

2020 MathWorks 中国汽车年会

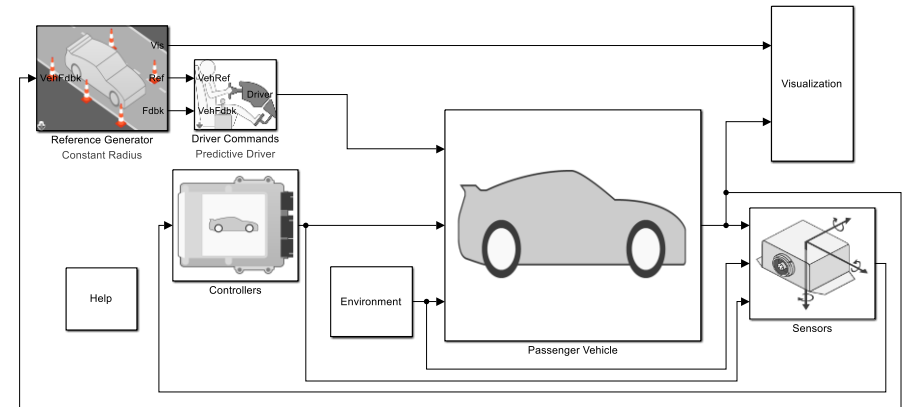
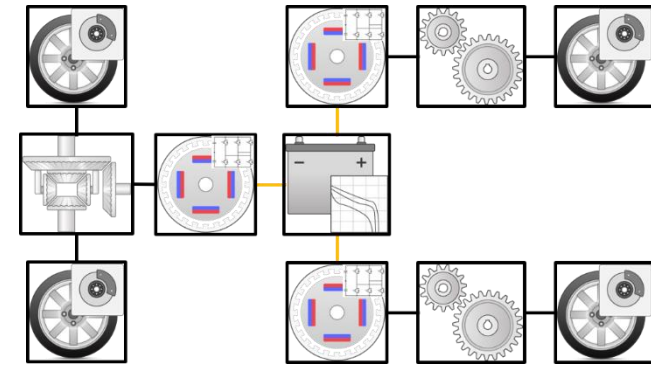
基于参考应用程序
快速开发虚拟电动汽车模型

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MathWorks 中国区高级应用工程师

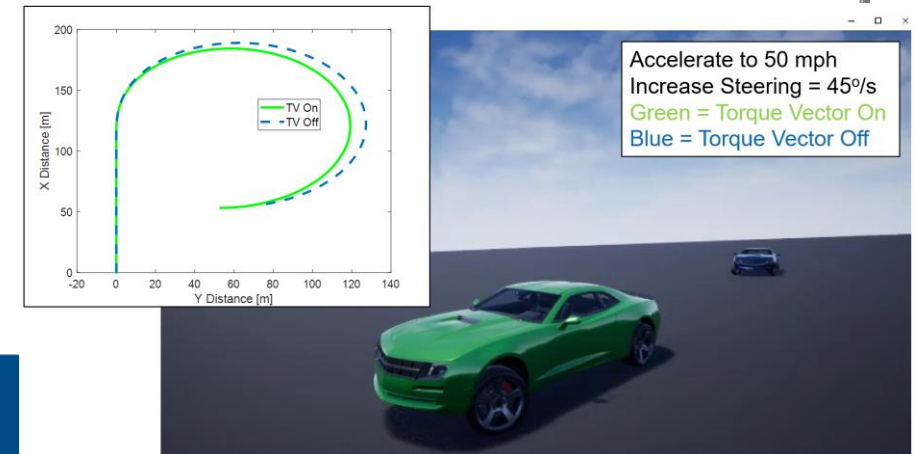


内容提要

- MathWorks 在虚拟车辆仿真上的应用:
 - 使用Powertrain Blockset 和 Vehicle Dynamics Blockset快速评估电气化动力总成
 - 参考应用提供了模型构架和测试用例的模板
 - 单个模型用于支持多种基于模型设计的活动



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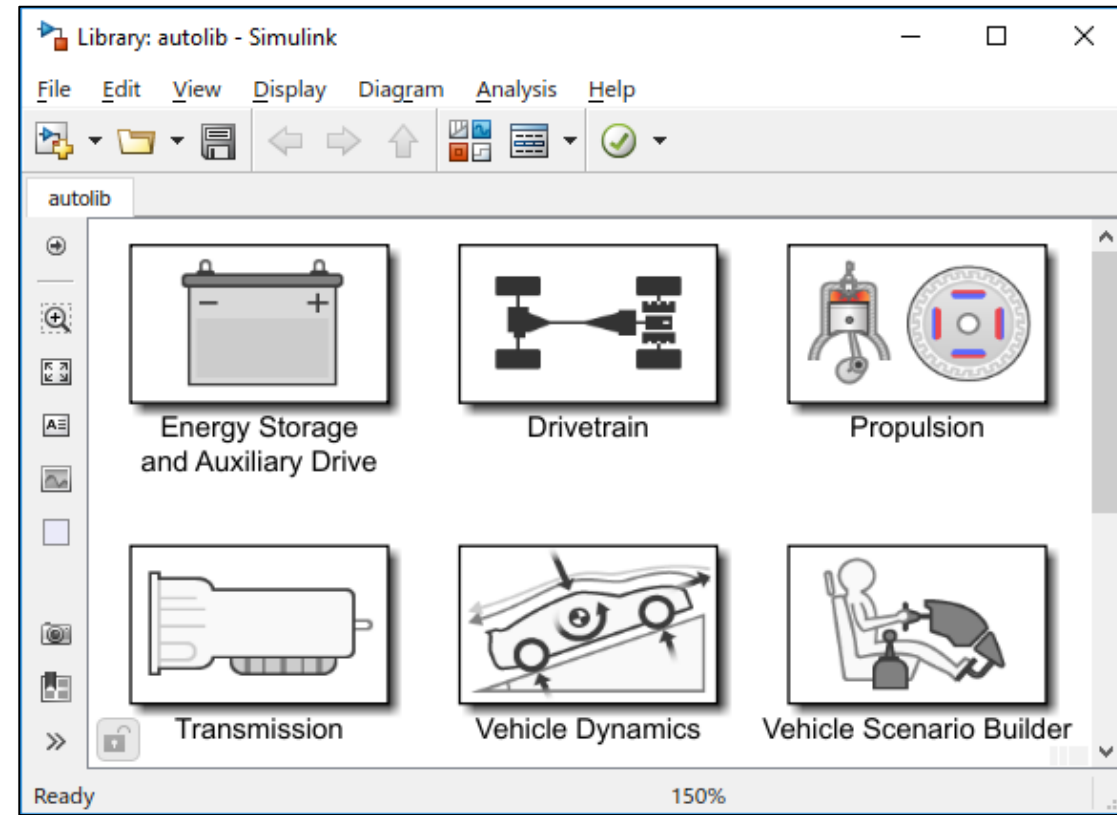


