MathWorks
AUTOMOTIVE CONFERENCE 2019

Electrified Powertrain Vehicle Simulation in Simulink

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Models == Understanding

Model-Based Design

Systematic use of models throughout the development process

Modeling

Simulation

Fast repeatable tests

+

Automation

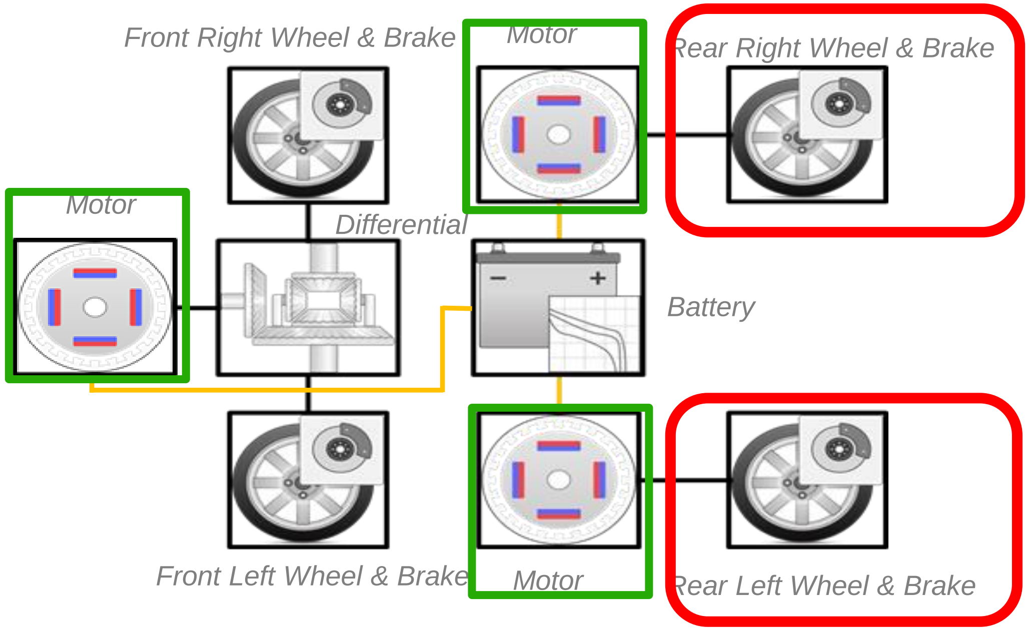
Coding

Verification

Fast agile development loops

Electric Vehicle Example

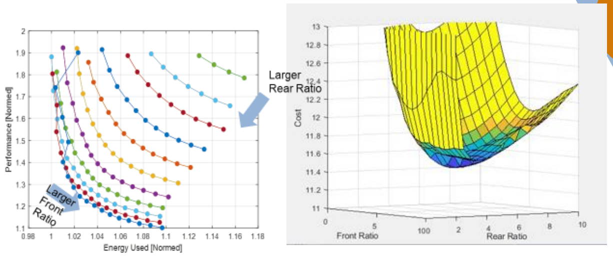
- 3-Motors Architecture
  - Rear : 2 x 40kW Motor
  - Front: 60kW Motor
  - 50kW-hr battery
- Torque Vectoring Capability
  - Independent dual motors
- Use Model-Based Design to
  - Assess performance
  - Develop control algorithms
  - Visualize and test
  - Deploy to hardware



