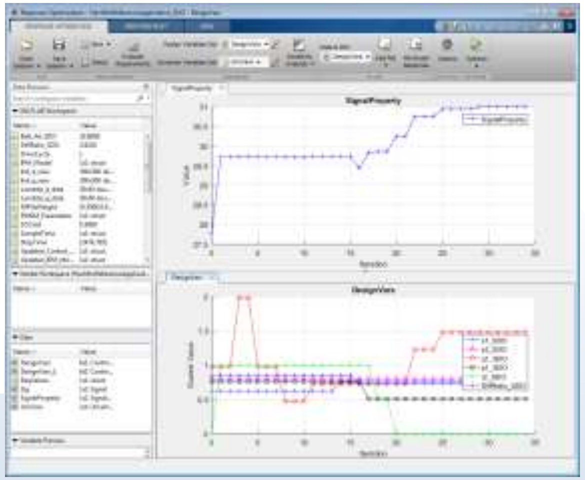
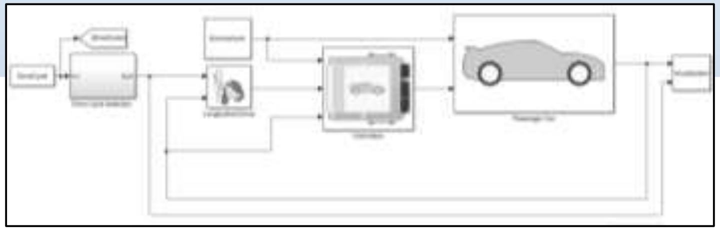
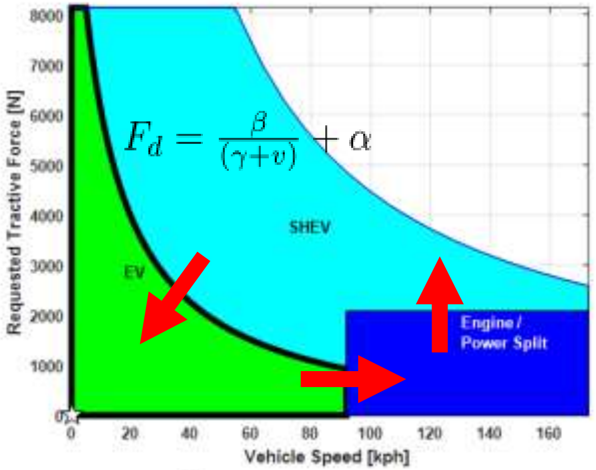
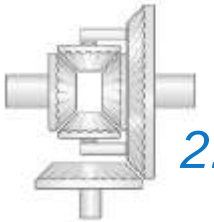




~ 12 Hours

+ 2% MPGe

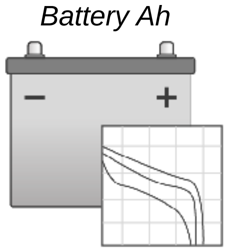




2.92:1

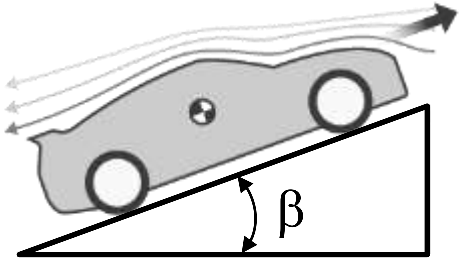
How Can the Problem be Expanded?

- Different Initial SOC Points



\# Series, # Parallel ?

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

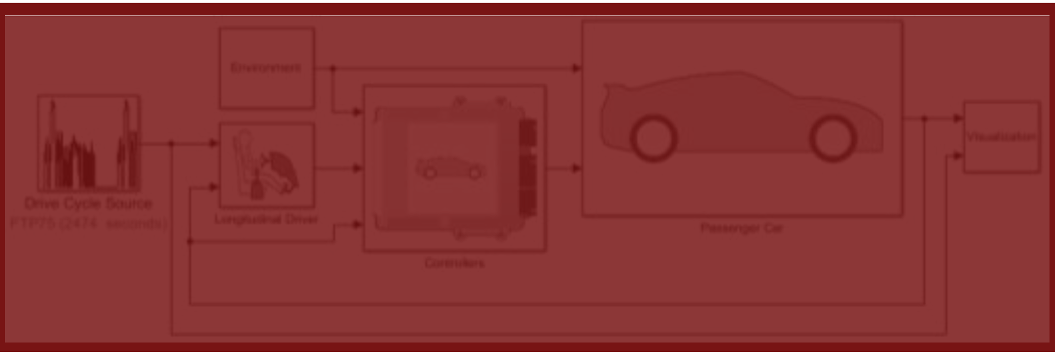


- Road Grade Profiles

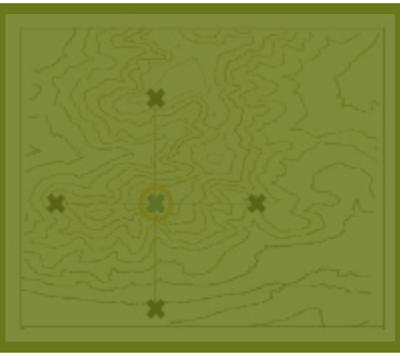
- Utilize 'Uncertain Variables' in SDO
  - Optimize for Robustness