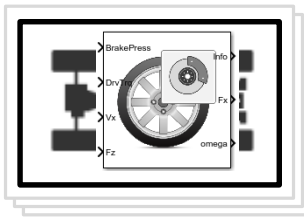
Powertrain Blockset

- 目标:
 - 为工程师建立被控对象/控制器模型提供良好的起点
 - 提供开放的模型和详细的文档说明
 - 提供快速运行的模型，可与主流的HIL系统配合使用

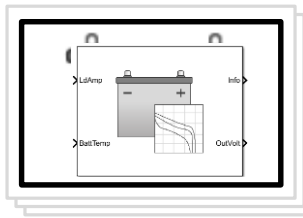
降低基于模型设计的准入门槛

模块库

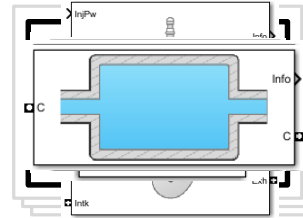




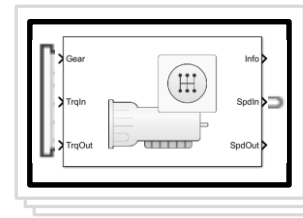
Drivetrain



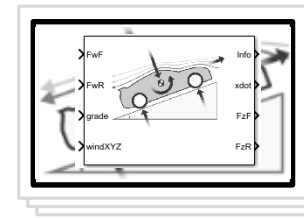
Energy Storage and Auxiliary Drive



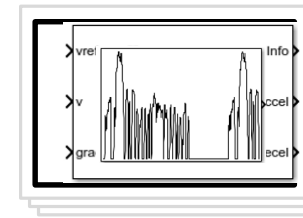
Propulsion



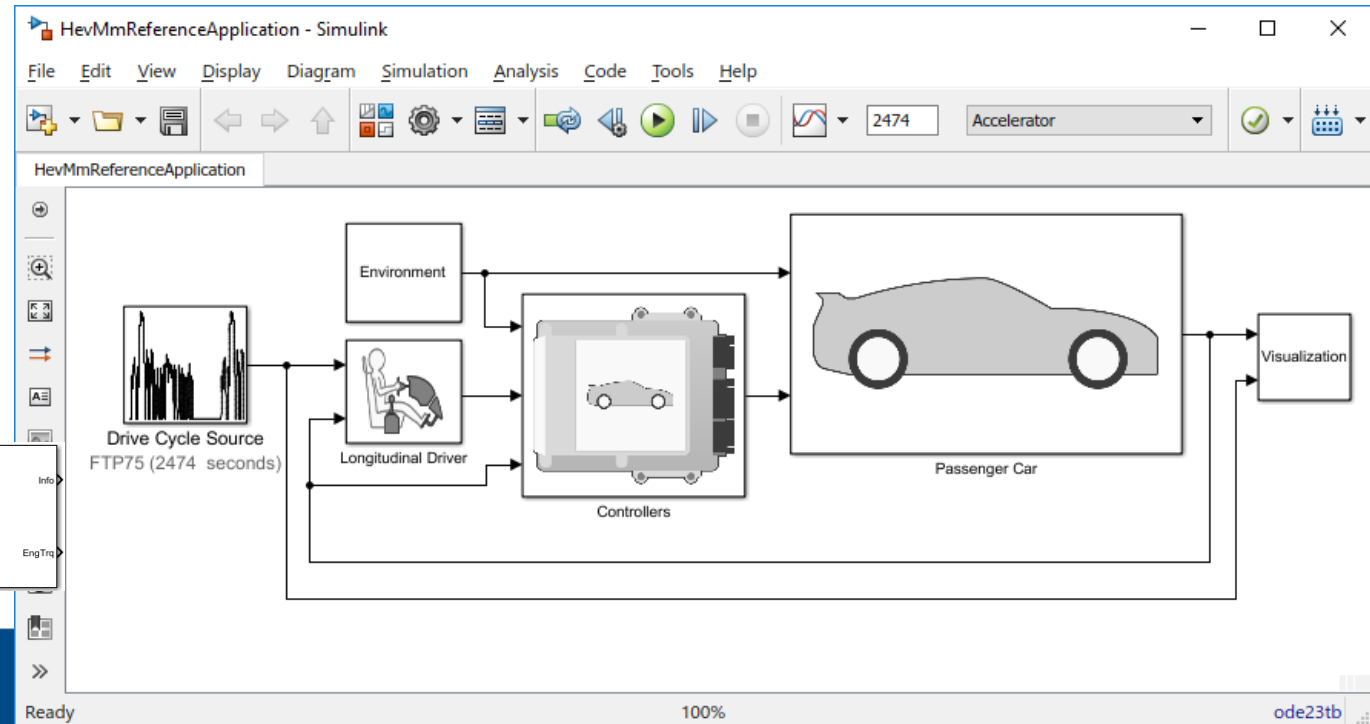
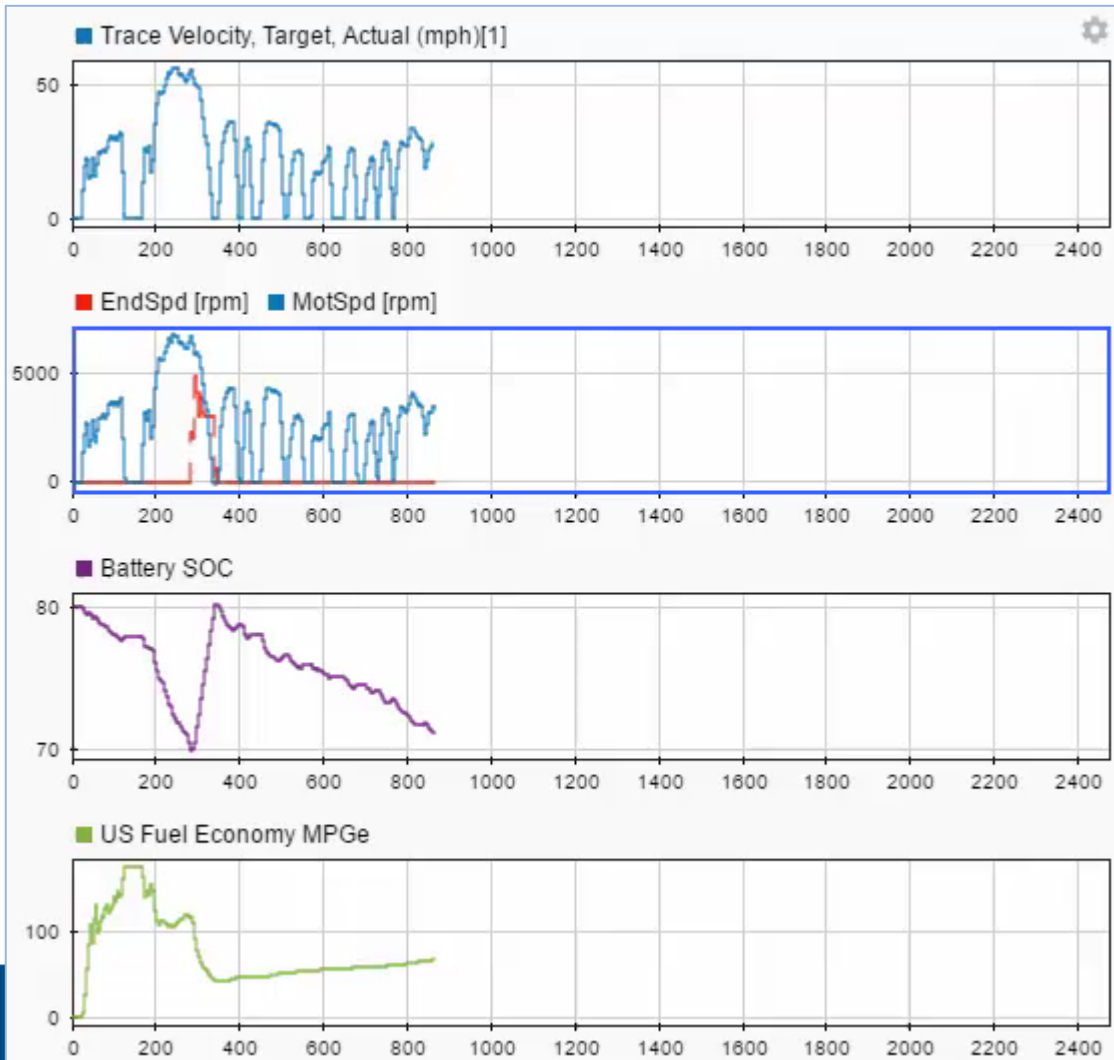
Transmission



Vehicle Dynamics

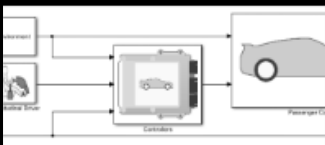
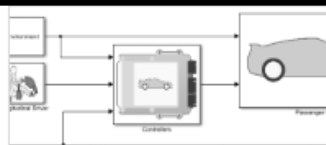
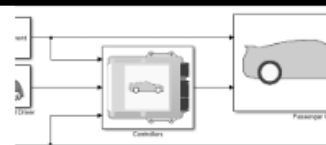
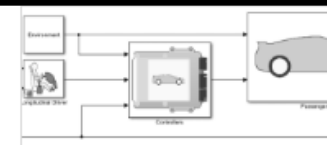
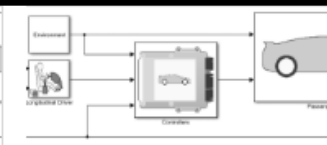
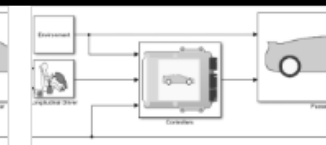
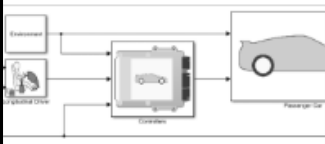
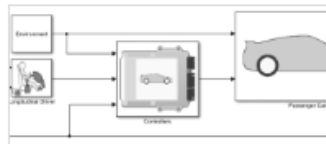
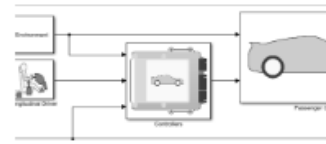
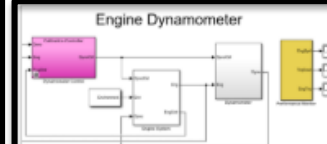
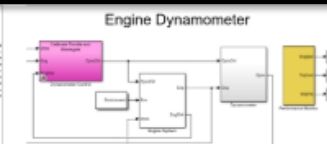


Vehicle Scenario Builder



参考应用

虚拟车
辆模型

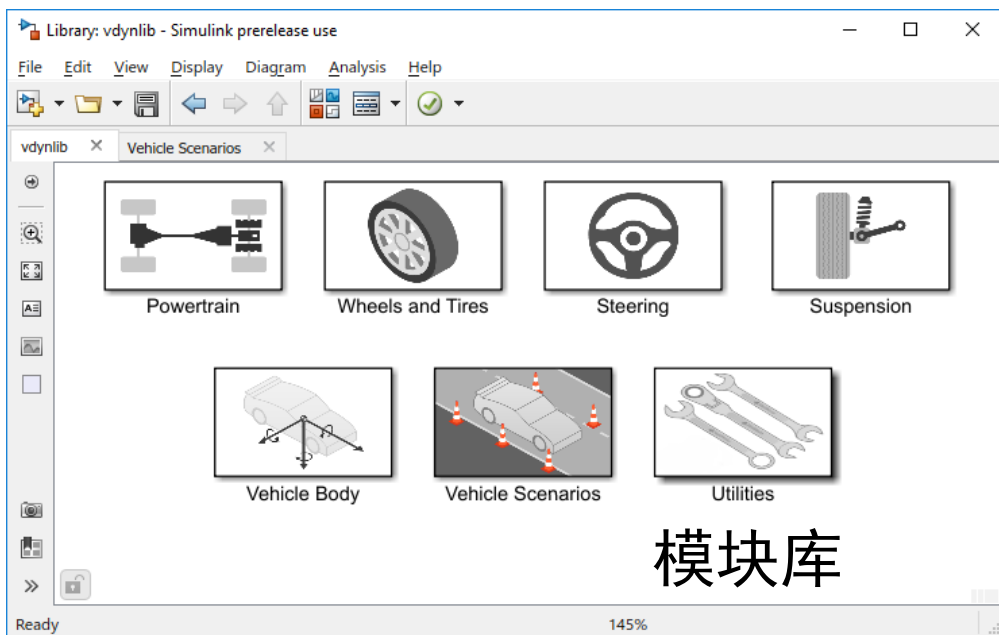
 <p>Conventional Vehicle Reference Application</p> <p>Simulate a full vehicle model with an internal combustion engine, transmission, and associated powertrain control algorithms. Use</p> <p>Open Example</p>	 <p>HEV Multimode Reference Application</p> <p>Simulate a full multimode HEV model with an internal combustion engine, transmission, battery, motor, generator, and associated</p> <p>Open Example</p>	 <p>HEV Input Power-Split Reference Application</p> <p>Simulate an input power-split HEV model with an internal combustion engine, transmission, battery, motor, generator, and associated</p> <p>Open Example</p>	 <p>HEV P0 Reference Application</p> <p>Simulate a P0 HEV model with an internal combustion engine, transmission, battery, motor, generator, and associated</p> <p>Open Example</p>	 <p>HEV P1 Reference Application</p> <p>Simulate a P1 HEV model with an internal combustion engine, transmission, battery, motor, generator, and associated</p> <p>Open Example</p>	 <p>HEV P2 Reference Application</p> <p>Simulate a P2 HEV model with an internal combustion engine, transmission, battery, motor, generator, and associated</p> <p>Open Example</p>
 <p>HEV P3 Reference Application</p> <p>Simulate a P3 HEV model with an internal combustion engine, transmission, battery, motor, generator, and associated</p> <p>Open Example</p>	 <p>HEV P4 Reference Application</p> <p>Simulate a P4 HEV model with an internal combustion engine, transmission, battery, motor, generator, and associated</p> <p>Open Example</p>	 <p>EV Reference Application</p> <p>Simulate an EV model with a motor-generator, battery, direct-drive transmission, and associated powertrain control algorithms. Use</p> <p>Open Example</p>	 <p>CI Engine Dynamometer Reference Application</p> <p>Simulate a CI engine plant and controller connected to a dynamometer with a tailpipe emission analyzer. Use to calibrate,</p> <p>Open Example</p>		 <p>SI Engine Dynamometer Reference Application</p> <p>Simulate a SI engine plant and controller connected to a dynamometer with a tailpipe emission analyzer. Use to calibrate,</p> <p>Open Example</p>

虚拟发动机
台架

Vehicle Dynamics Blockset

R2018a

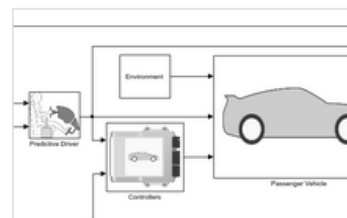
预制的参考应用



模块库



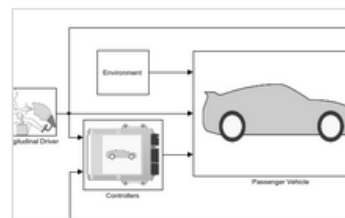
Unreal Engine



Double-Lane Change Reference Application

Simulate a full vehicle dynamics model undergoing a double-lane change maneuver according to standard ISO 3888-2. You can

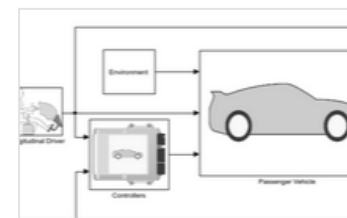
[Open Example](#)



Increasing Steering Reference Application

Simulate a full vehicle dynamics model undergoing a slowly increasing steering maneuver according to standard SAE J266.