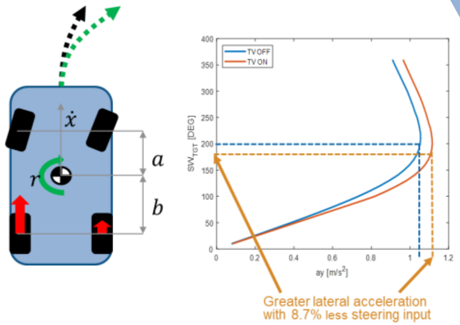
Model Use Cases Across the V-cycle

Design

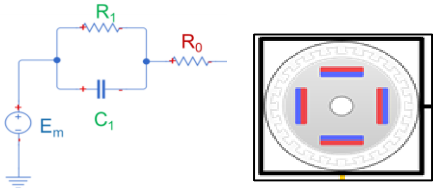
Test



EV Design Exploration/Component Sizing

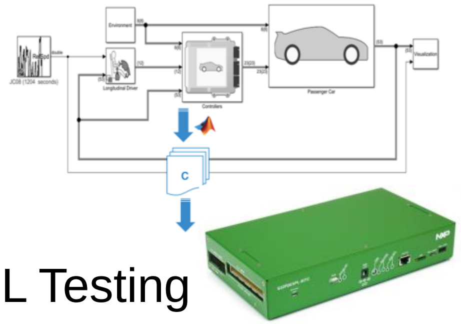


Control Design

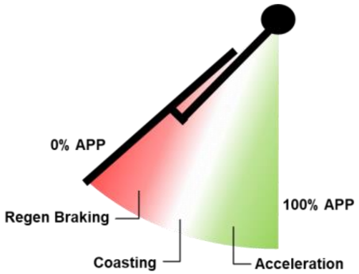


Subsystem Design

HIL Testing

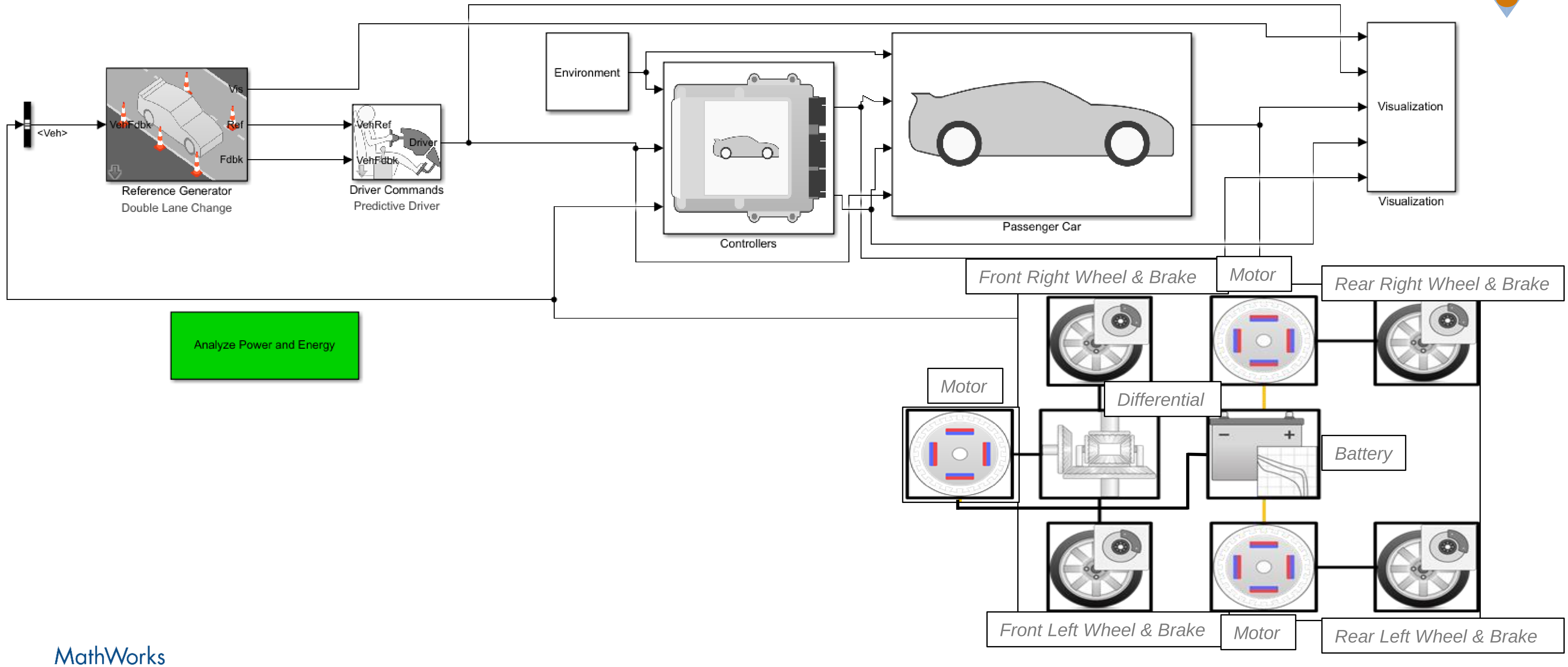


PIL Testing



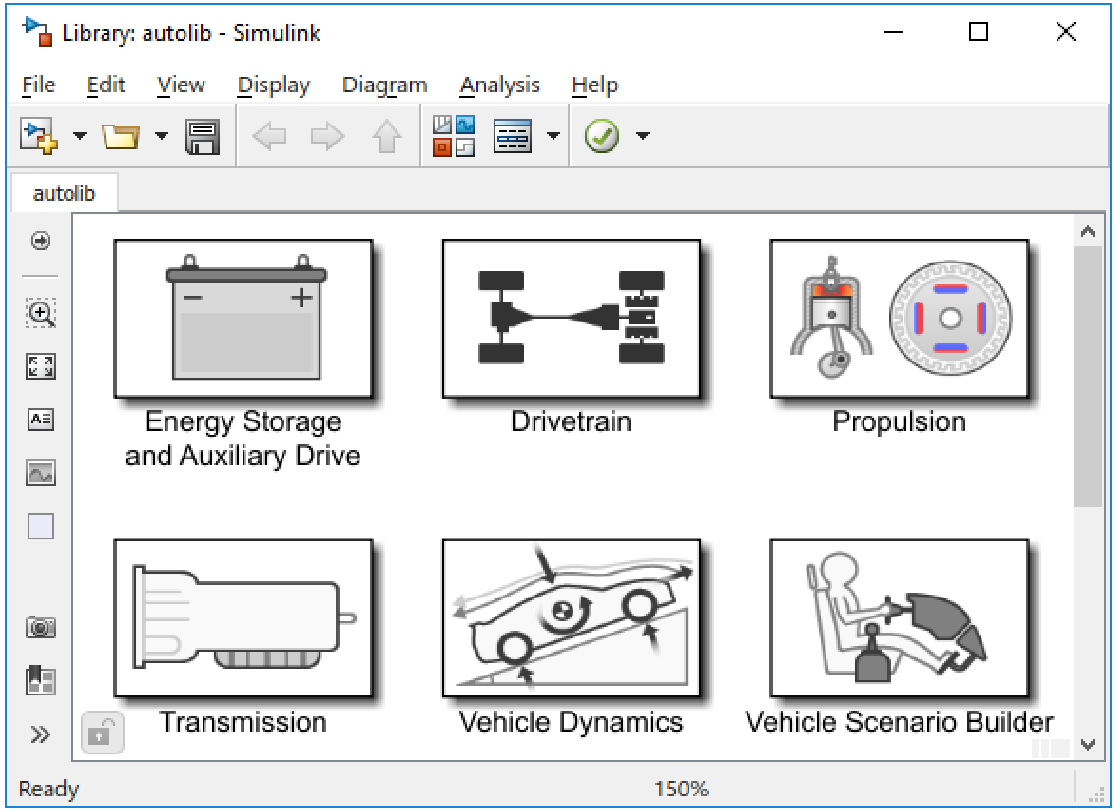
Drivability Validation

Electric Vehicle Energy Management Strategy & Performance Simulation

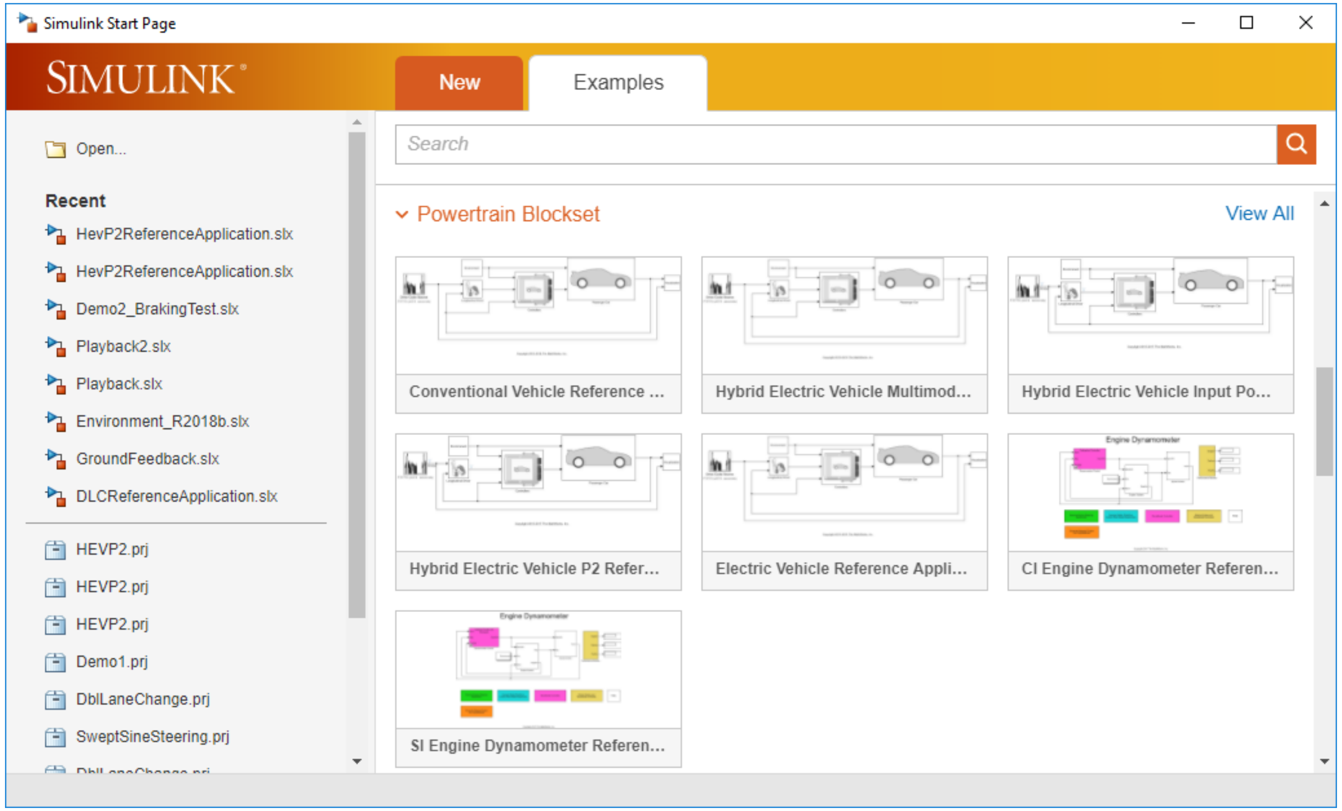


Powertrain Blockset Features

Library of blocks



Pre-built reference applications



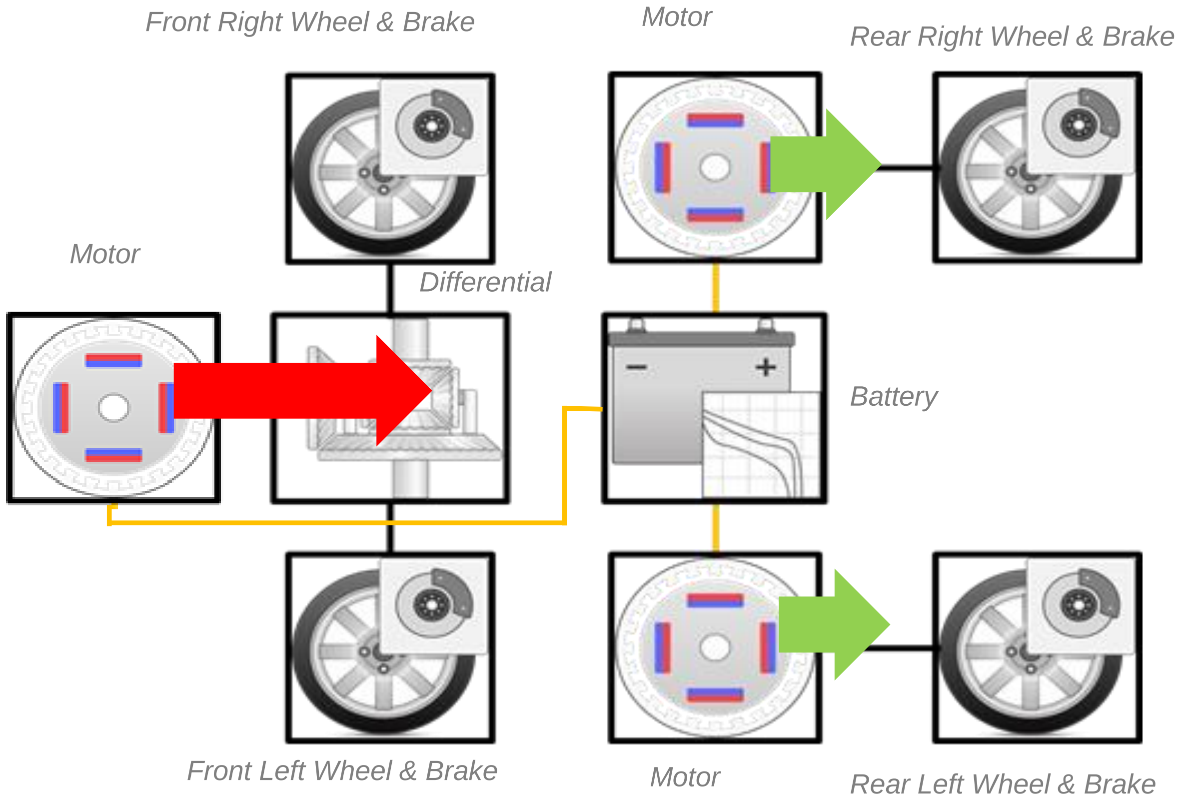
EV Energy Management Strategy (EMS)

- Instantaneous torque (or power) command to actuators (electric machines)
- Subject to constraints:

$$\tau_{min}(\omega) \leq \tau_{act} \leq \tau_{max}(\omega)$$
$$P_{chg}(SOC) \leq P_{batt} \leq P_{dischg}(SOC)$$
$$I_{chg}(SOC) \leq I_{batt} \leq I_{dischg}(SOC)$$

- Attempt to minimize energy consumption, maintain drivability

$$T_{demand} = T_{mot,f} + T_{mot,r}$$



EV Energy Management Strategy (EMS) Process

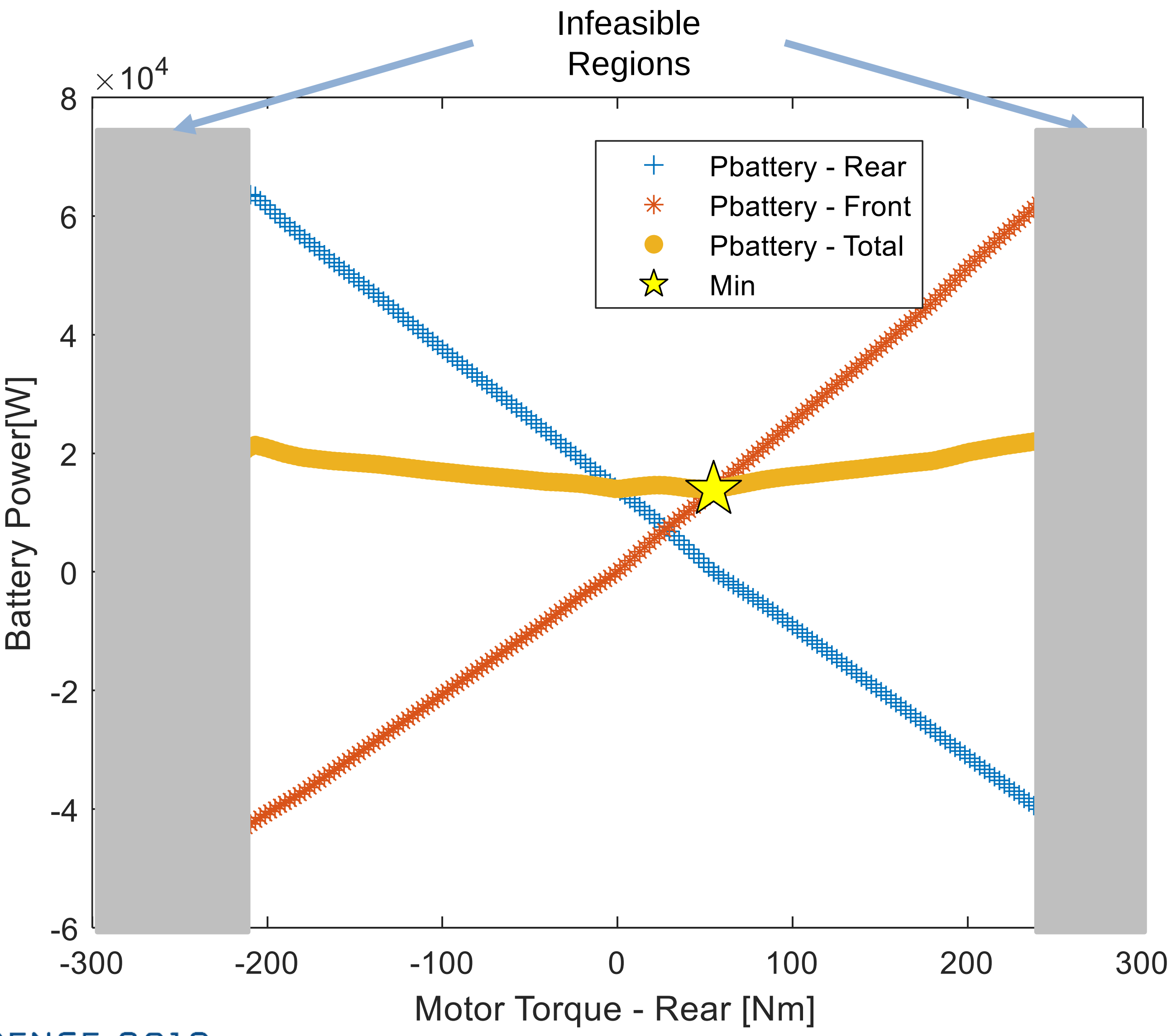
1. Create torque split vector
2. Check constraints, determine infeasible conditions
3. Calculate and minimize cost function(Battery Power)

$$\begin{bmatrix} -Min\ Rear\ Torque \\ \vdots \\ +Max\ Rear\ Torque \end{bmatrix}$$