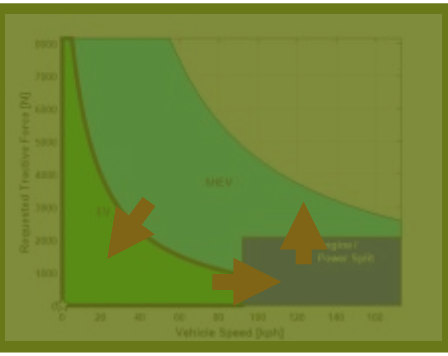
Agenda

Create



Optimize





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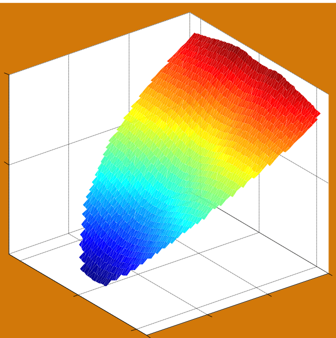
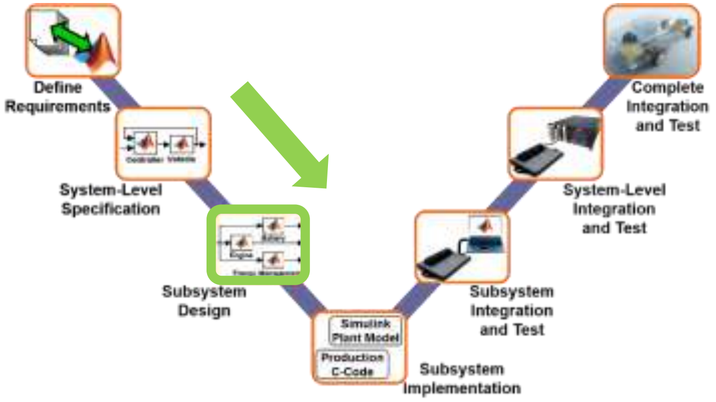


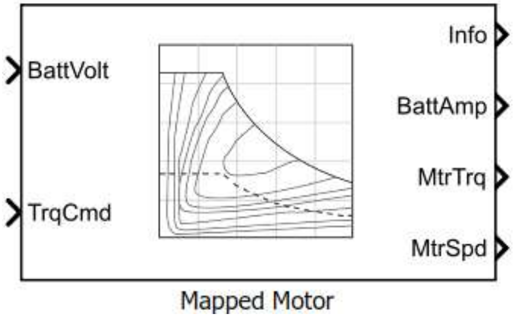
Challenges for the Automotive Controls Engineer

- 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?

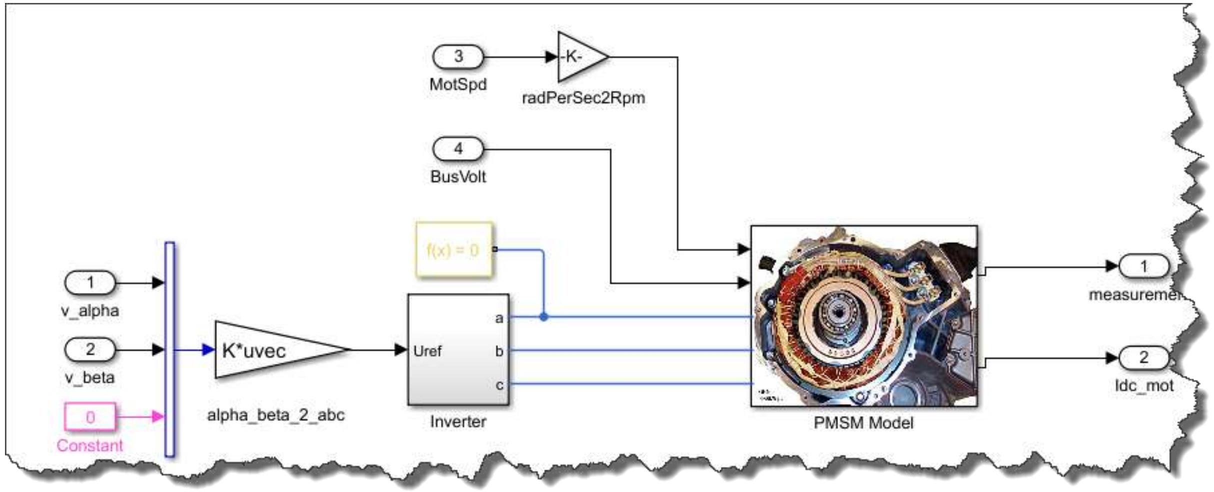
Different Motor Models for Different Needs



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



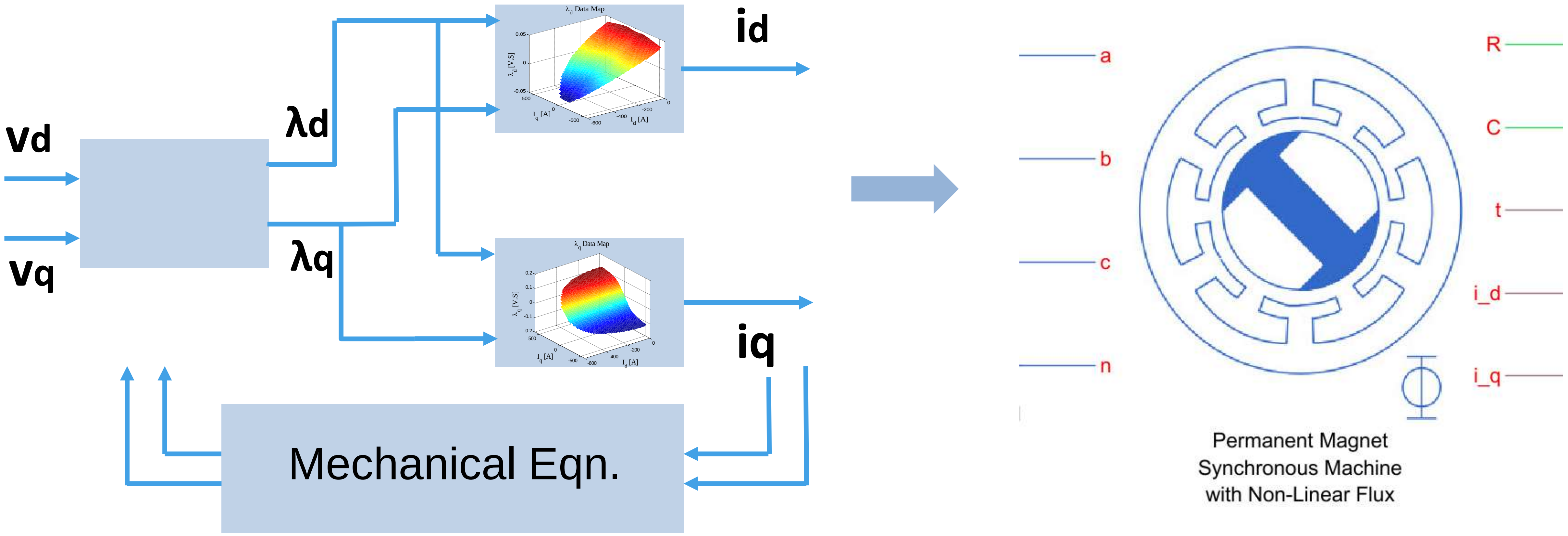
- Subsystem Control Design
  - Goal: Study controller interactions
  - Requirements: higher accuracy, inclusion of effects like saturation
  - Model choice: nonlinear saturation