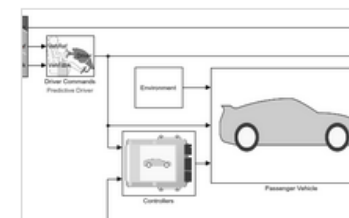
[Open Example](#)



Swept Sine Steering Reference Application

Simulate a full vehicle dynamics model undergoing a swept-sine steering maneuver. You can create your own versions, providing a

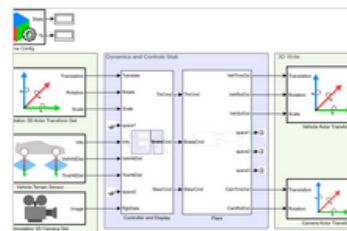
[Open Example](#)



Constant Radius Reference Application

Simulate a full vehicle dynamics model undergoing a constant radius maneuver. You can create your own versions, providing a framework to

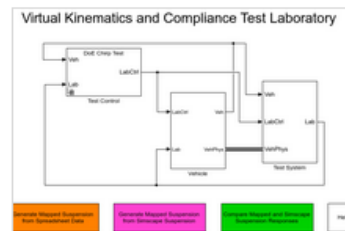
[Open Example](#)



Scene Interrogation with Camera and Ray Tracing Reference Application

Interrogate a 3D scene with a vehicle dynamics model by using a camera and ray tracing reference application project.

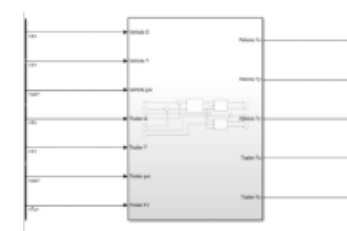
[Open Example](#)



Kinematics and Compliance Virtual Test Laboratory Reference Application

Generate optimized suspension parameters for the vehicle dynamics suspension blocks.

[Open Example](#)



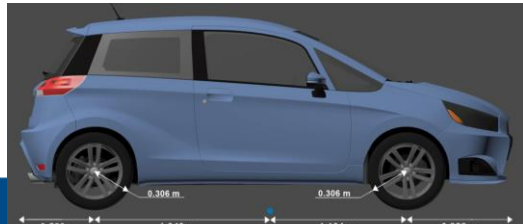
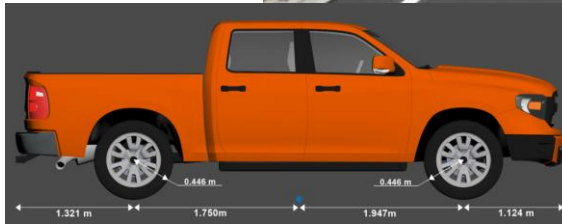
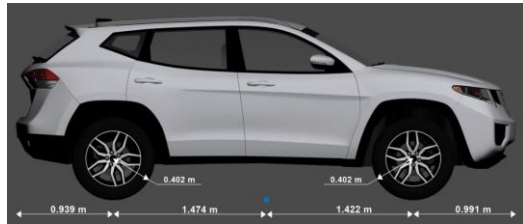
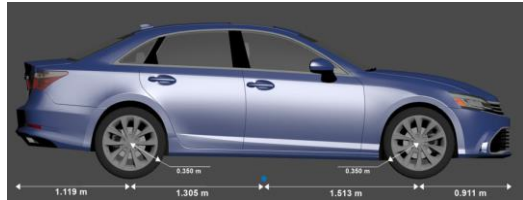
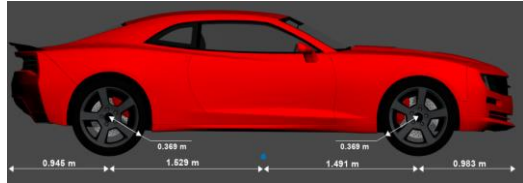
Three-Axle Tractor Towing a Trailer Reference Application

Simulate a three-axle tractor towing a three-axle trailer.

[Open Example](#)

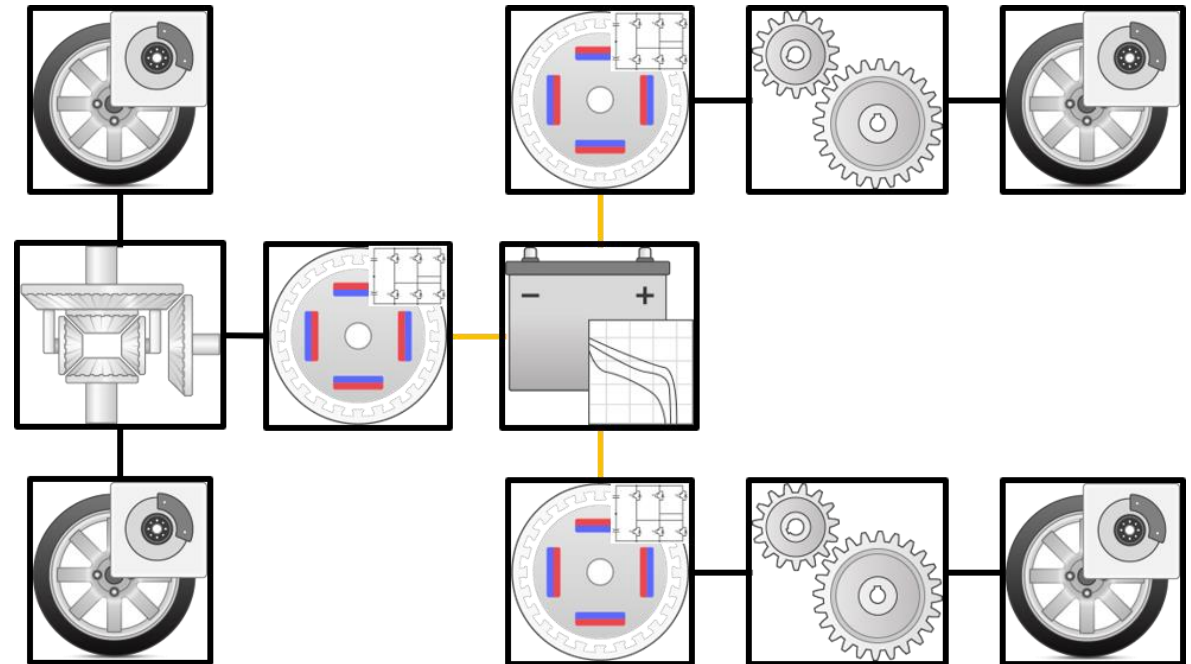
Vehicle Dynamics Blockset

- 使用虚幻引擎的3D逼真的环境（Epic Games）
- 预制场景和车辆类型



电动动力总成选择案例研究

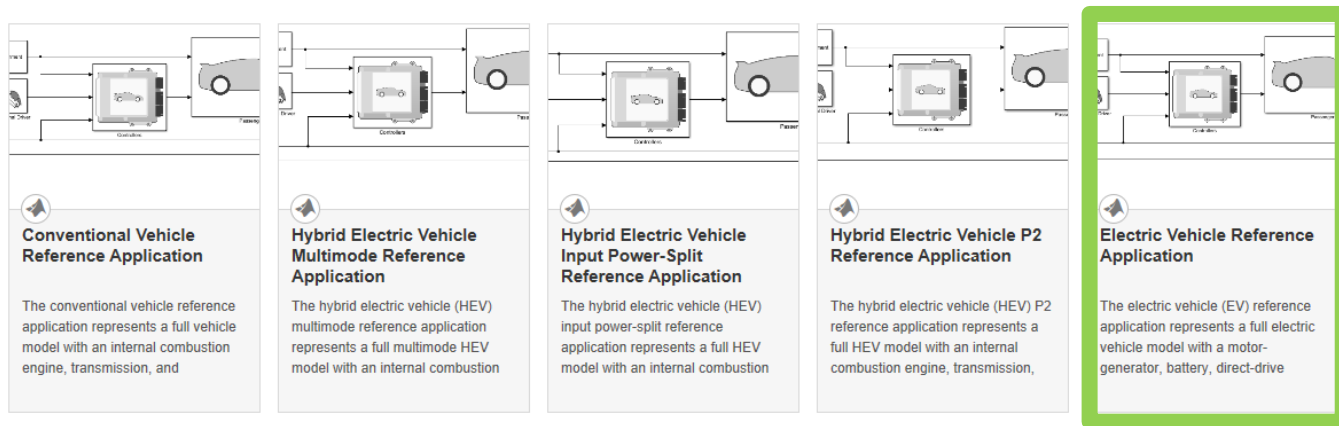
- 评估三电机纯电动汽车动力总成
- 使用一个模型开发和评估
 1. 整车能量管理的监督控制
 2. 前后轴传动比的优化
 3. 同轴的两个轮毂电机扭矩分配
 4. 集成详细的BMS/电池模型到系统级模型中
 5. 使用单踏板驱动算法的驾驶员在环功能