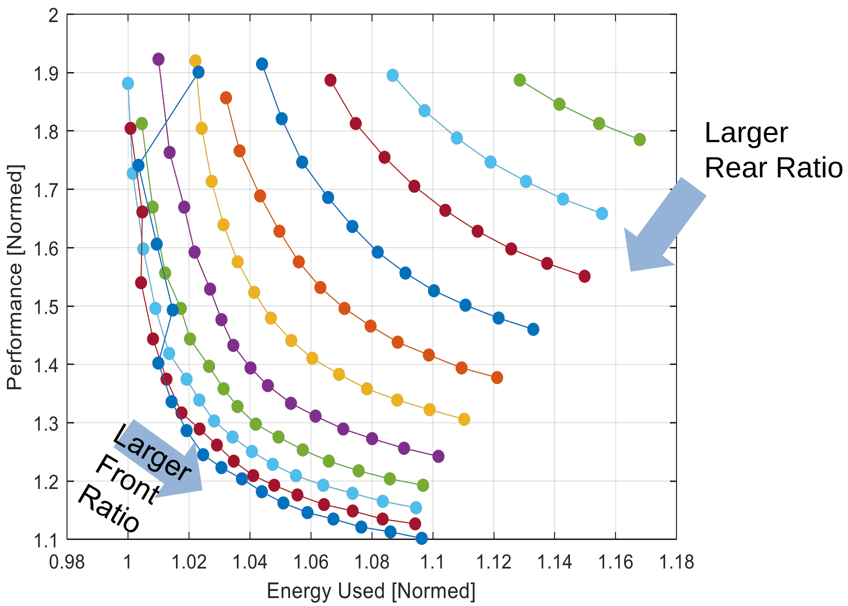
$$\tau_{min}(\omega) \leq \tau_{act} \leq \tau_{max}(\omega)$$
$$P_{chg}(SOC) \leq P_{batt} \leq P_{dischg}(SOC)$$
$$I_{chg}(SOC) \leq I_{batt} \leq I_{dischg}(SOC)$$
$$\tau_{demand} = \tau_{front} + \tau_{rear}$$

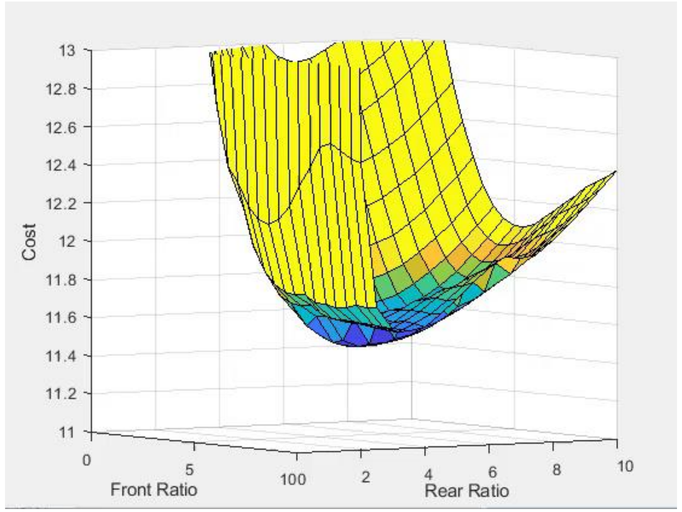
$$\min_{\tau_{rear}} P_b(\tau_{rear})$$

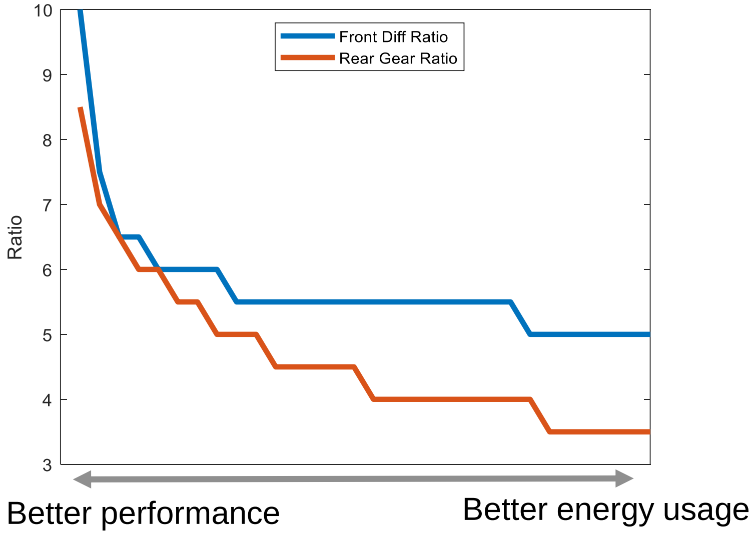
EV Energy Management Strategy (EMS) Process



Optimizing Front and Rear Gear Ratios



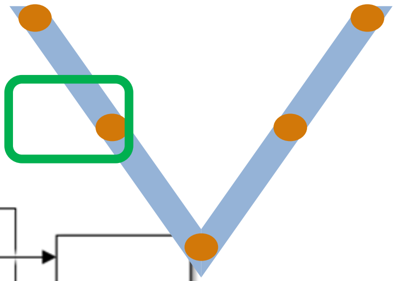


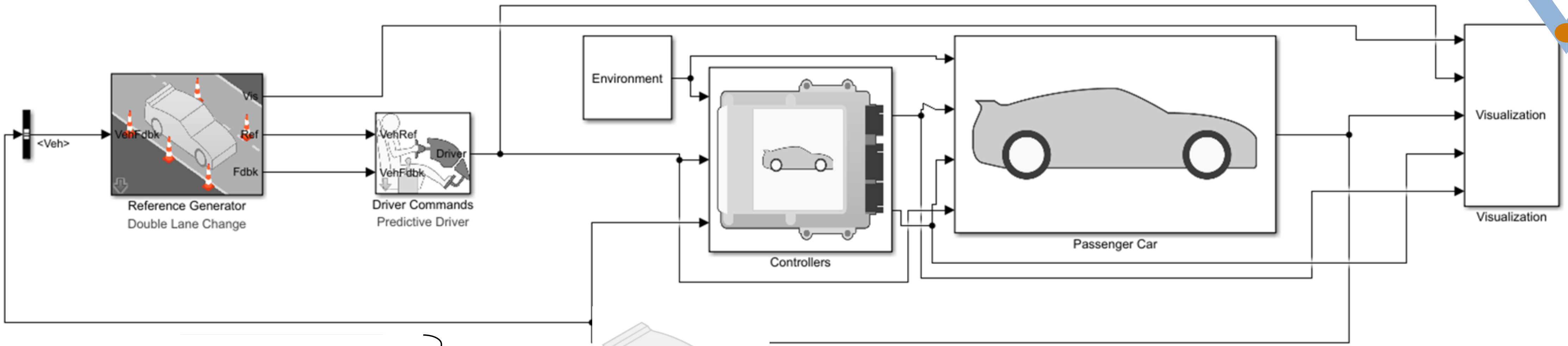


$$\min_{N_f, N_r} (0.55E_{FTP} + 0.45E_{HWY})\,W_1 + W_2(T_{0-120KPH})$$

- A pareto curve exists between energy usage and acceleration performance
- A cost function can be used to help determine the best set of ratios
- Higher weight towards system efficiency leads to lower over all gear ratios

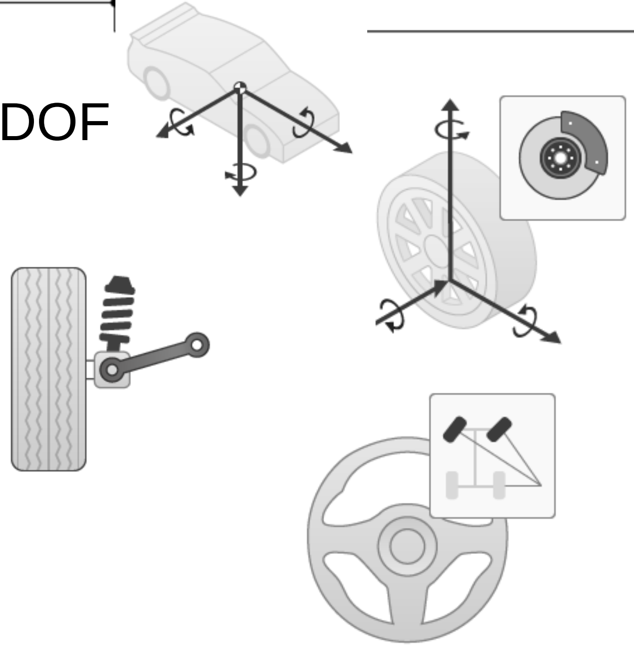
Electric Vehicle Torque Vectoring Simulation