Detailed model = inverter controller + nonlinear motor model

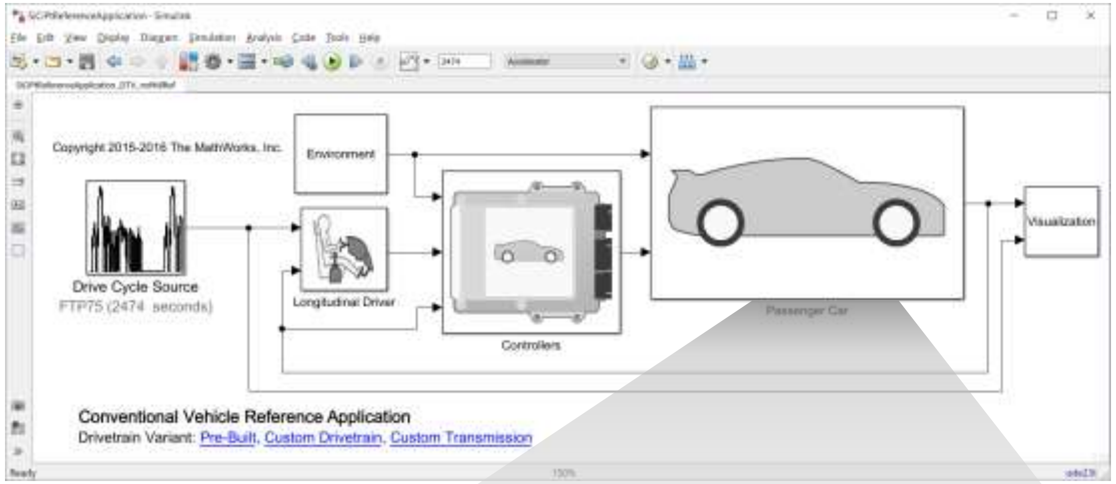
High Fidelity Detailed Motor Model in Simscape

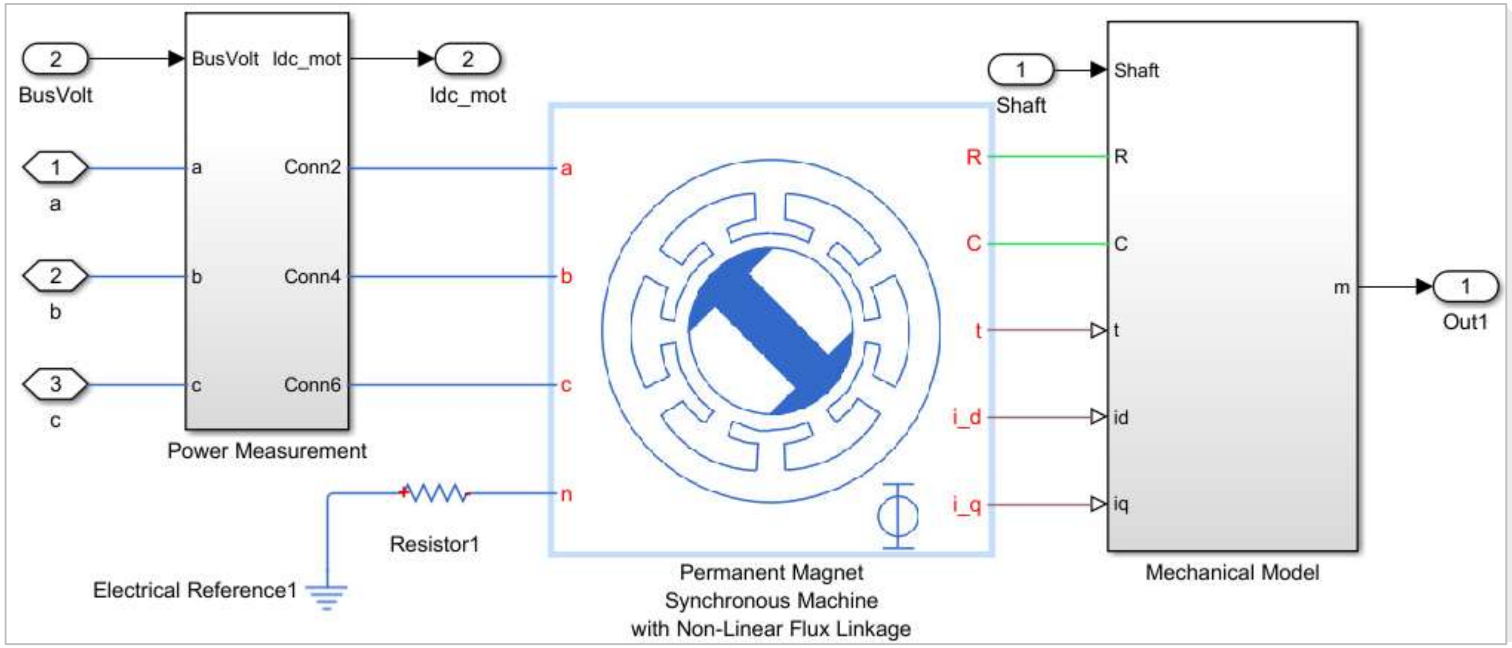
- FEA simulations or dynamometer data used to obtain non-linear flux table
- Simscape-based model created to capture this effect