参考应用 workflow

1. 选择一个车辆构型

- 选择一个参考应用作为起点



2. 自定义被控对象模型

- 参数化组件
- 自定义现有子系统
- 使用可变子系统添加自定义的子系统

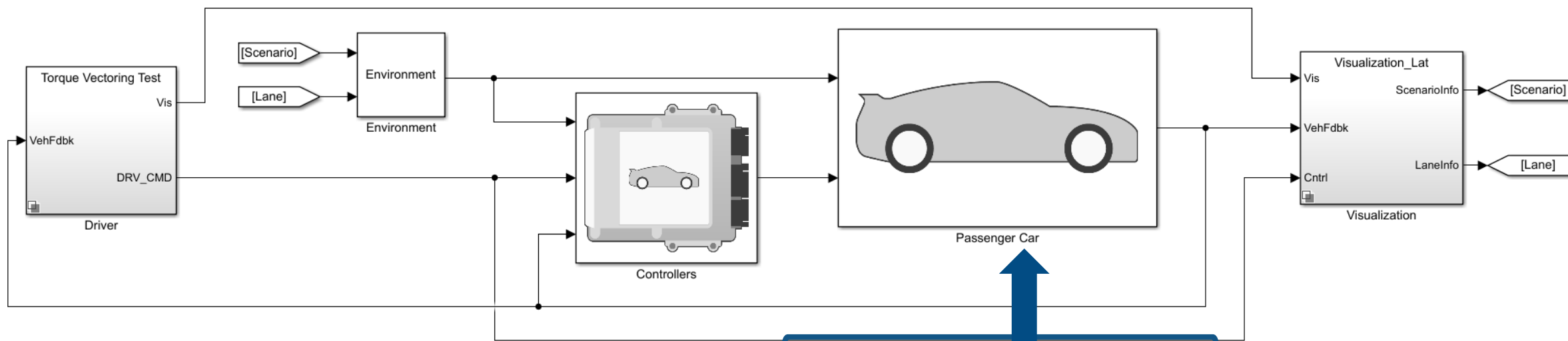
3. 自定义控制器

- 参数化组建
- 自定义控制逻辑
- 使用可变子系统添加自己的控制子系统

4. 执行闭环测试

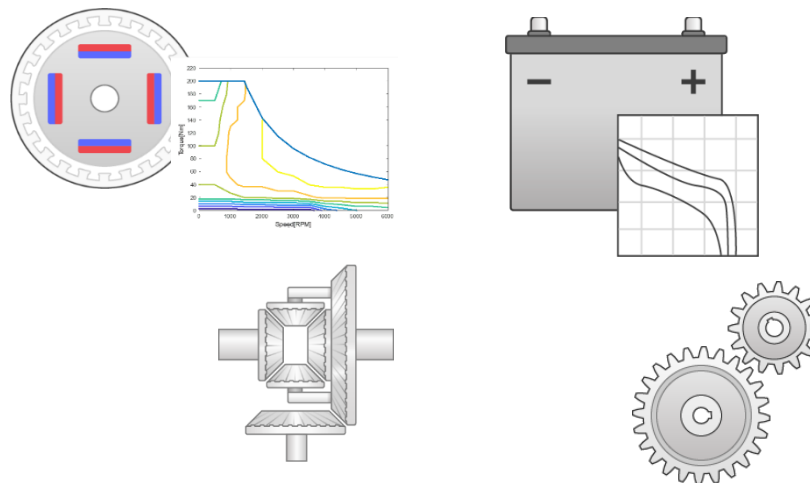
- 敏感度分析
- 设计优化
- MIL / SIL / HIL 测试

动力总成被控对象模型



■ 修改EV的参考应用案例

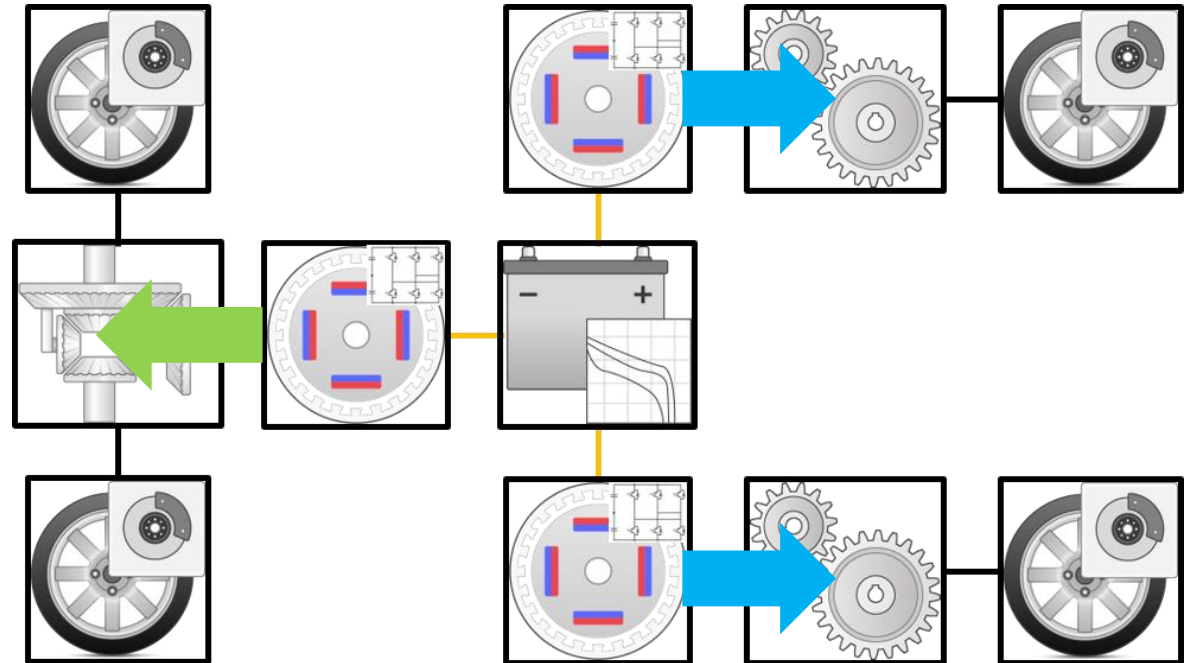
- 3个永磁同步电机
- 电池
- 前差速器/后轴齿轮组



1. EV 能量管理策略(Energy Management System)

- 需要能量管理策略控制电机的前/后扭矩分配
- 对所需的能量管理策略仿真
 - 不同驾驶循环下的能耗
 - 性能 (i.e. 0-100 km/h)

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



1. EV 能量管理策略(Energy Management System)

- 瞬时优化算法

- 动力源（电机）的扭矩（或功率）

- 受到以下约束:

$$\tau_{min}(\omega) \leq \tau_{act} \leq \tau_{max}(\omega)$$

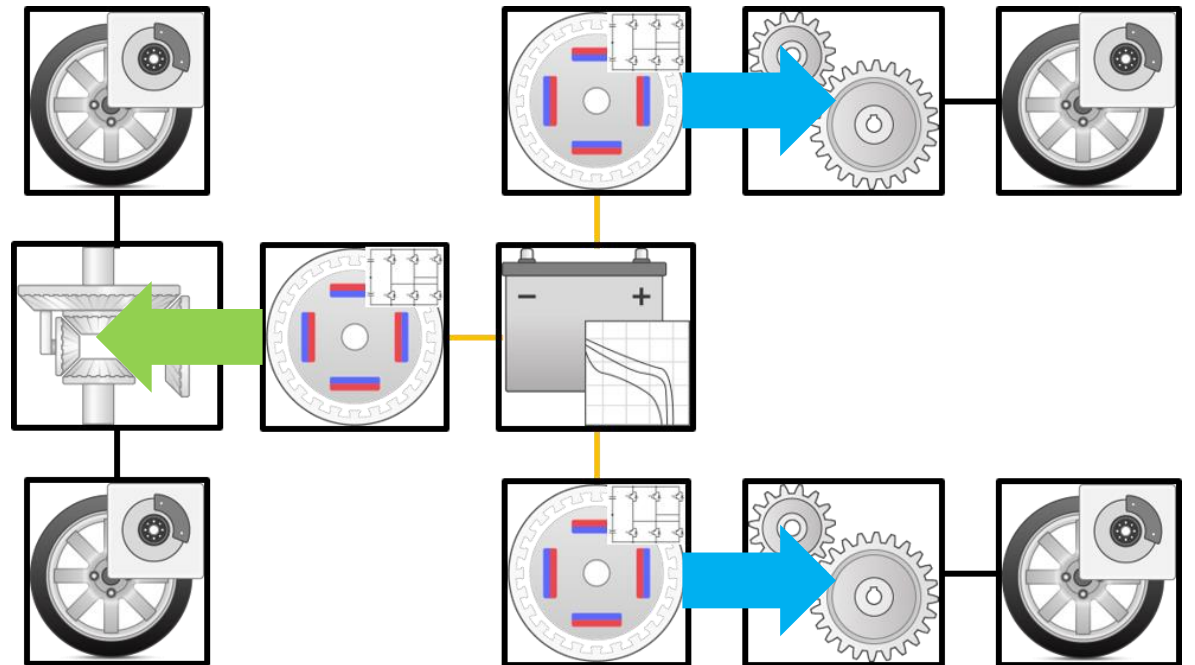
$$P_{chg}(SOC) \leq P_{batt} \leq P_{dischg}(SOC)$$

$$I_{chg}(SOC) \leq I_{batt} \leq I_{dischg}(SOC)$$

- 尽量减少能源消耗， 维持驾驶性

- 类似于混动车辆控制中的“等效油耗最低算法(Equivalent Consumption Minimization Strategy)”

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



EV 能量管理策略(EMS)实现过程

每个控制器时间步执行一次

1. 创建扭矩矢量
2. 检查约束条件, 确定不可行条件
3. 计算并最小化目标函数 (电池耗电量)

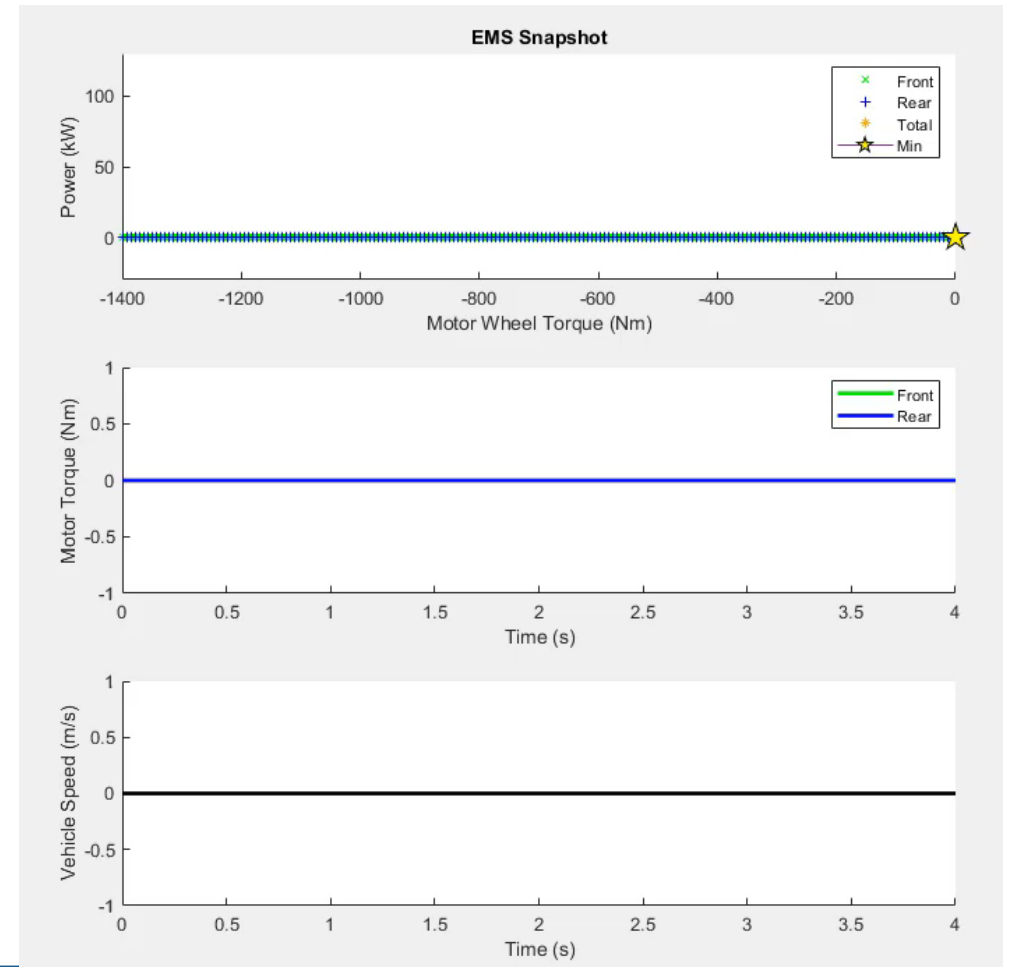
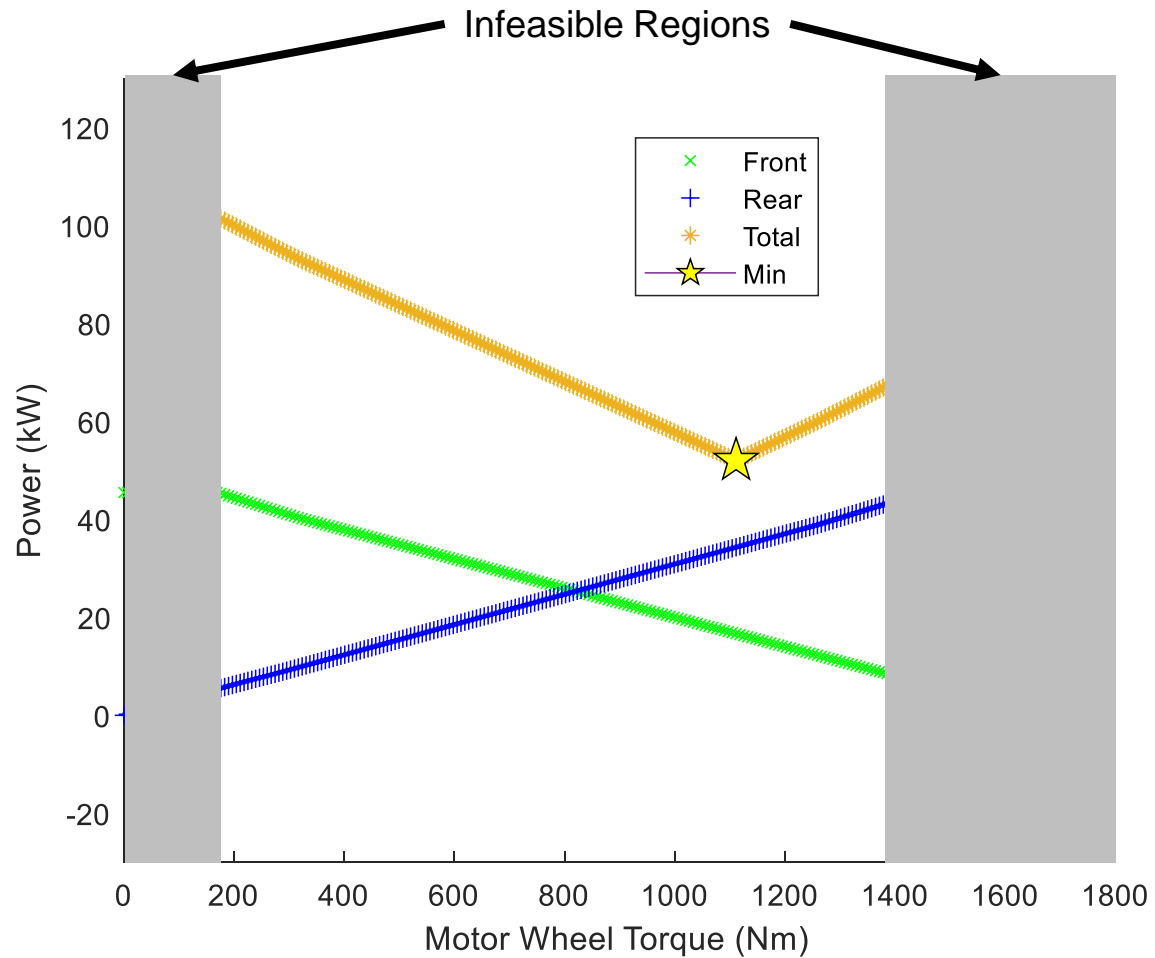
$$\begin{bmatrix} -Min\ Rear\ Torque \\ \vdots \\ +Max\ Rear\ Torque \end{bmatrix}$$