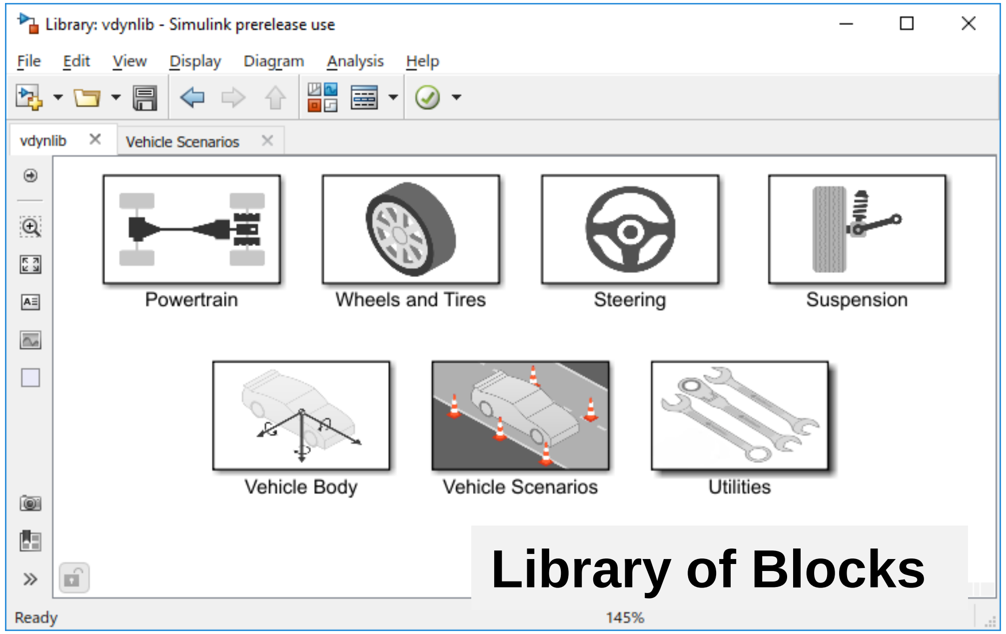


- 6-DOF Vehicle
- 2-DOF Tire + Brake
- Suspension
- Steering

14-DOF



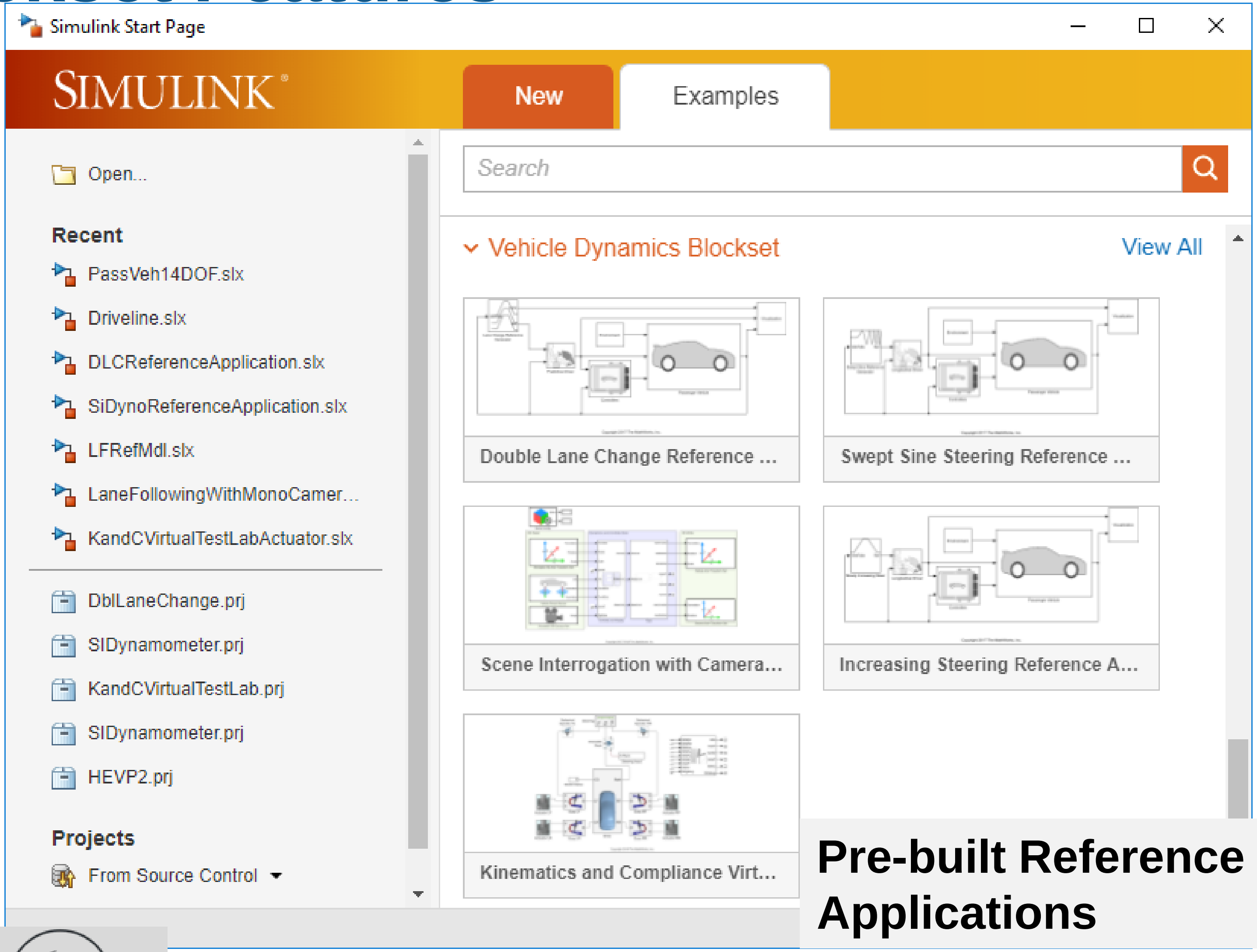
Vehicle Dynamics Blockset Features



Library of Blocks

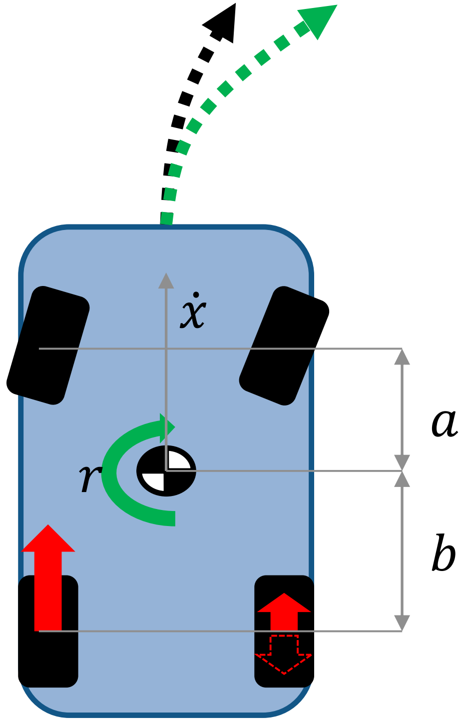
Game engine

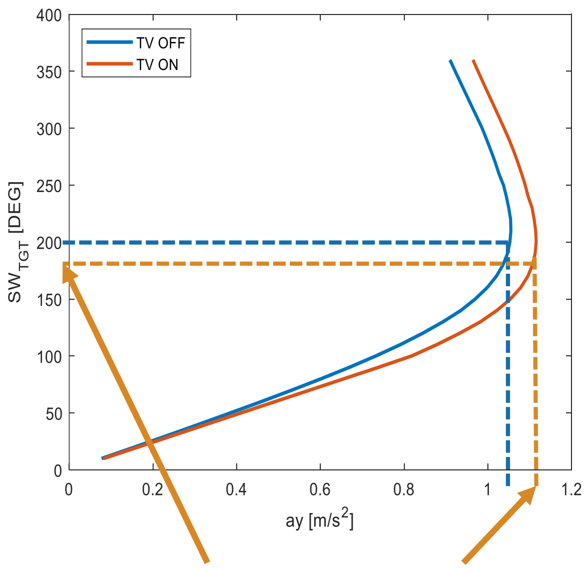
UNREAL ENGINE



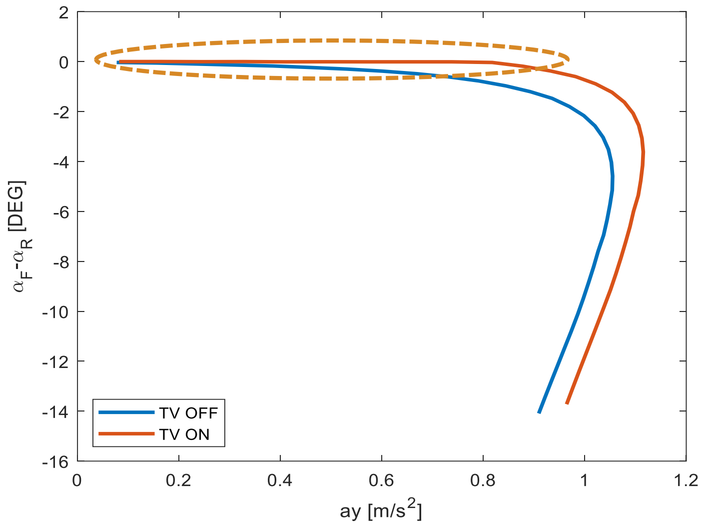
Pre-built Reference Applications

Vehicle Dynamics Control – Torque Vectoring

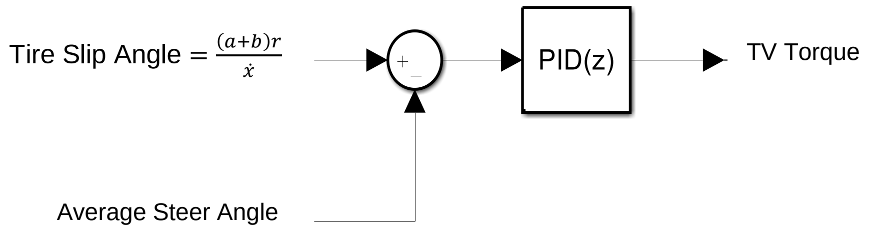




Greater lateral acceleration with 8.7% less steering input



Longer linear tire slip angle region and 5.7% greater lateral acceleration



A Torque Vectoring Strategy for Improving the Performance of a Rear Wheel Drive Electric Vehicle

Jyotishman Ghosh, Andrea Tonoli, Nicola Amati
Department of Mechanical and Aerospace Engineering
Politecnico di Torino
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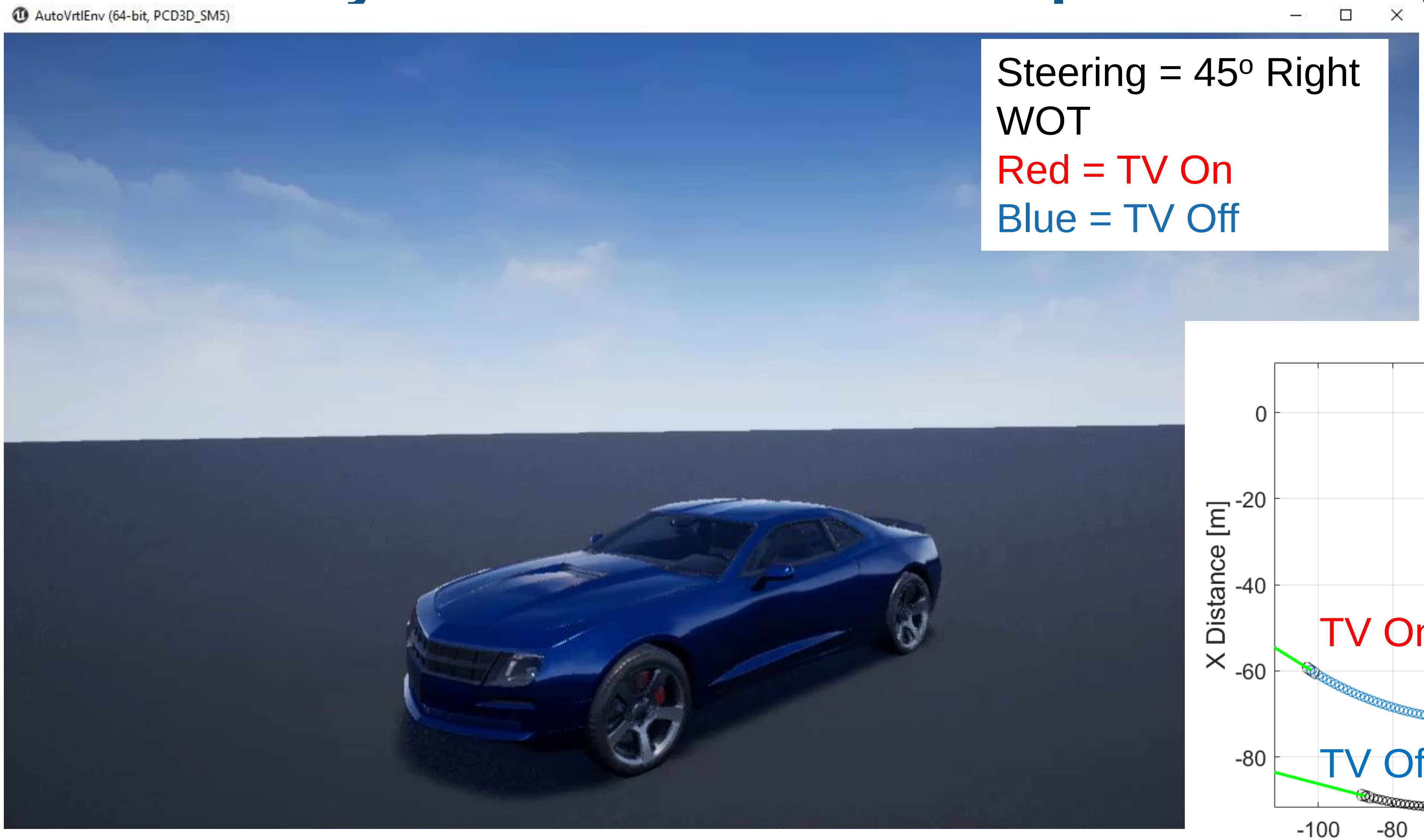
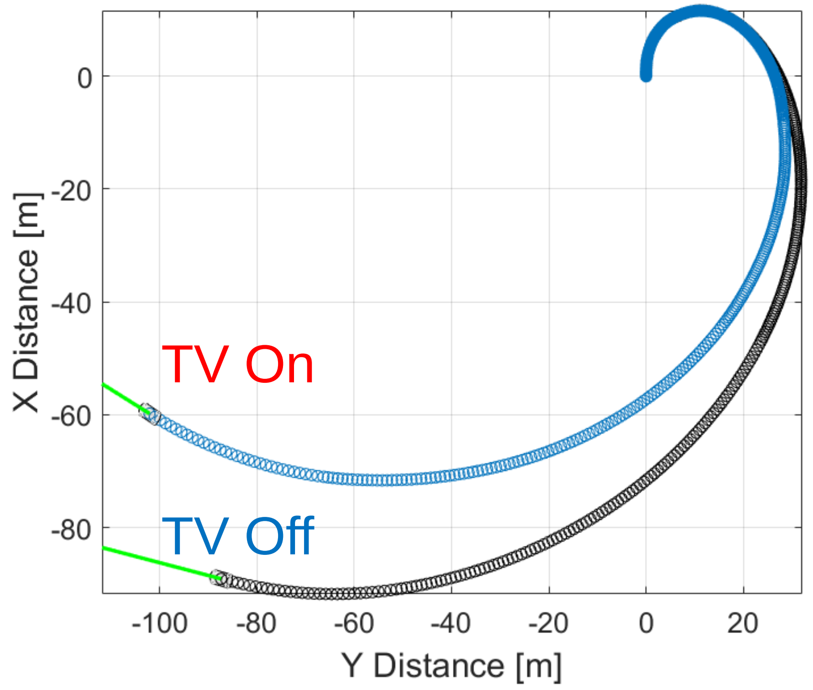
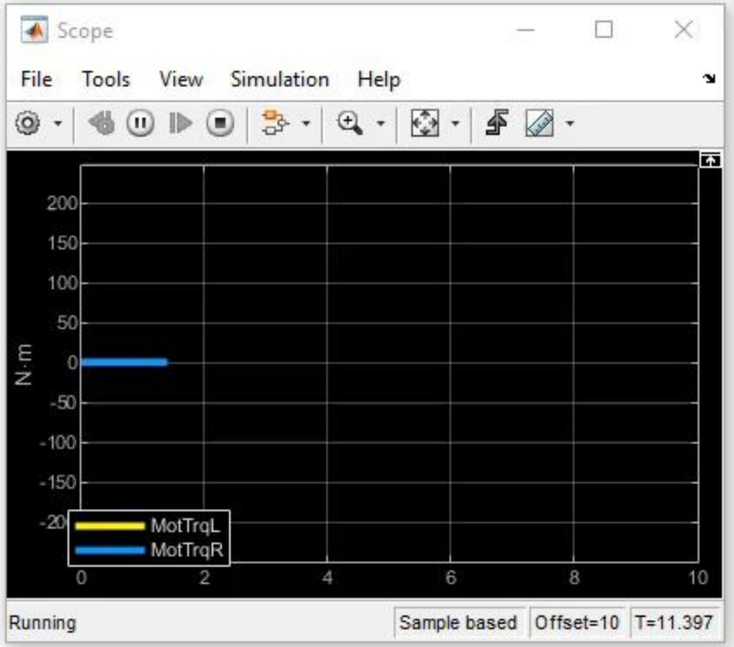
Vehicle Dynamics Control – Torque Vectoring