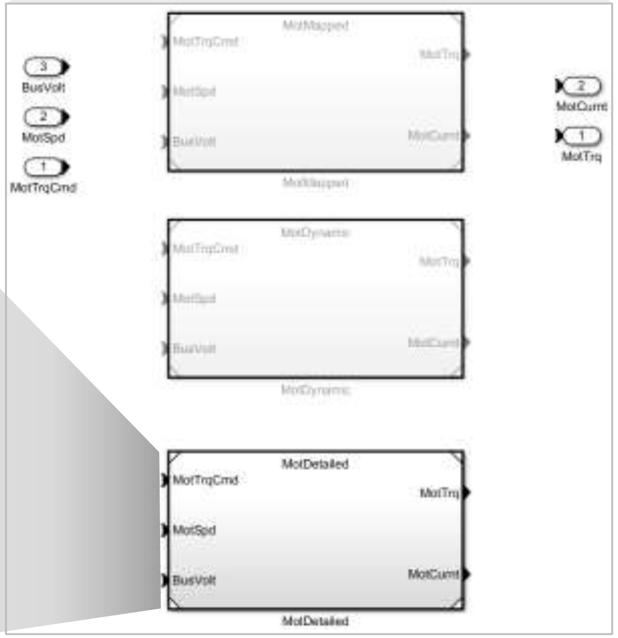


Including Detailed Subsystem Variants

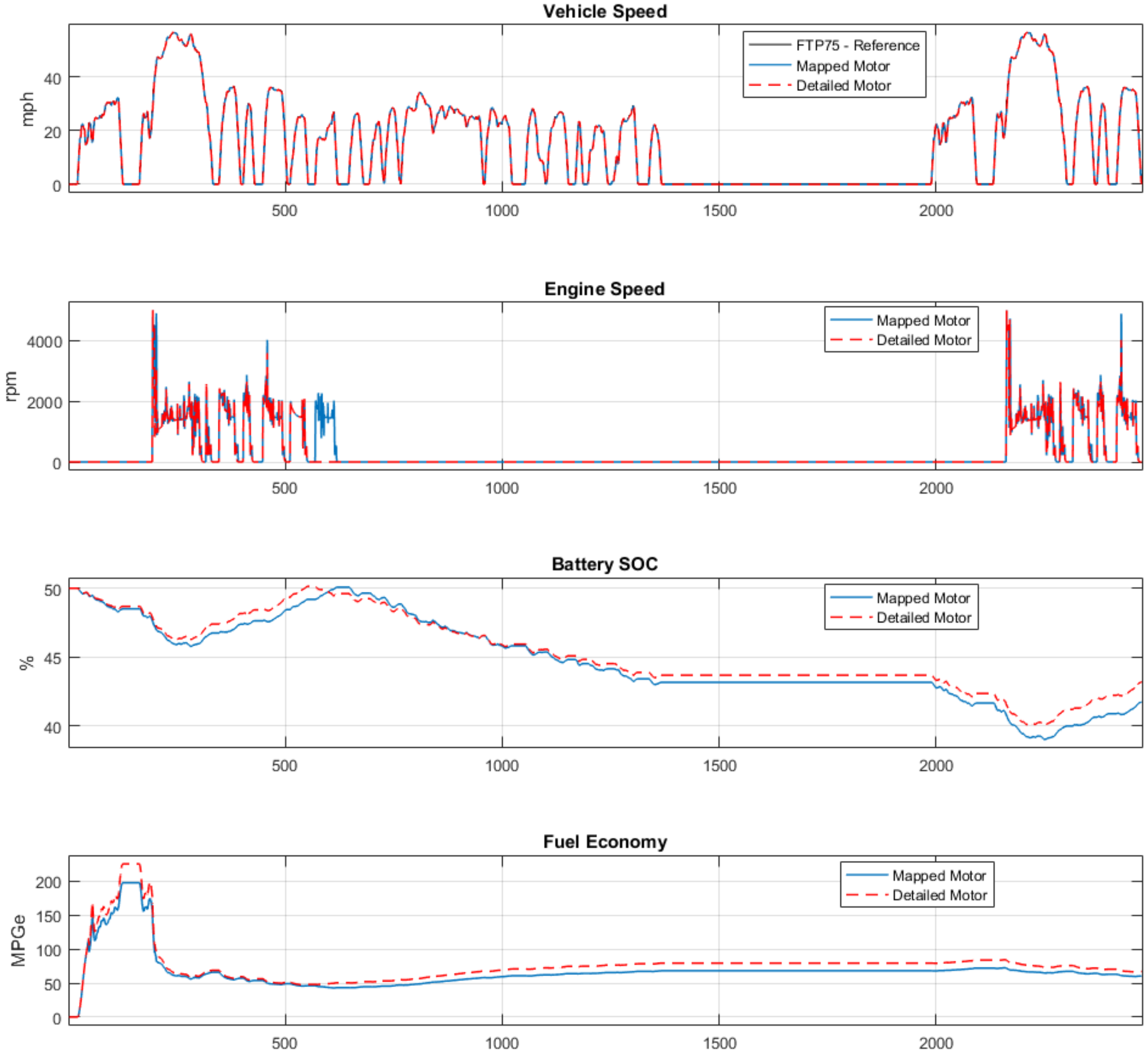
- Add your own subsystem variants to the existing vehicle models
  - Simulink-based
  - Simscape-based
  - S-function