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

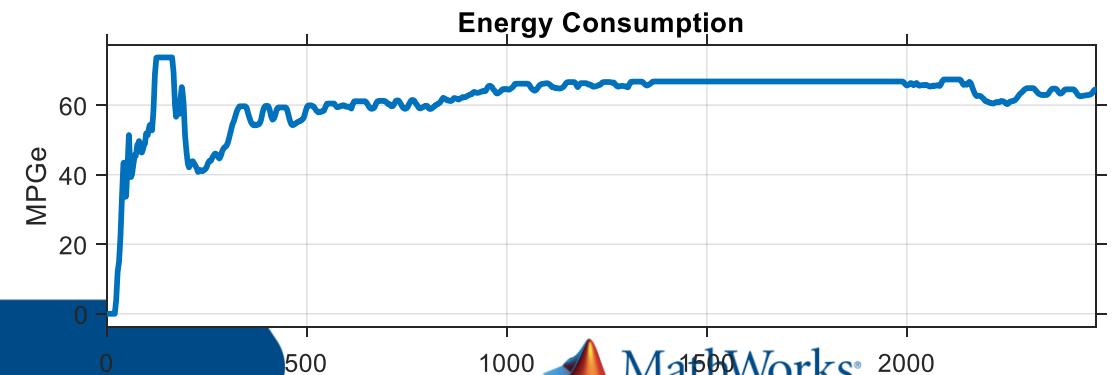
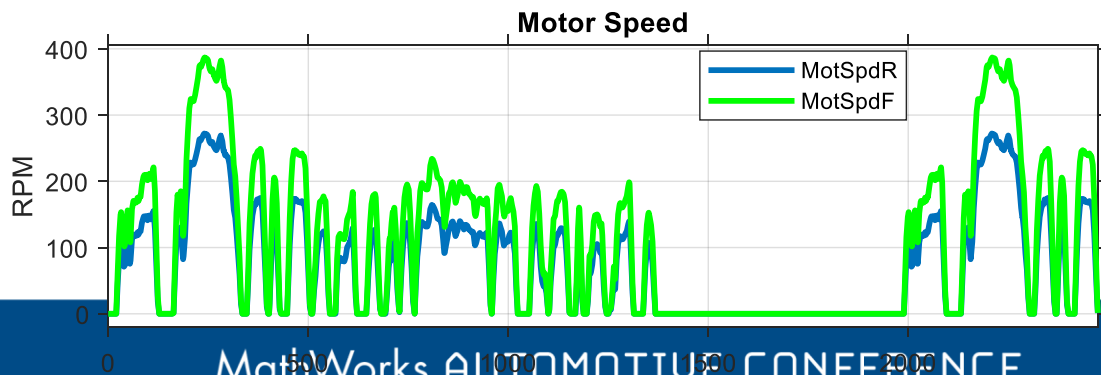
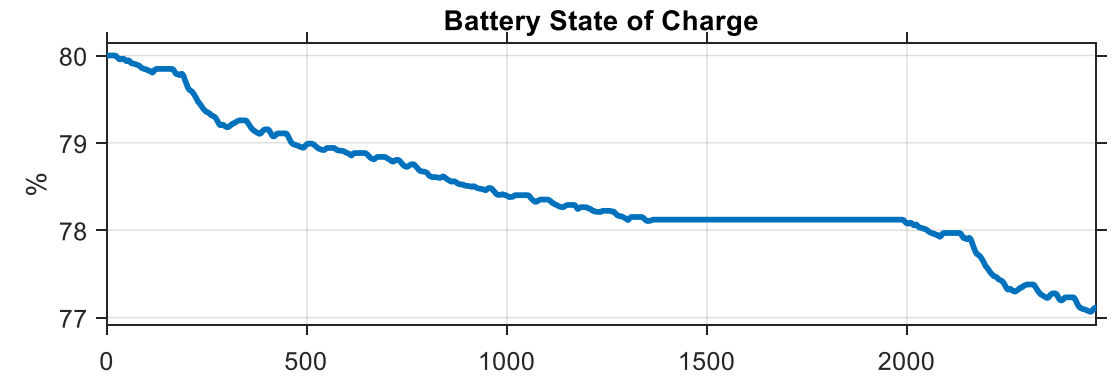
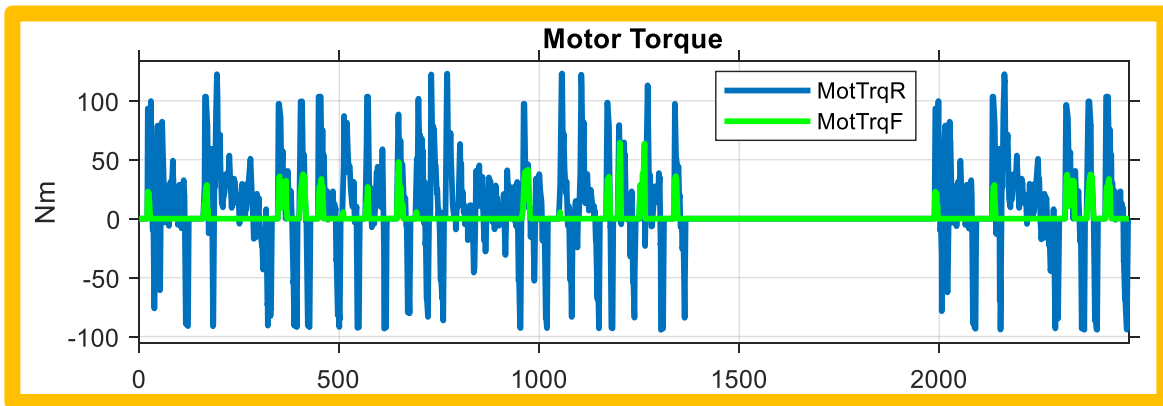
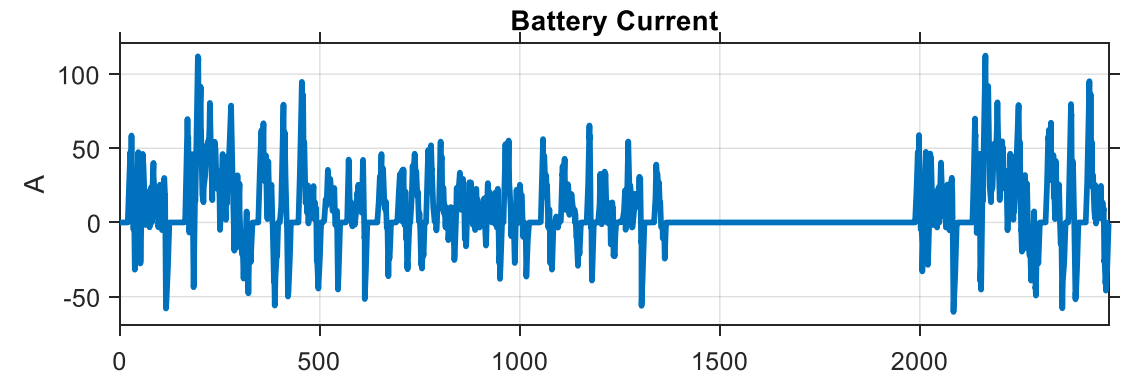
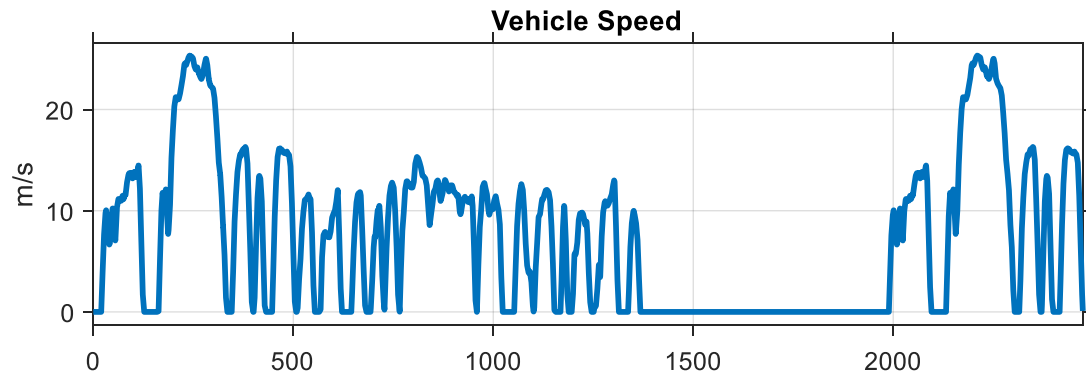
$$\min_{\tau_{rear}} P_b(\tau_{rear})$$