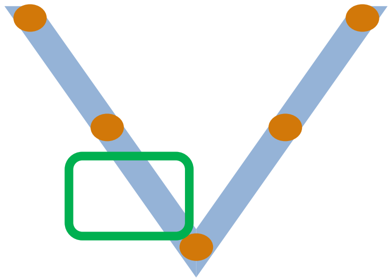




Vehicle Model Simulation – Driver-in-the-Loop

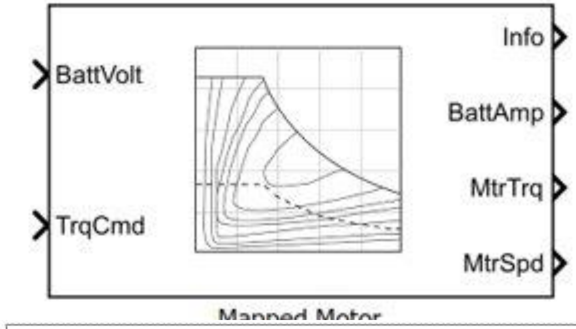


Subsystem & Components Modeling
-- Motor / Motor Control

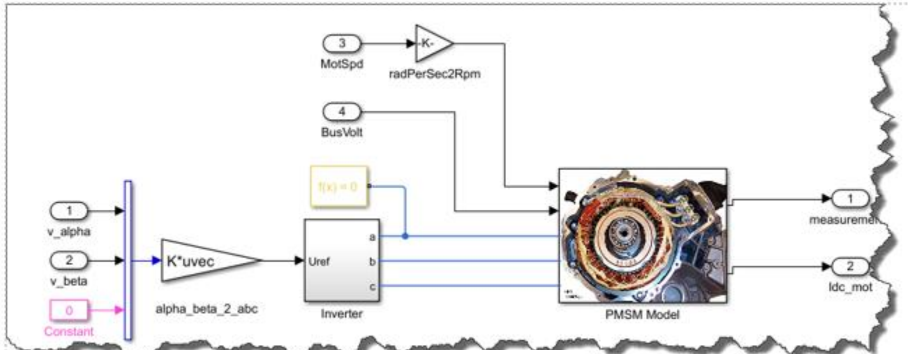


Different Fidelity of Motor Modeling:

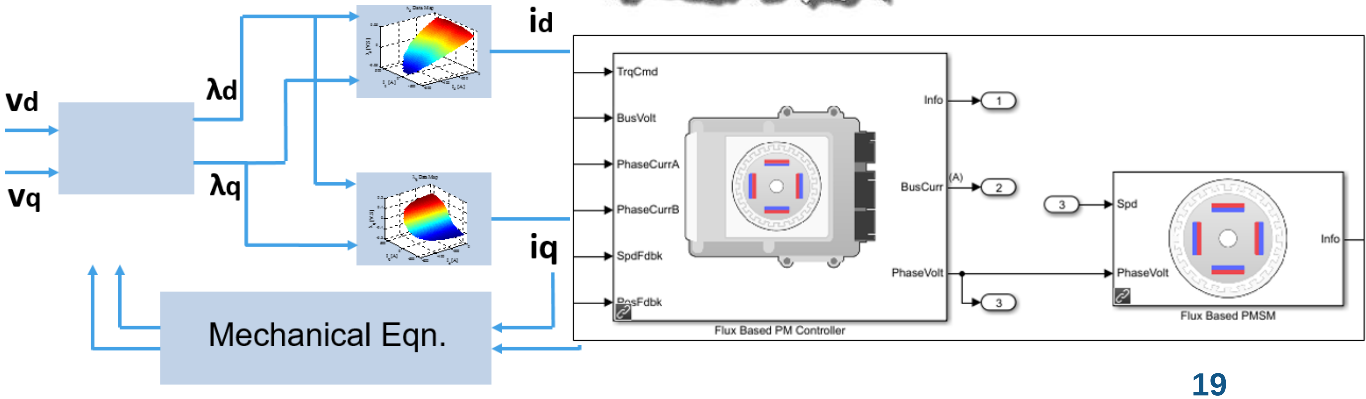
- Map Based



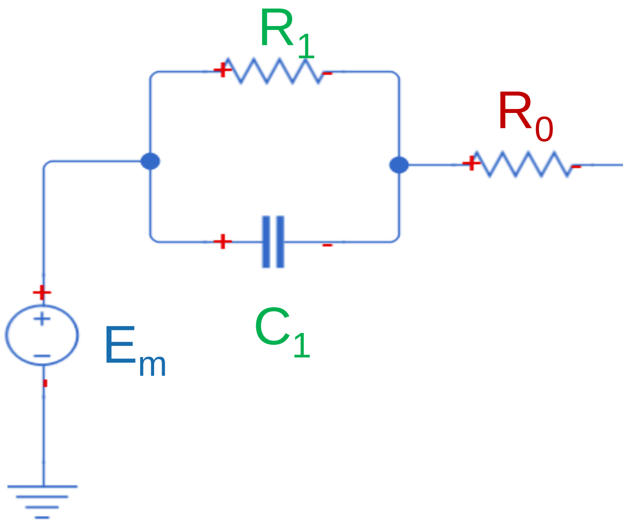
- Detail Model (Inverter controller + nonlinear motor model)

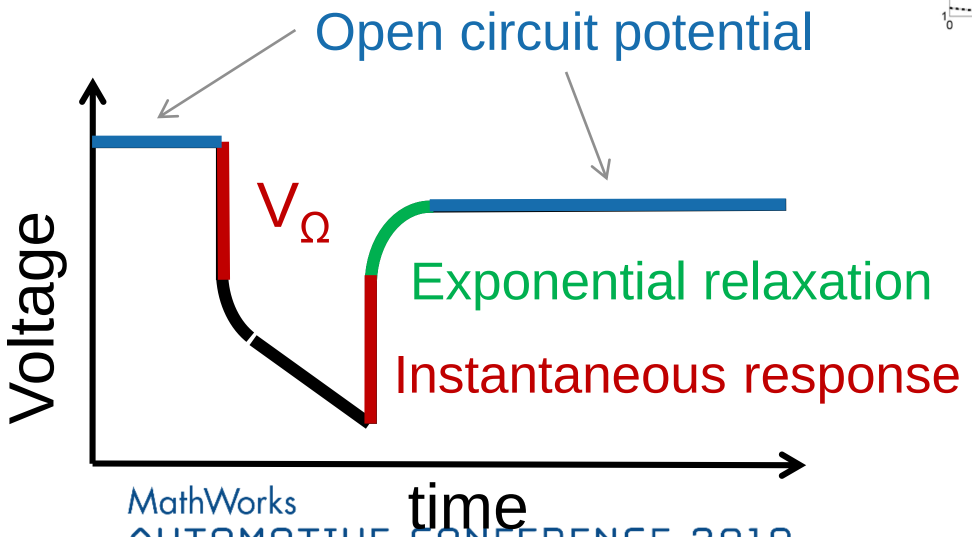


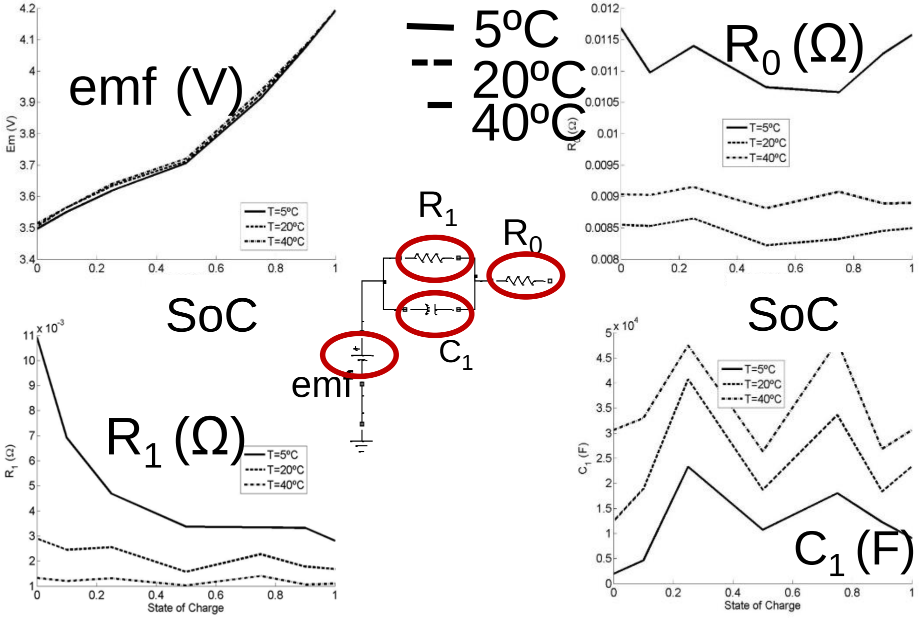
- High Fidelity Model
  - FEA simulations
  - or dyno data used to obtain flux table