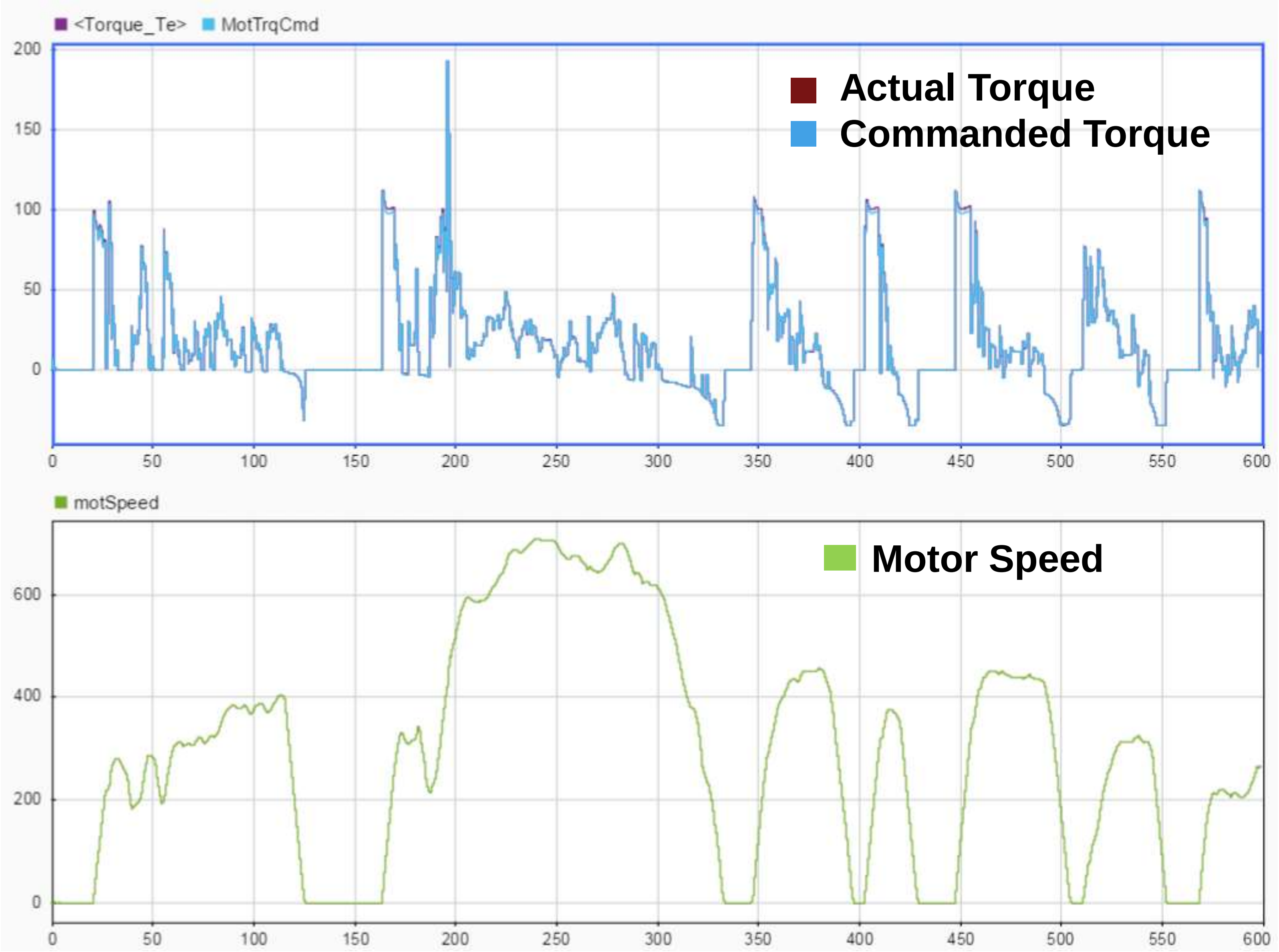
Detailed Model Variant Simulation



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

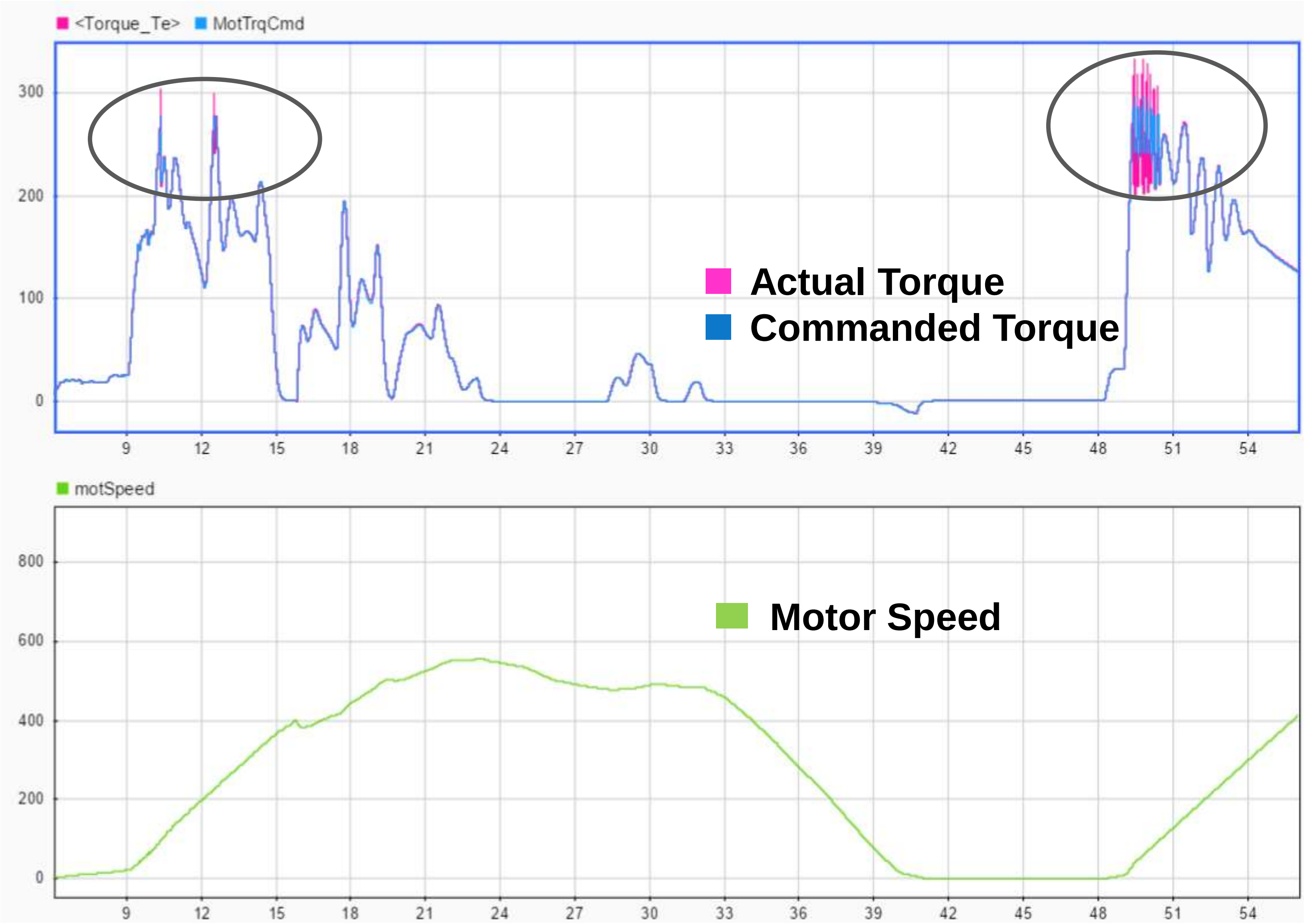
Torque Control Performance



FTP75 Drive Cycle

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

Torque Control Performance

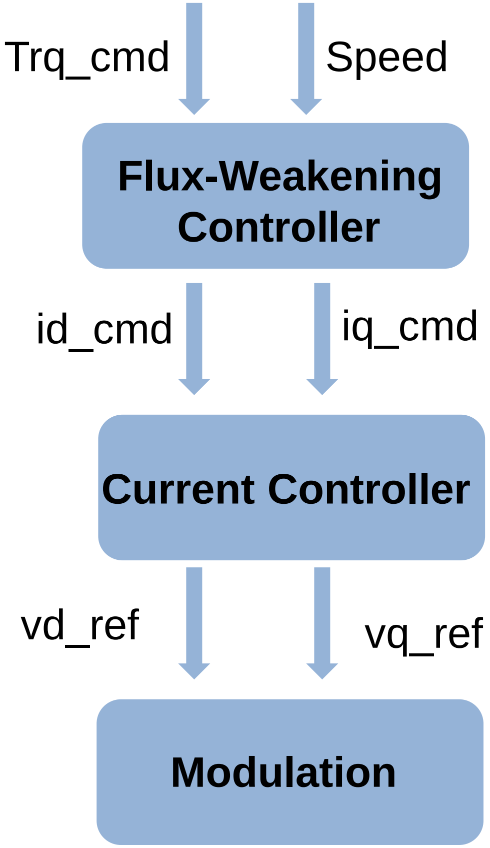