EV 能量管理策略(EMS)实现过程

某时间点的EMS快照

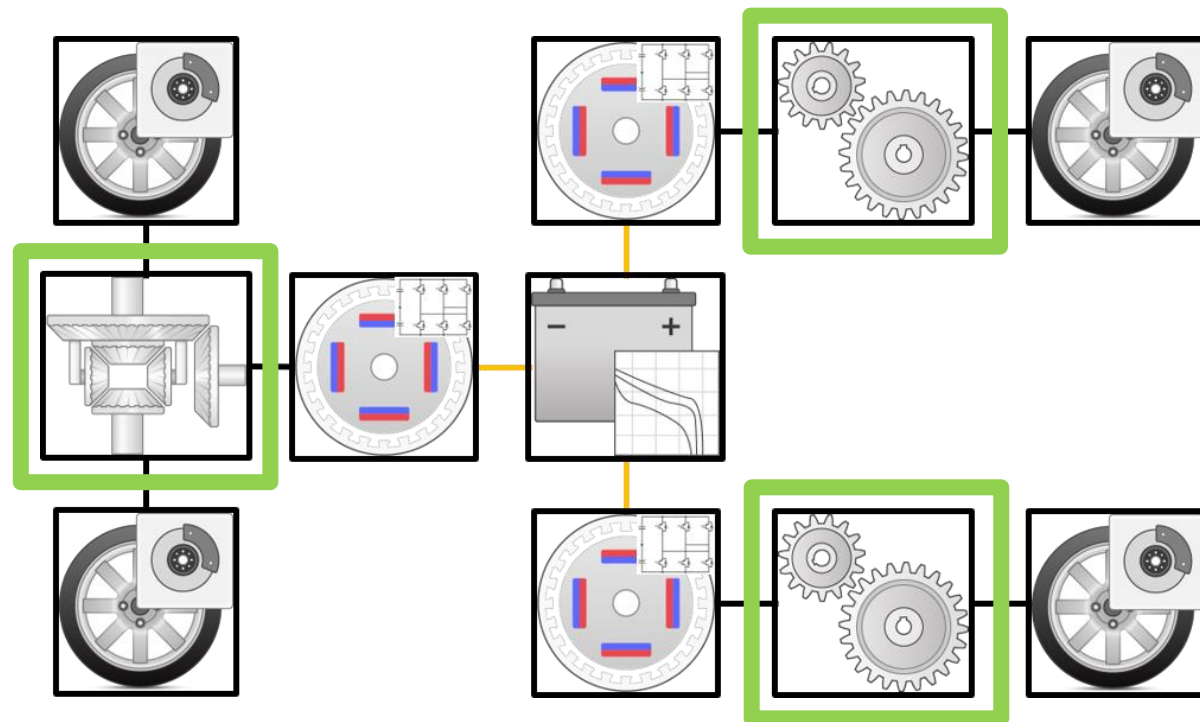


EV 能量管理策略(EMS)实现过程

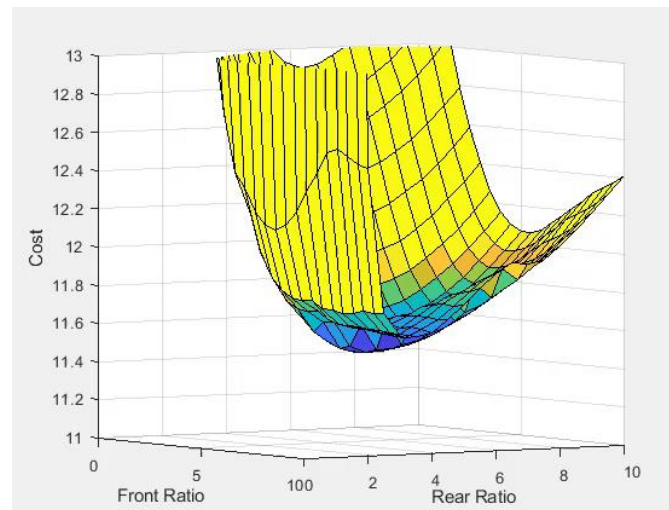
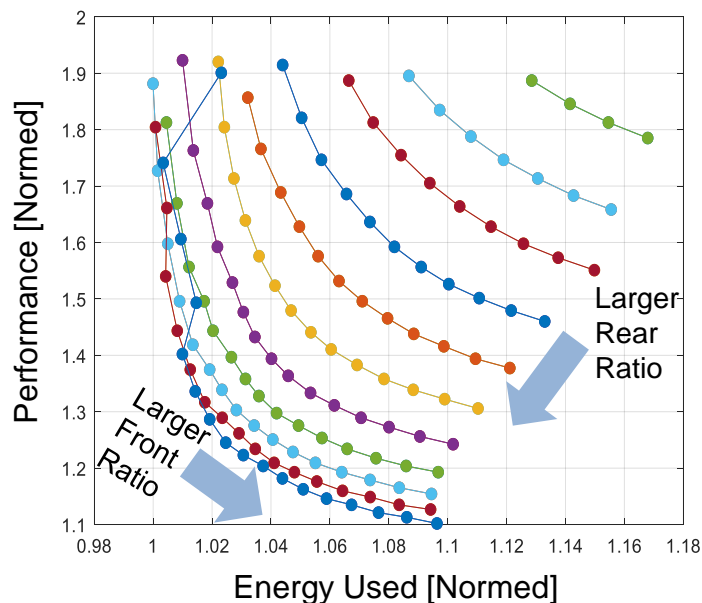


2. 优化前后轴的传动比

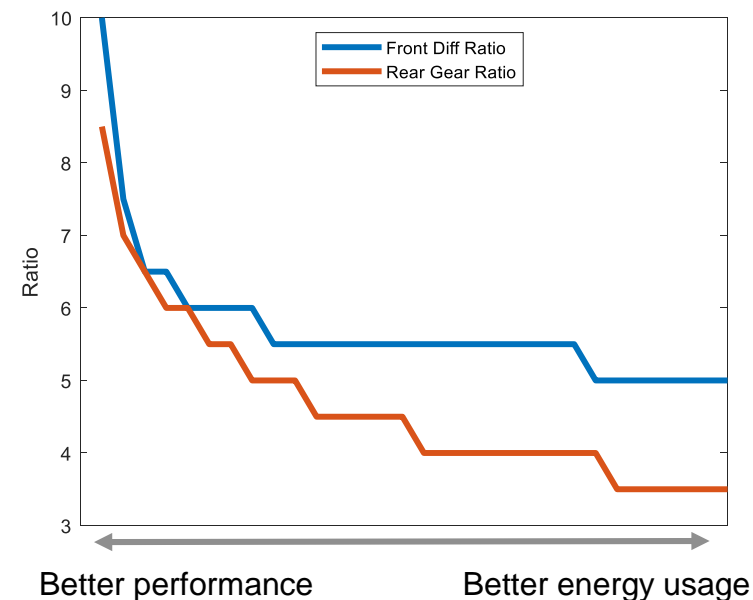
- 重用模型/EMS控制，支持调整各个部件参数的仿真
- 是否可以优化传动比？
 - 将多个驾驶循环的能耗降至最低
 - 优化车辆加速性能



2. 优化前后轴的传动比



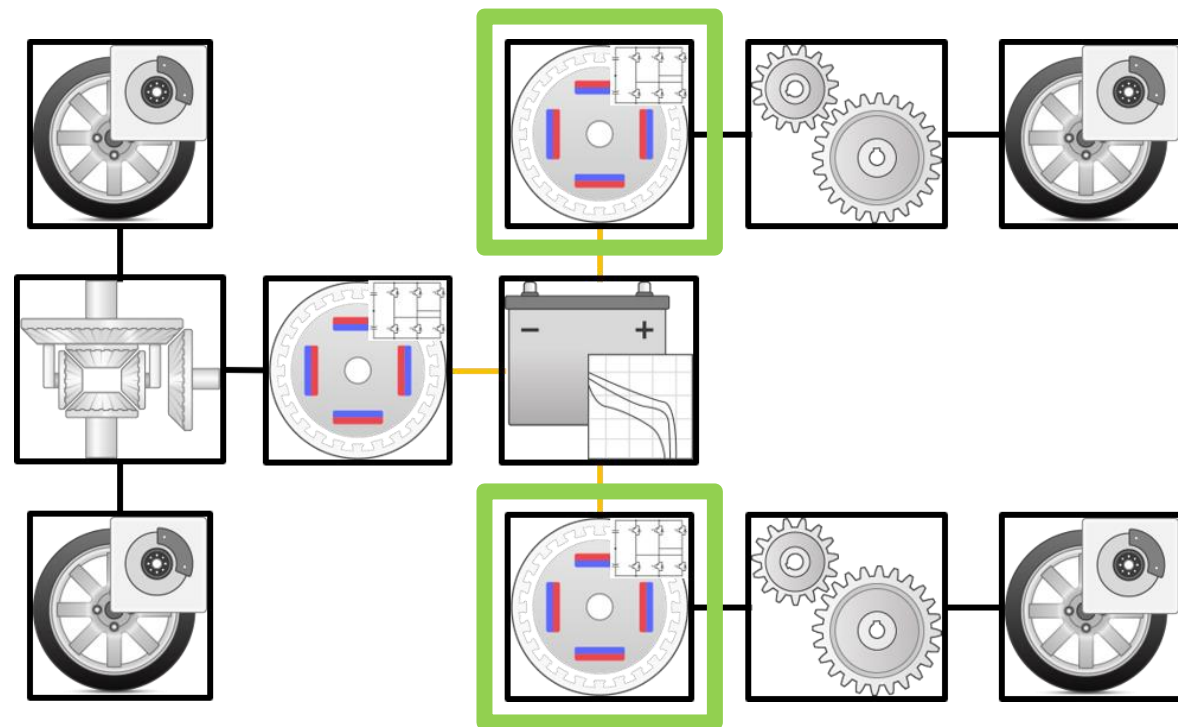
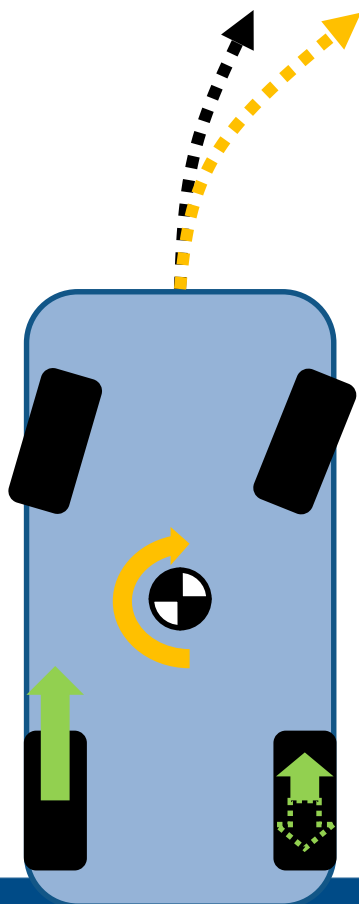
$$\min_{N_f, N_r} (0.55E_{FTP} + 0.45E_{HWY}) W_1 + W_2(T_{0-120KPH})$$