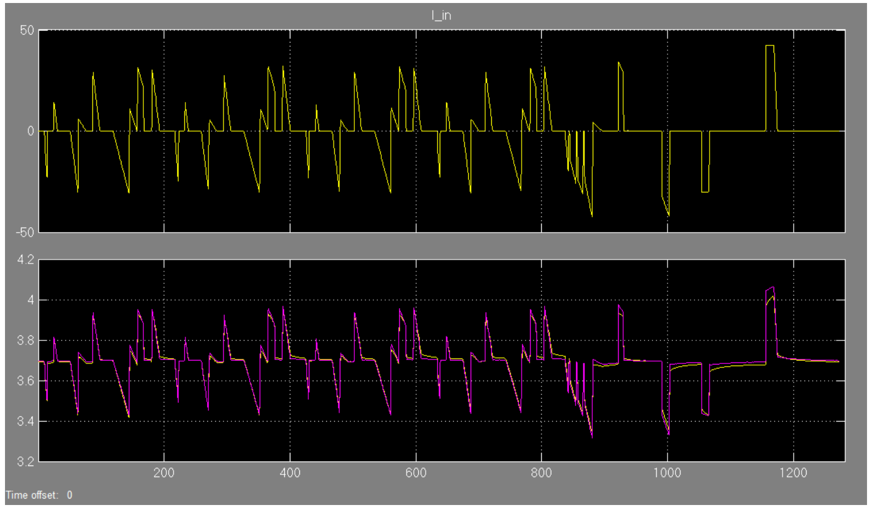


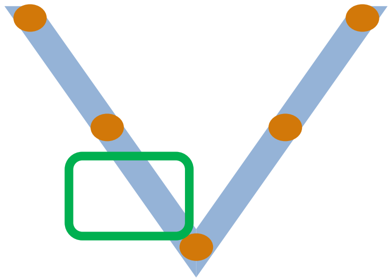
Subsystem & Components Modeling
-- Battery / BMS



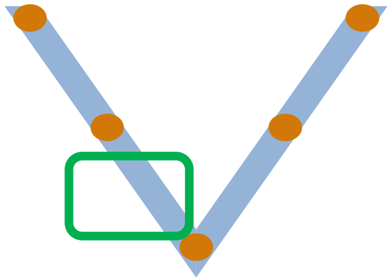




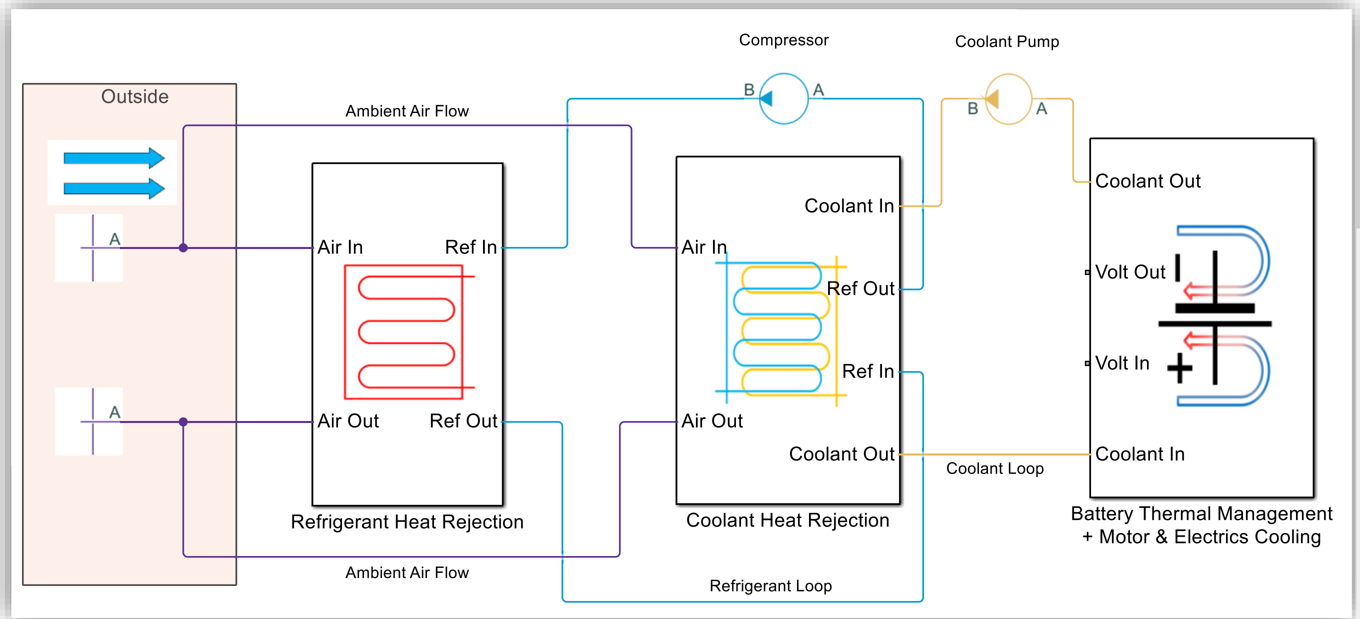


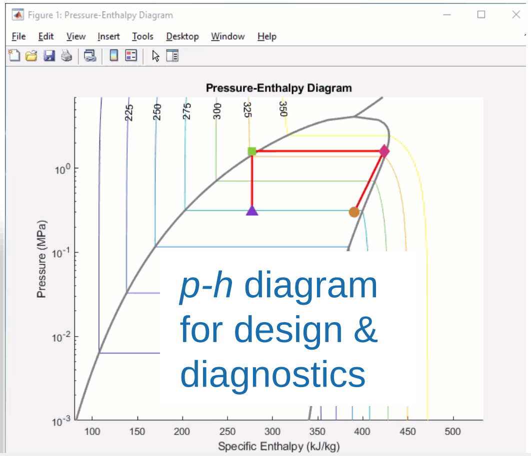


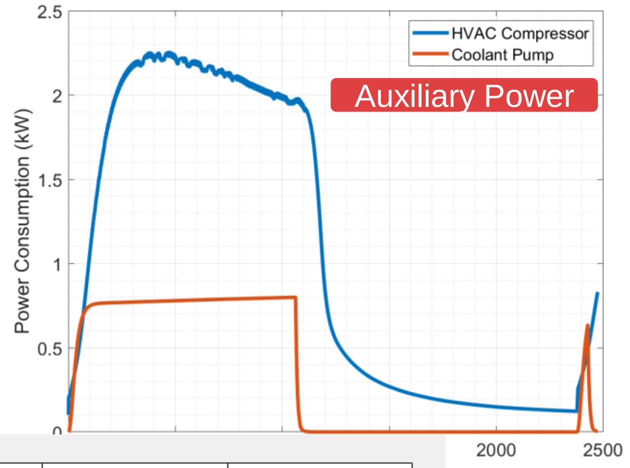
Subsystem & Components Modeling
-- Cooling System (Battery/Electrical)

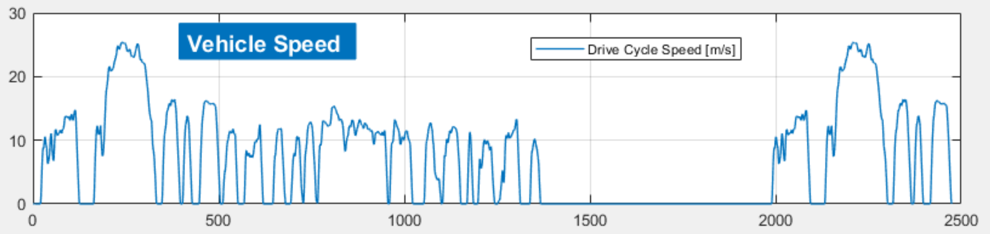


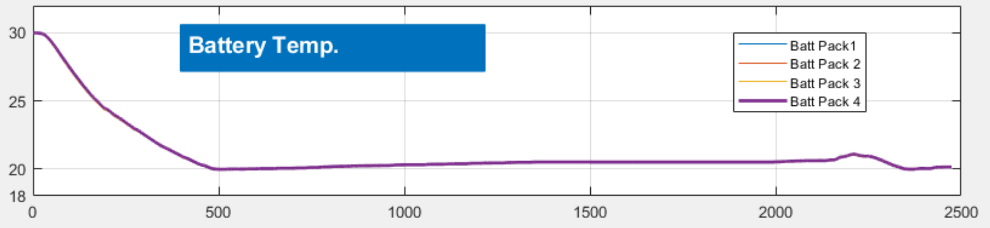
- Multi-physics model:
  Moist Air – 2-Phase Fluid – Thermal Liquid
- Thermal management algorithm design, power consumption estimate & component sizing