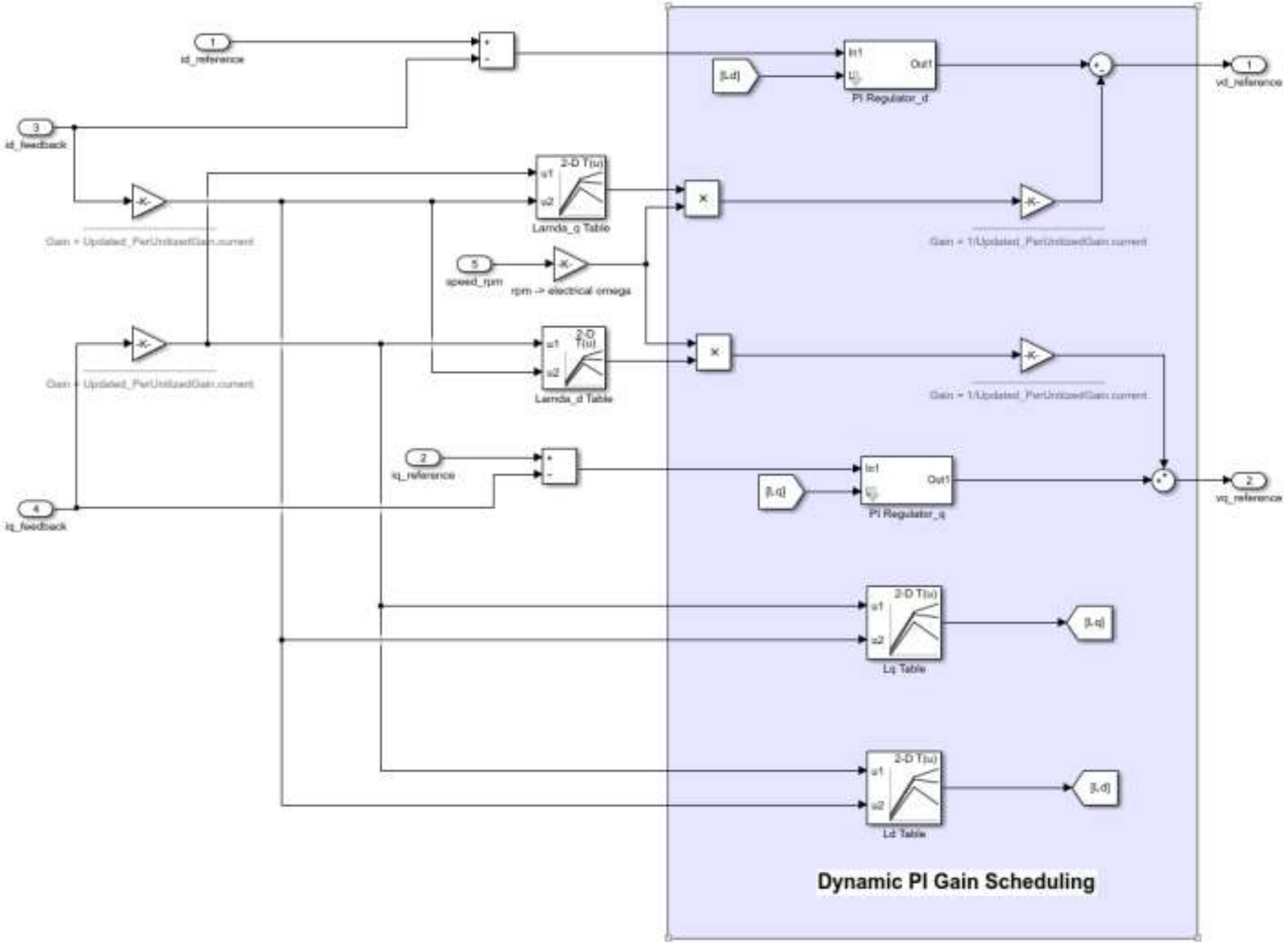
US06 Drive Cycle

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

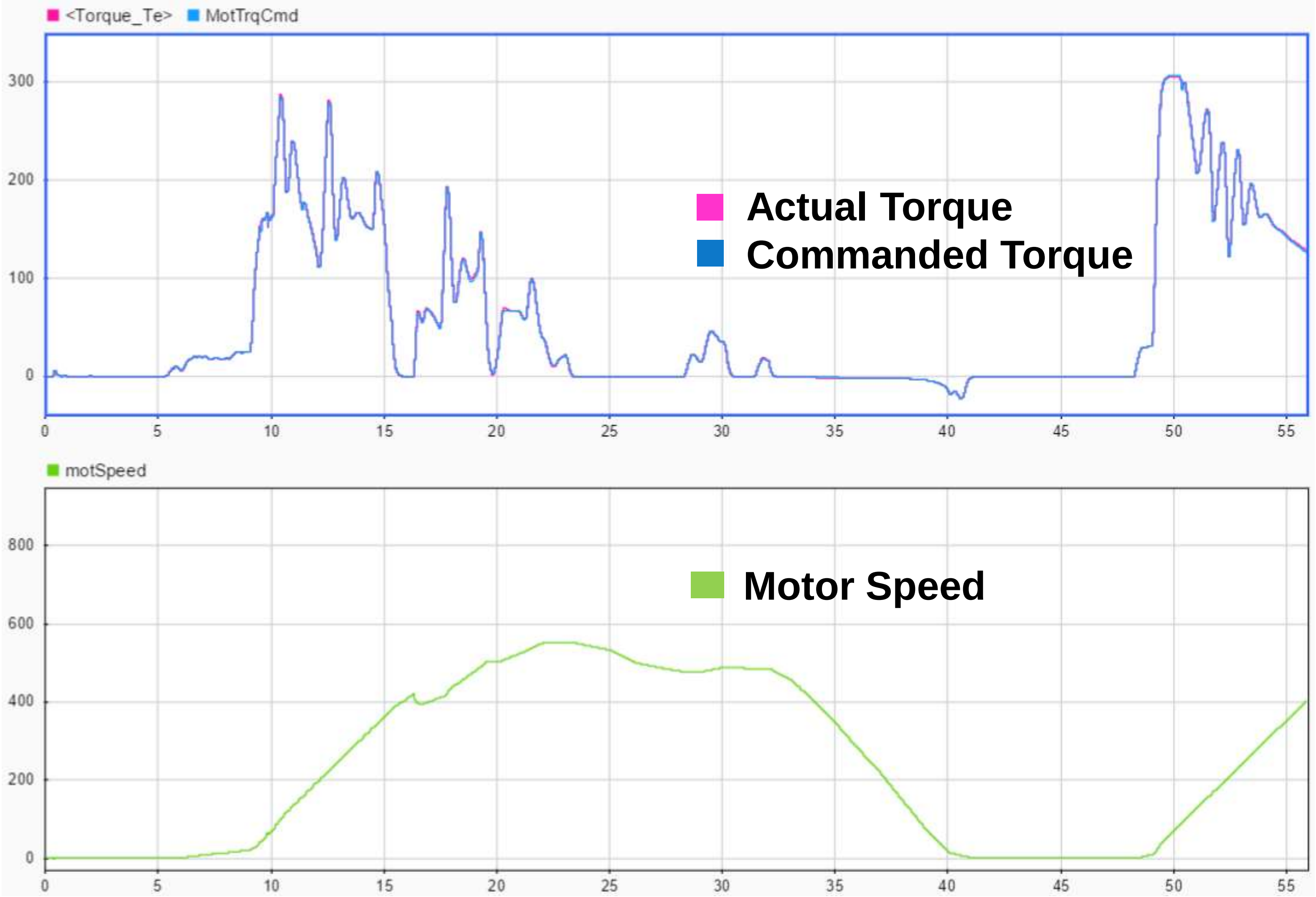
Controller Enhancements

- Controller robustness was improved via dynamic gain scheduling





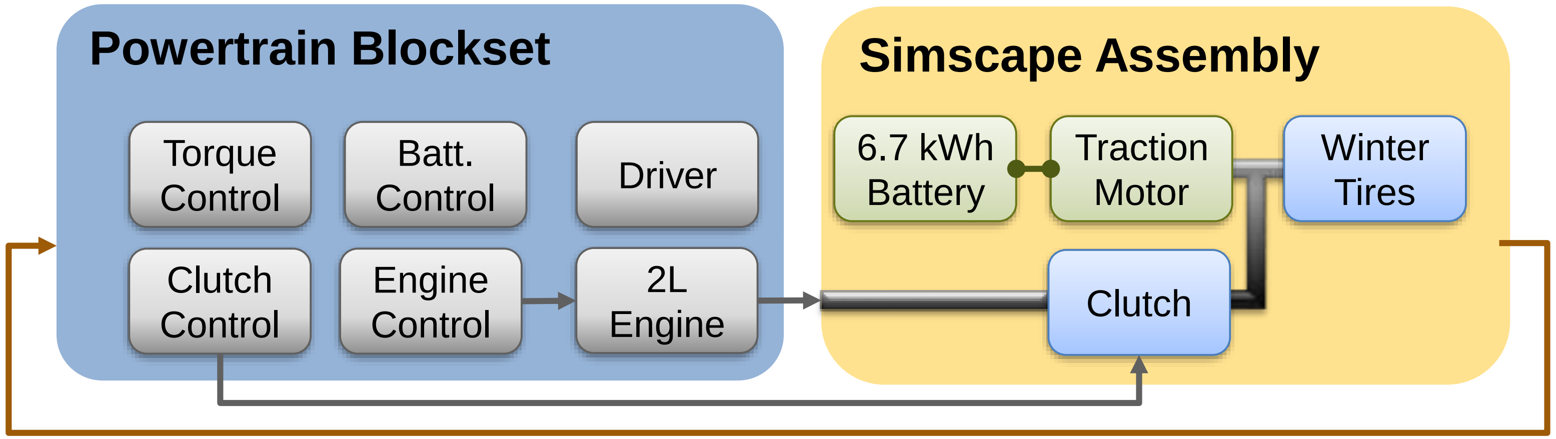
Torque Control Performance

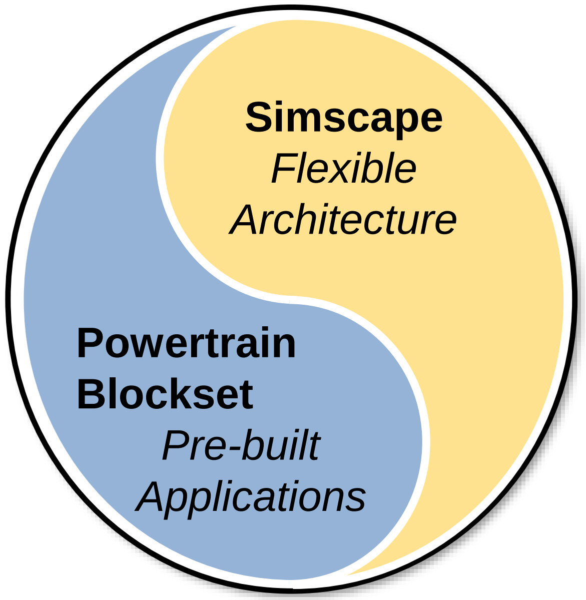