- 能量消耗与加速性能之间存在帕累托曲线
- 成本函数可以用于帮助确定最佳传动比
- 系统效率的权重越高，优化的传动比越低

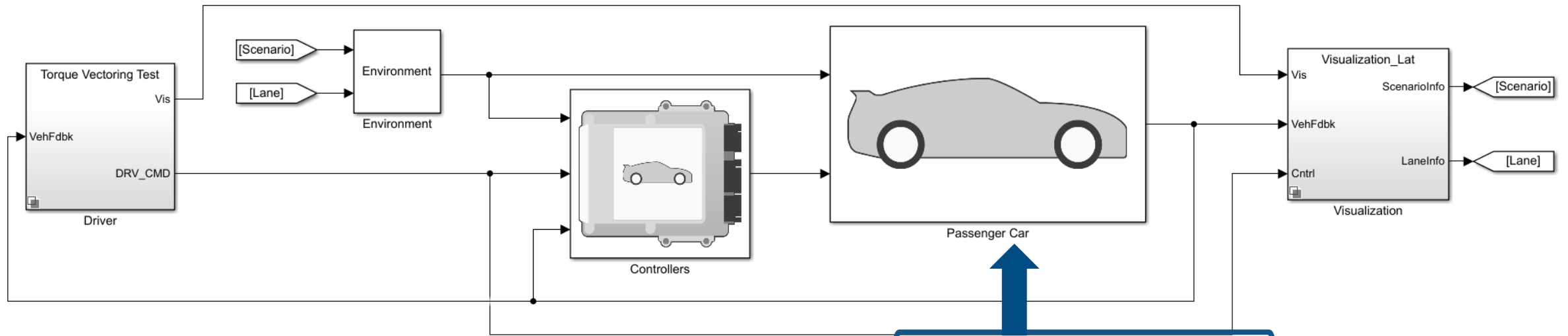
3. 轮毂电机扭矩分配

- 双后轮电机



- 评估扭矩分配 (Torque Vectoring):
 - 详细的传动系统+ 横向车辆动力学模型
 - 扭矩控制策略可以与能量管理策略兼容
 - 确定改进目标

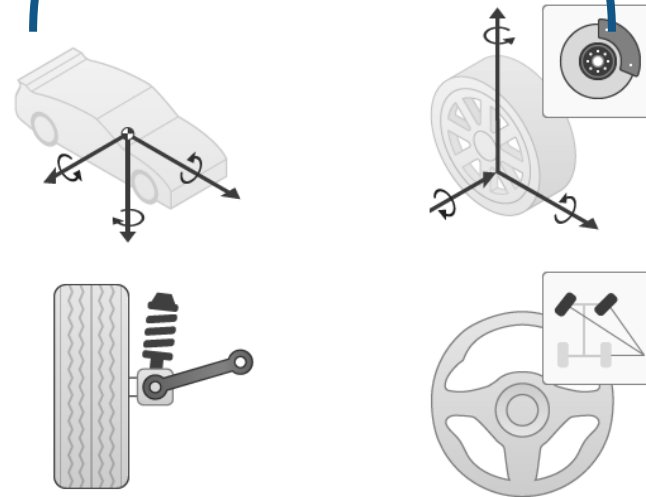
车辆动力学模型



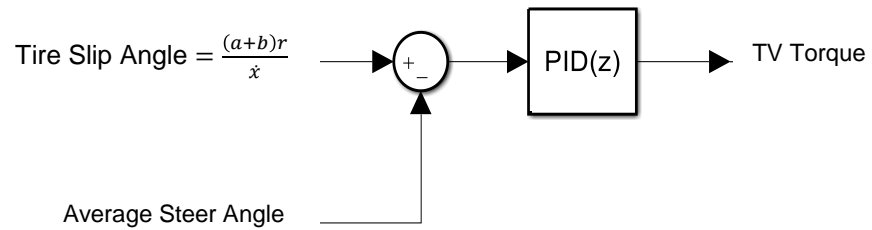
- 在车辆模型上添加可变子系统:

- 6 DOF 车辆模型
 - 2 DOF 轮胎+制动模型
 - 悬架
 - 转向
- } 14-DOF

- 沿用详细的传动控制和能量管理控制

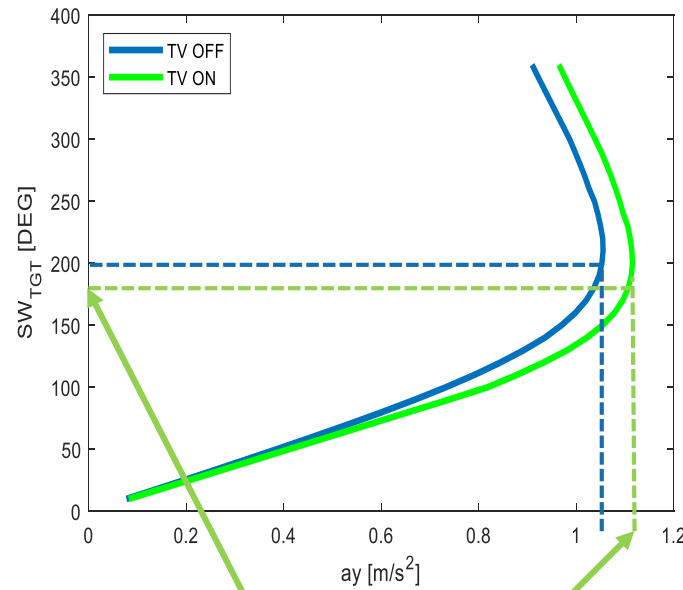
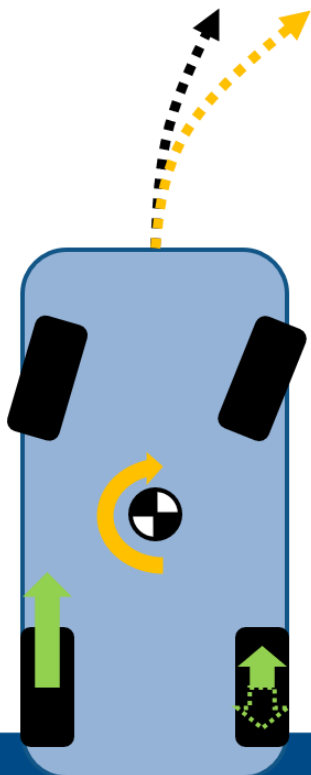


车身动态控制 – 轮毂电机扭矩分配

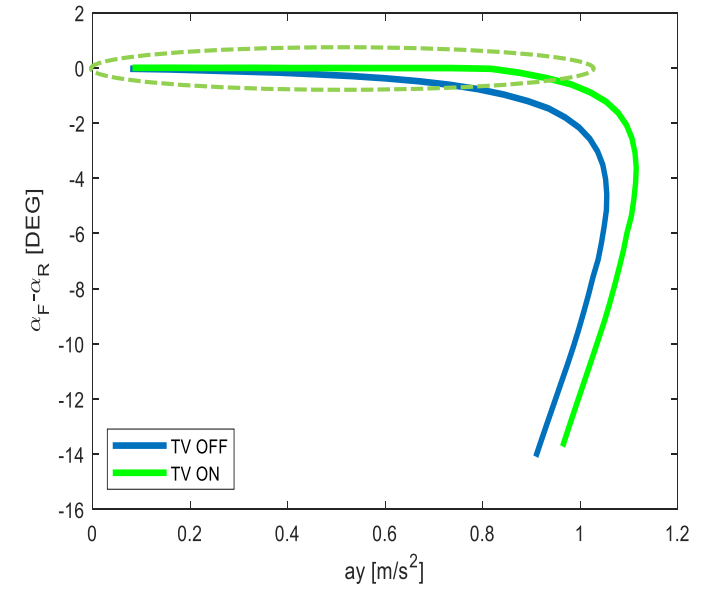


A Torque Vectoring Strategy for Improving the Performance of a Rear Wheel Drive Electric Vehicle

Jyotishman Ghosh, Andrea Tonoli, Nicola Amati
 Department of Mechanical and Aerospace Engineering
 Politecnico di Torino
 Turin, Italy
 Email: jyotishman.ghosh@polito.it

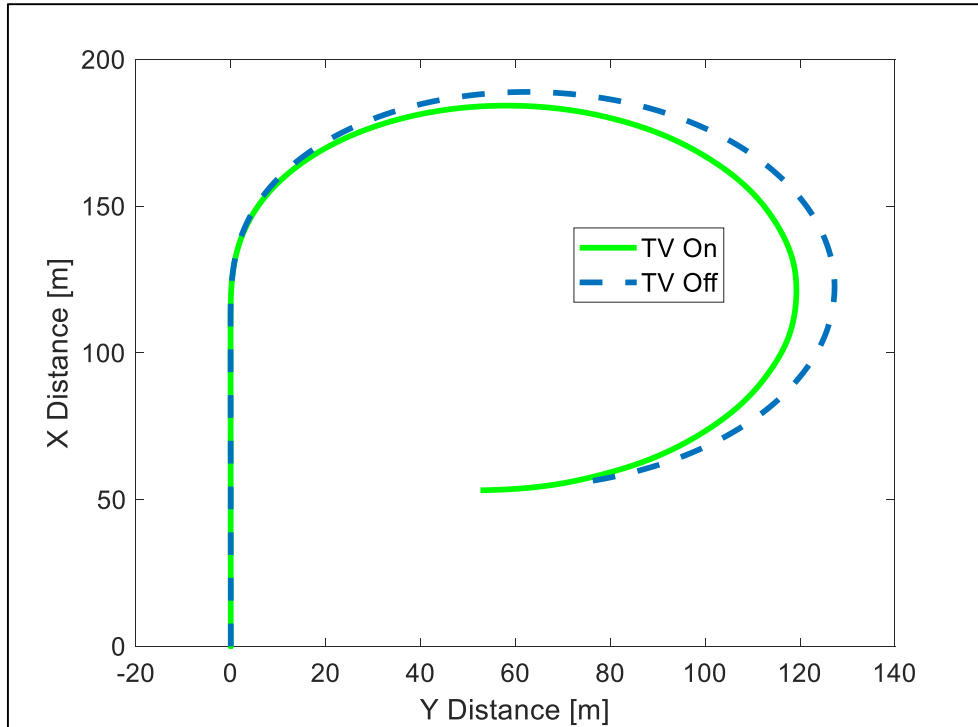


横向加速度更大，而转向输入减少8.7%



更长的轮胎线性滑移角区域，而横向加速度增加了5.7%

车身动态控制 – 轮毂电机扭矩分配



Accelerate to 50 mph
Increase Steering = $45^\circ/\text{s}$
Green = Torque Vector On
Blue = Torque Vector Off



4. 集成详细的电池管理系统（BMS） / 电池



The screenshot shows the MATLAB Central interface for a project titled "Design and Test Lithium Ion Battery Management Algorithms". The page includes a navigation bar with "MATLAB Central", "Files", "Authors", "My File Exchange", "Contribute", and "About". The project title is in large orange text, followed by "version 1.0.2 (8.89 MB) by Chirag STAFF". A description states: "This example project can be used as a reference design to get started with designing Battery Management System with MATLAB and Simulink." On the right, it shows "Trial software", "★★★★★ 3 Ratings", "386 Downloads", "Updated 12 Nov 2019", and a "View License" link. At the bottom right are "+ Follow" and "Download" buttons. A thumbnail image on the left shows a Simulink block diagram with a battery icon. Navigation tabs for "Overview", "Functions", and "Models" are visible at the bottom.