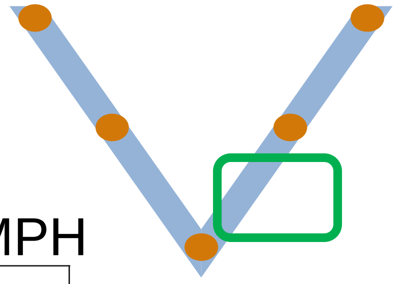


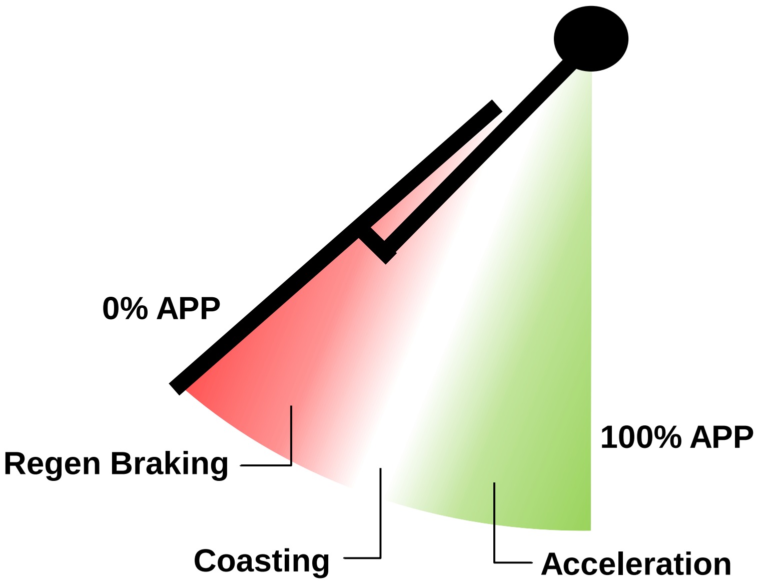


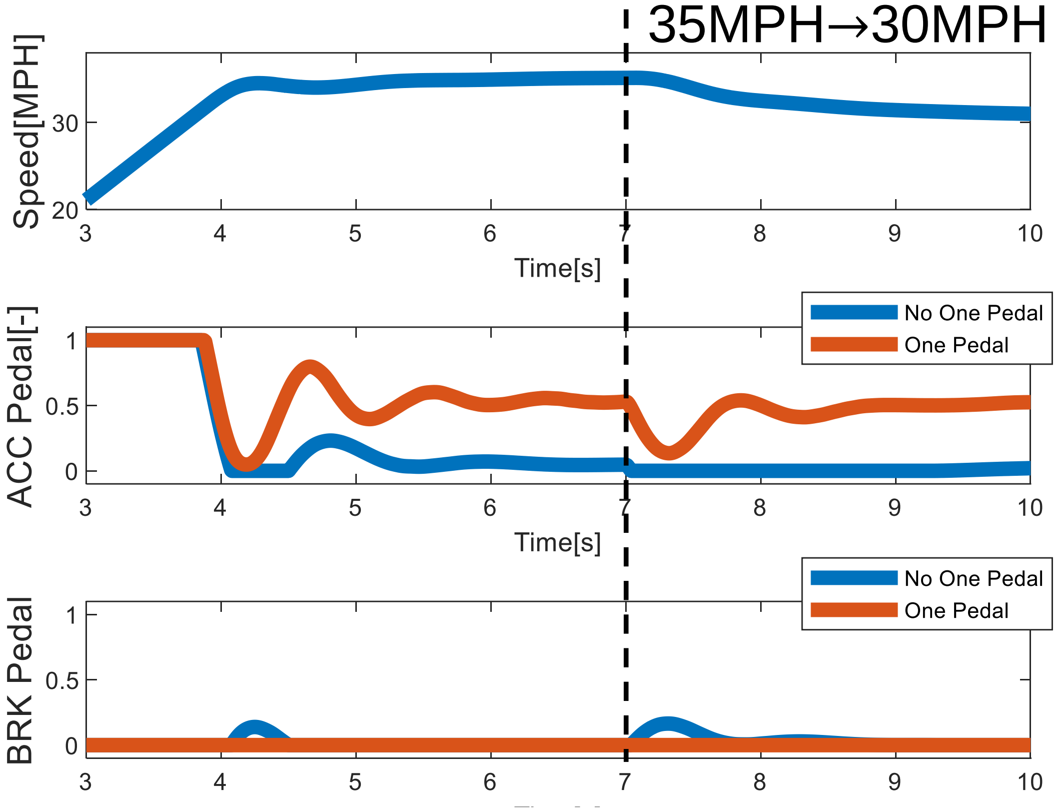




Control Feature Testing and Validation
-- One-Pedal Control

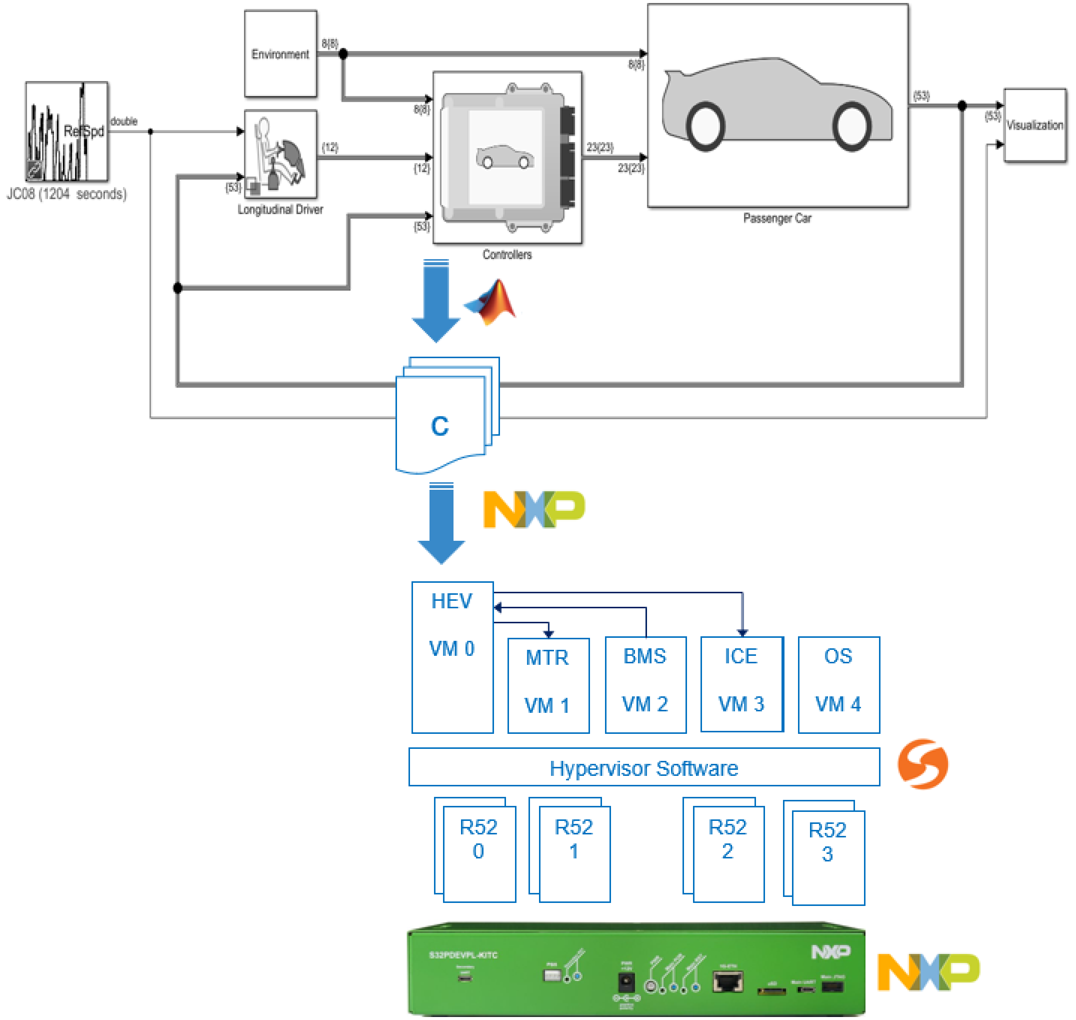


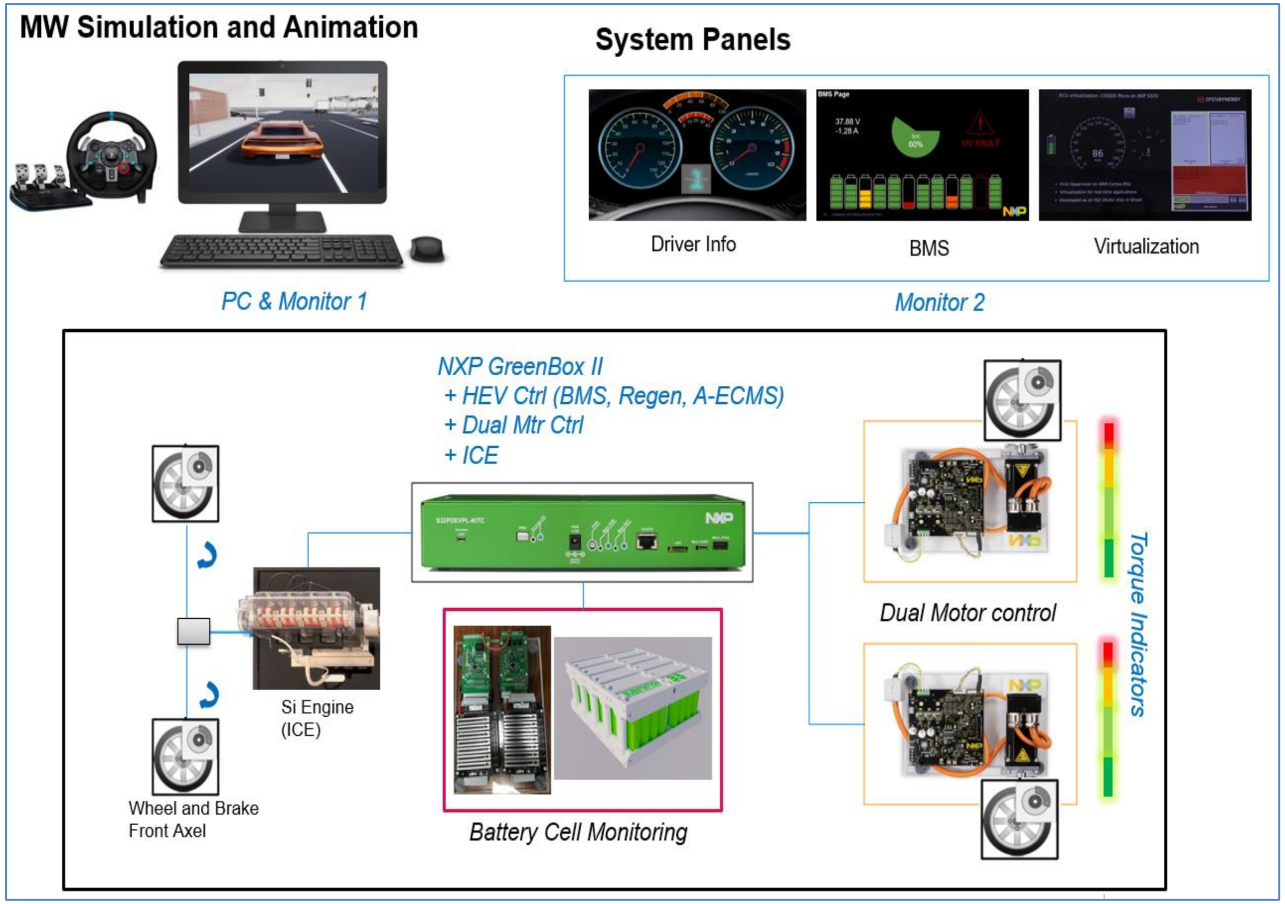




- One Pedal algorithm allows for braking behavior with only pedal actuation
- Zone calibration effects drivability behavior and “Fun To Drive” characteristics