US06 Drive Cycle

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

Powertrain Blockset and Simscape

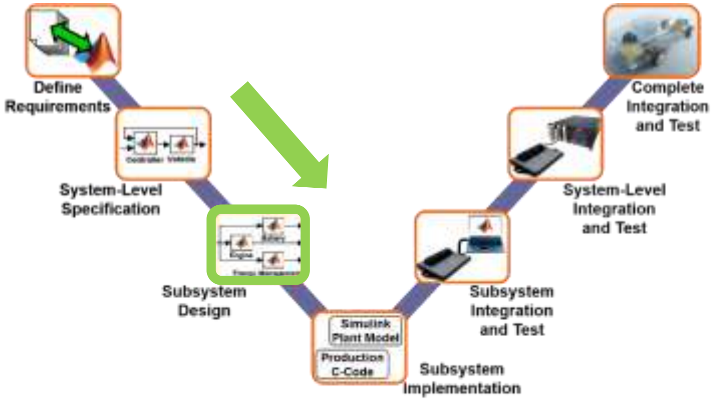




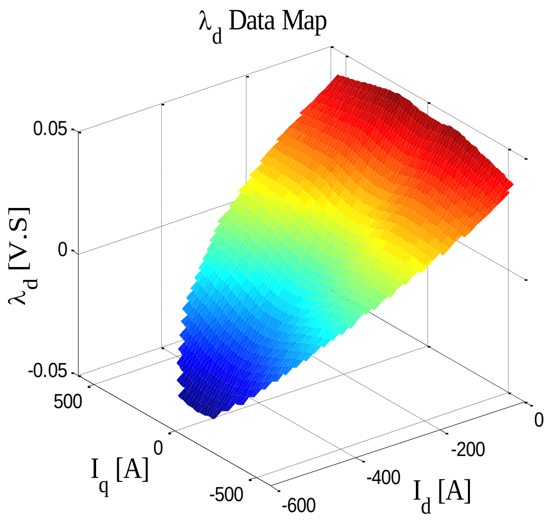
Complementary Technologies

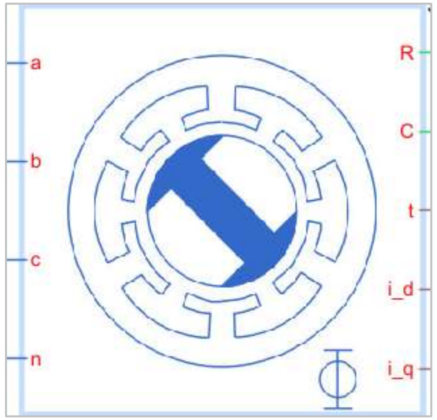
Powertrain Blockset Focus	Simscape Focus
Empirical studies	Predictive studies
Engine modeling	Electrical, fluid system design