Processor –in-the-Loop (PIL) Simulation
NXP + MathWorks Collaboration Demo





Processor –in-the-Loop (PIL) Simulation
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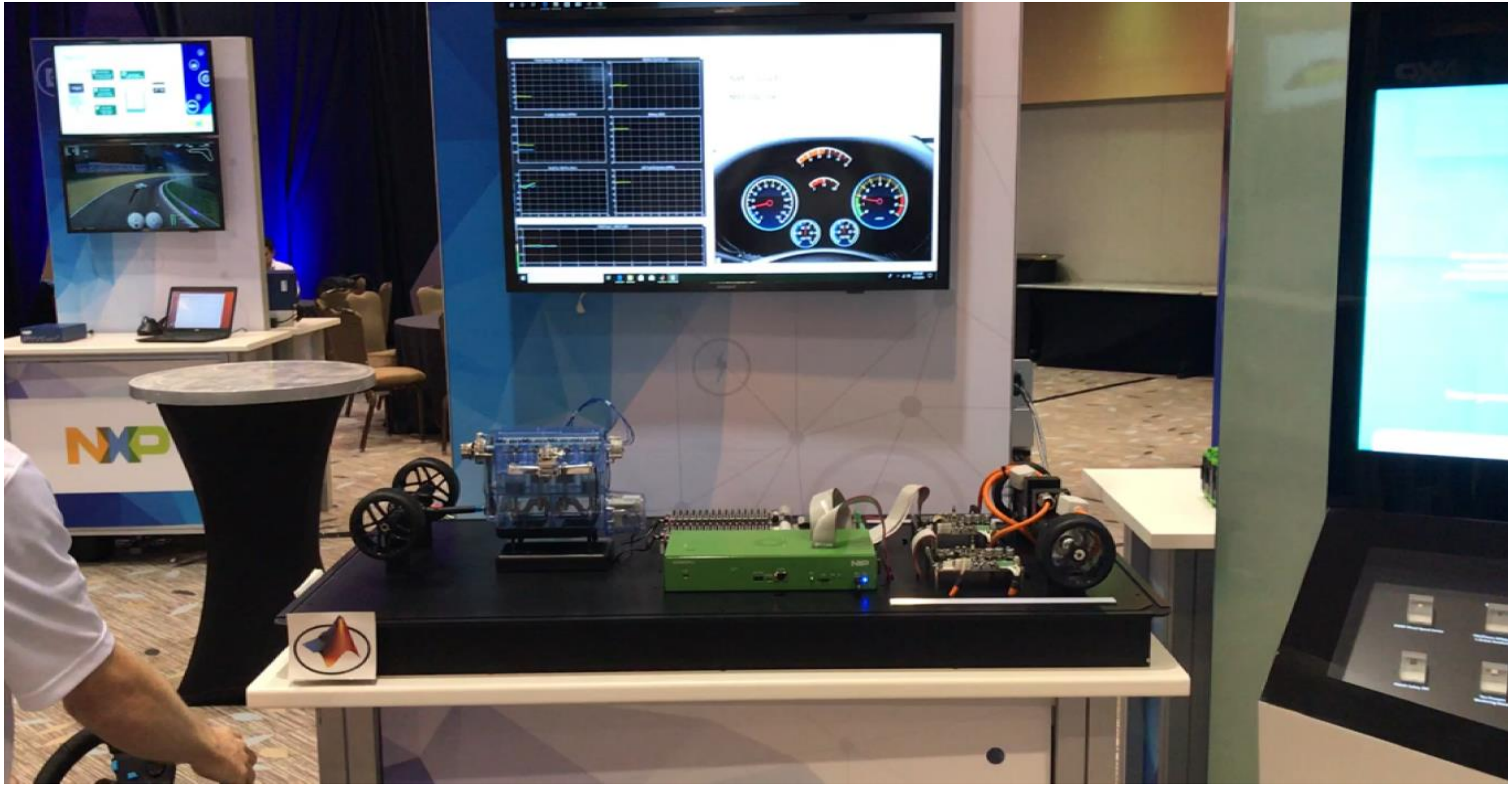
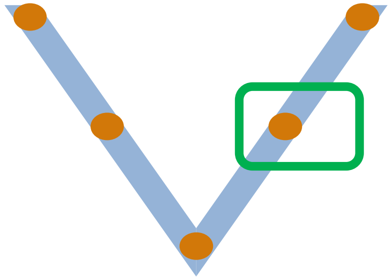
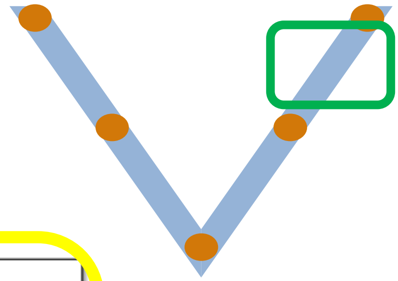
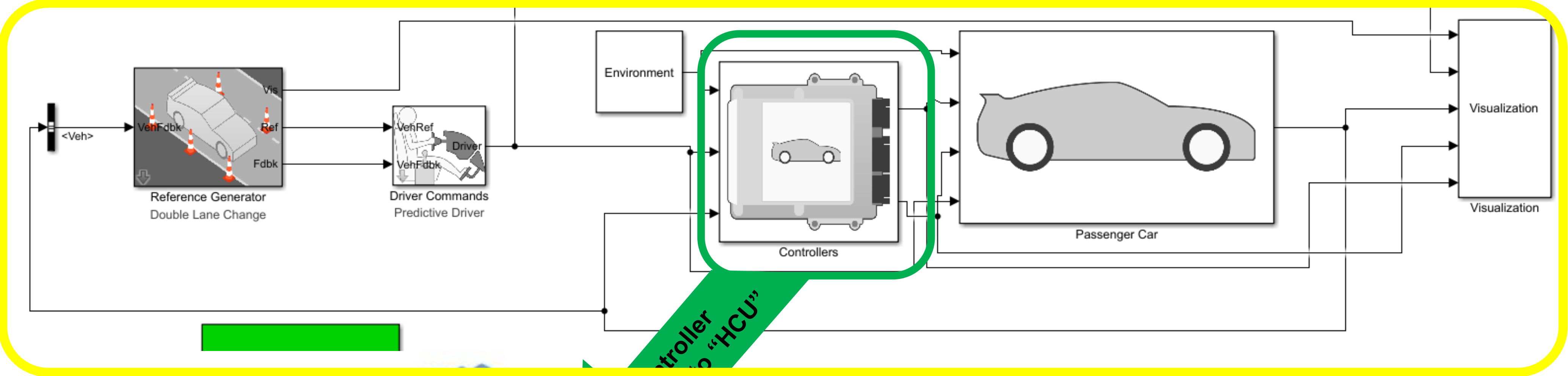
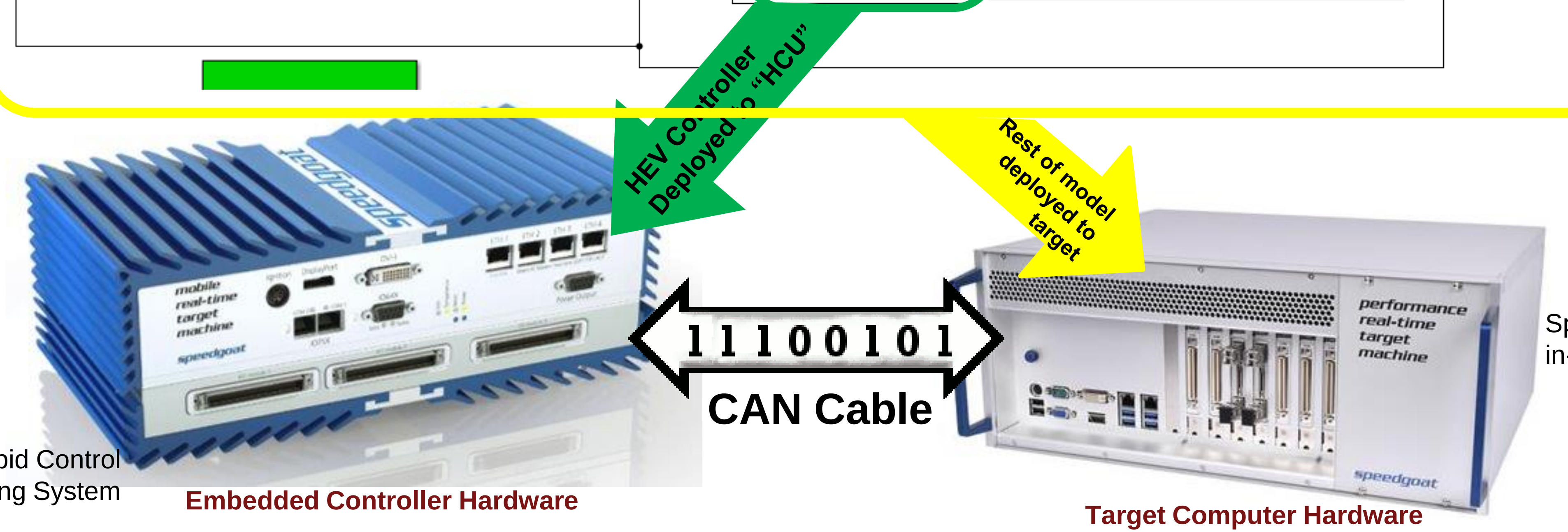




Hardware-in-the-Loop (HIL) Simulation







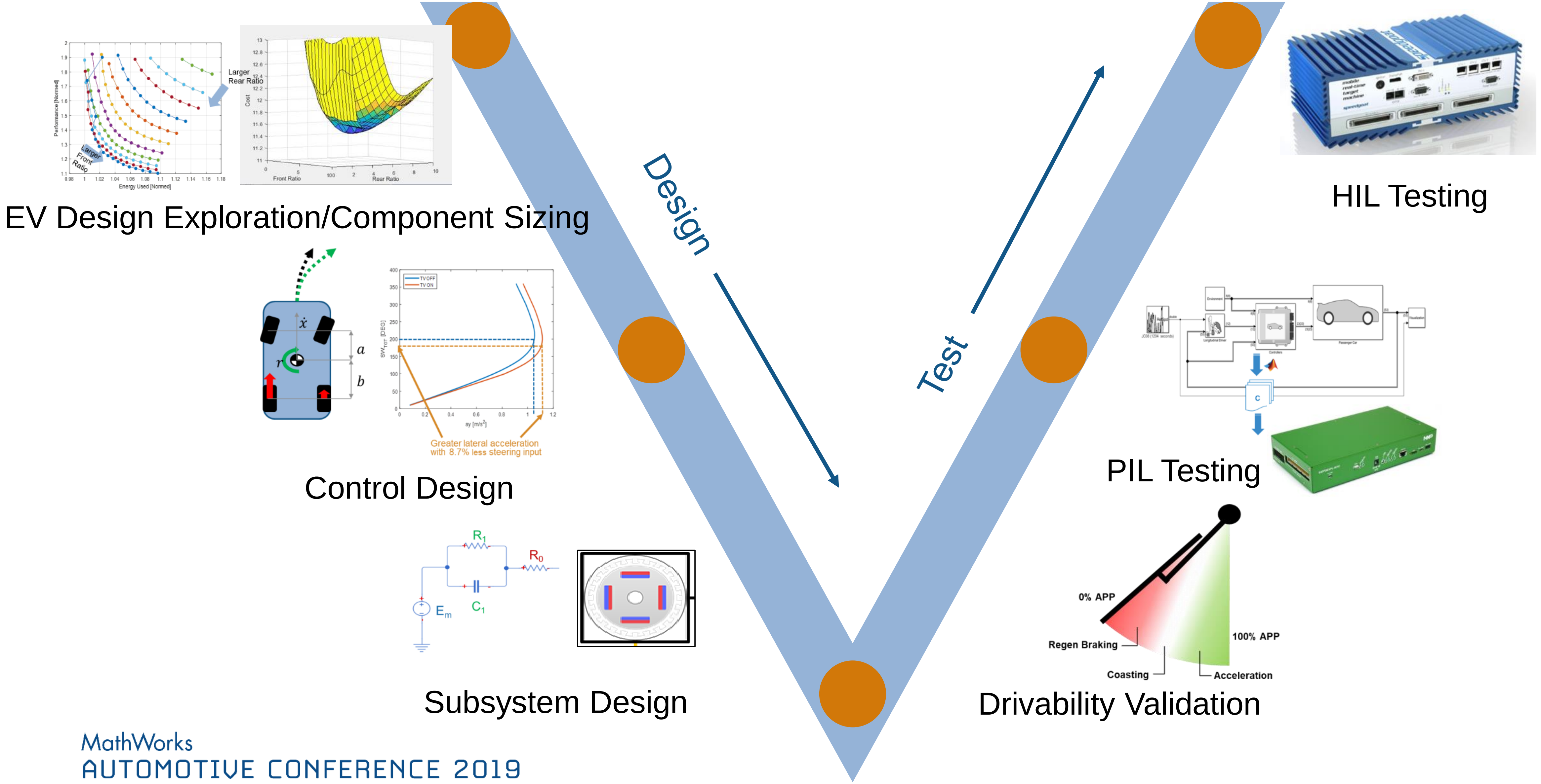
Speedgoat Rapid Control Prototyping System

Embedded Controller Hardware

Speedgoat Hardware in-the-loop System

Target Computer Hardware

Summary


EV Design Exploration/Component Sizing
Larger Rear Ratio
Larger Front Ratio
Energy Used [Normed]
Performance [Normed]
Front Ratio
Rear Ratio
Cost
Control Design
TV OFF
TV ON
Greater lateral acceleration with 8.7% less steering input
Subsystem Design
Design
Test
HIL Testing
PIL Testing
Drivability Validation
0% APP
100% APP
Regen Braking
Coasting
Acceleration

Key Takeaways

Use Simulink based virtual vehicle capabilities to:

- Quantify tradeoffs between vehicle performance characteristics
- Develop and verify control features
- Verify detail components behavior and their affects in vehicle system
- PIL/HIL tests