Engine calibration	Multi-domain modeling
Fuel economy studies	Architecture concept evaluation

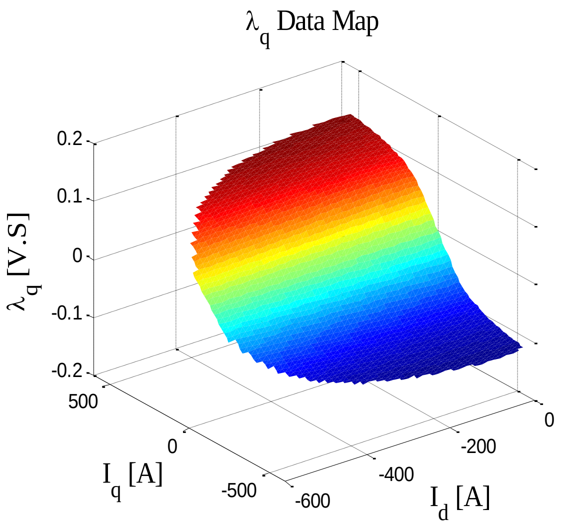
System Level Verification



- 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

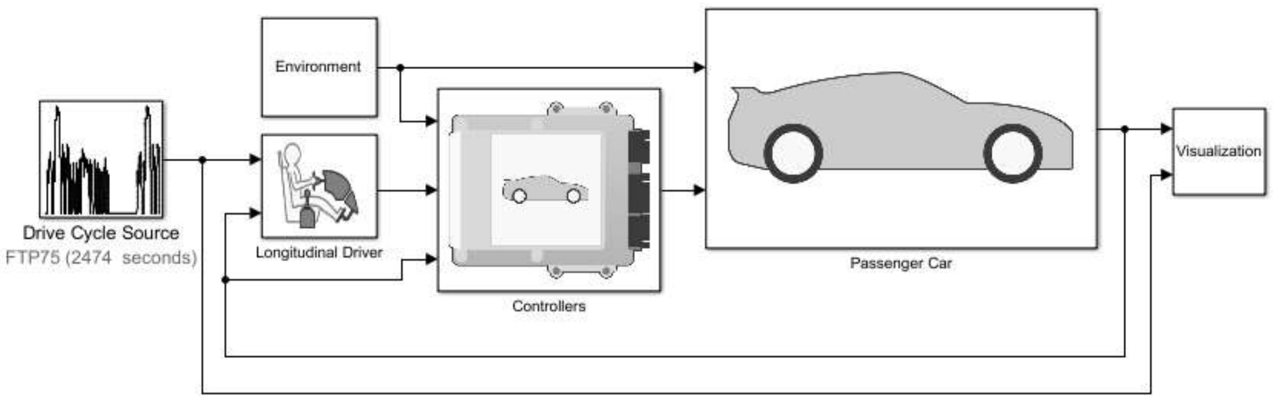






Key Takeaways

- 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