- 电池领域专家开发的[详细的电池管理系统（BMS） / 电池模型](#)
- 使用 Git “子模块” 把BMS项目添加引用到整车simulink project中
- 使用可变子系统集成BMS控制器和详细的电池

电池管理系统（BMS）子系统

1. 状态机

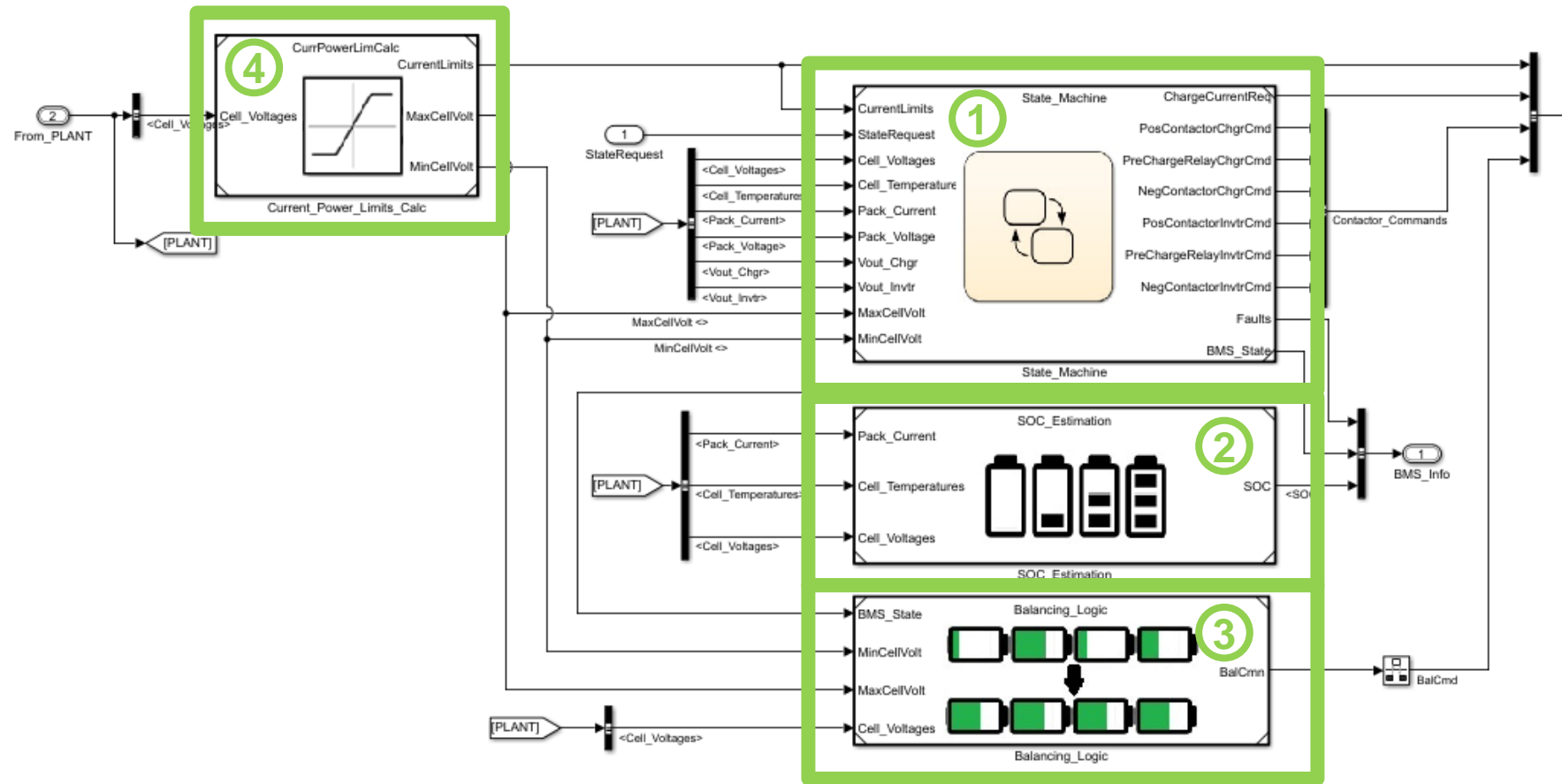
- BMS 状态
- 故障检测
- 接触器管理

2. SOC 估计

- 无迹卡尔曼滤波UKF / 扩展卡尔曼滤波EKF

3. 电池平衡逻辑

4. 限流计算



详细电池模型

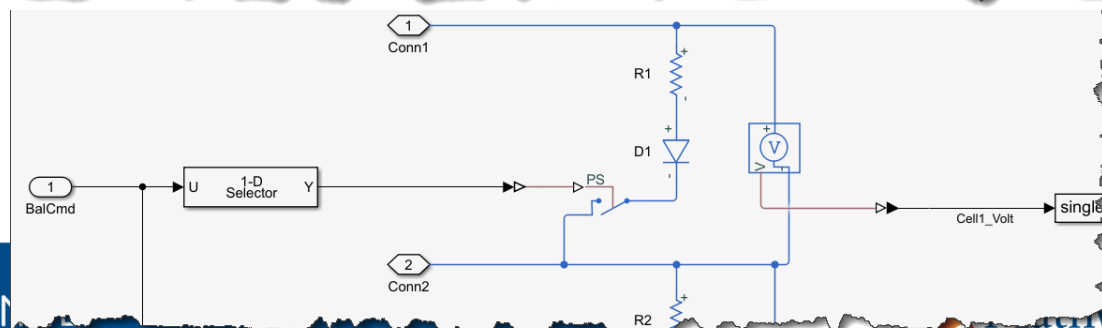
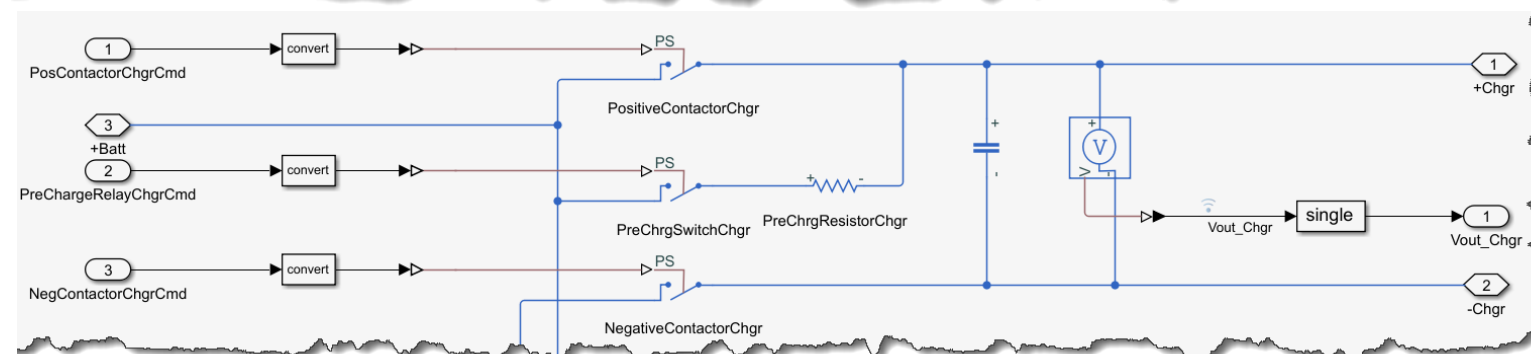
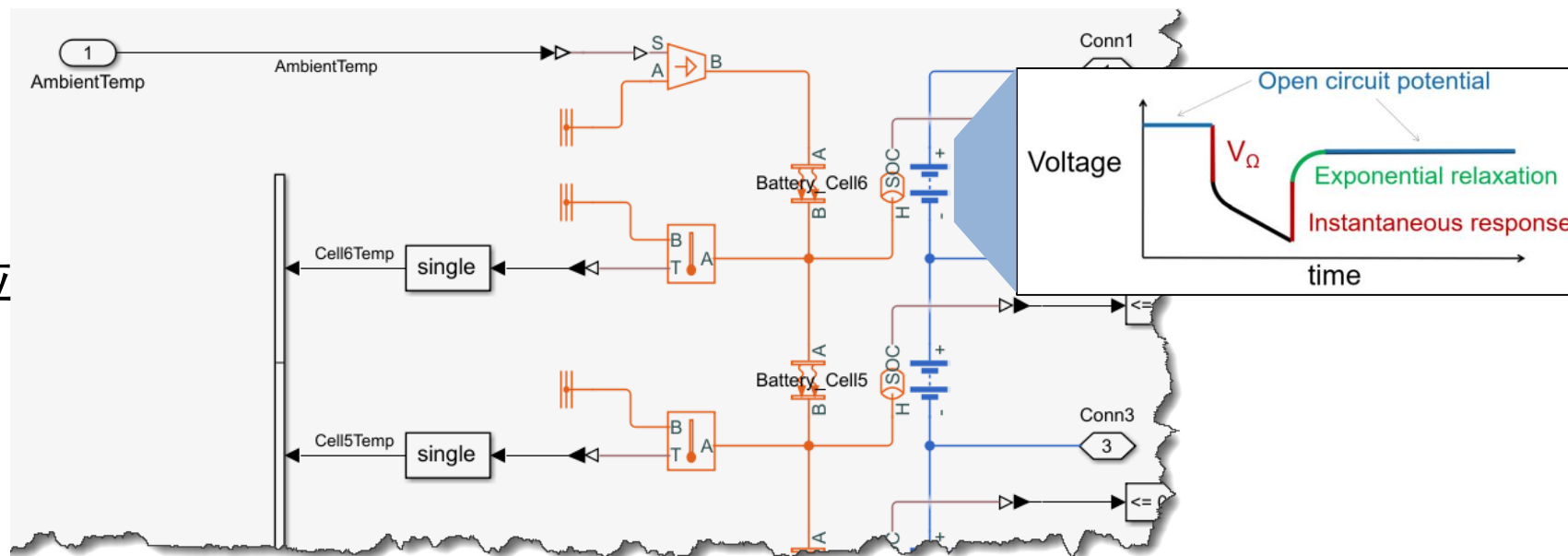
- Simscape

- RC 等效电路的动态响应
- 热效应

- 接触器

- 逆变器
- 充电器

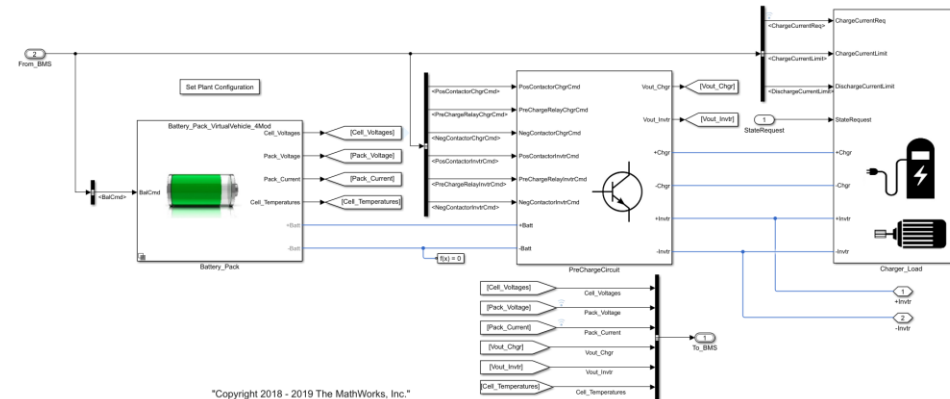
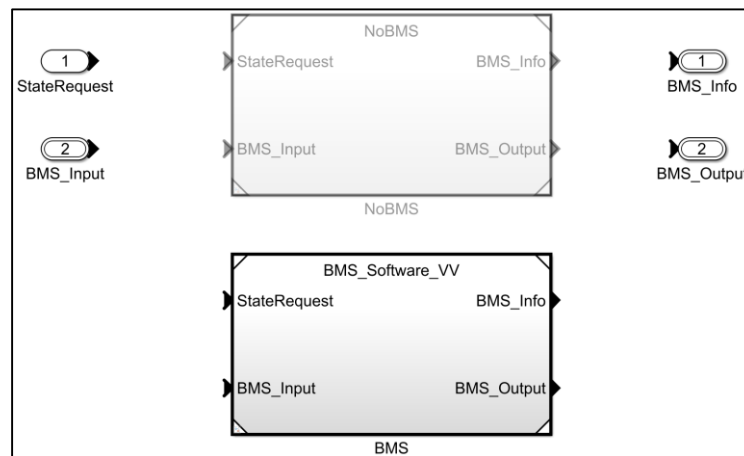
- 电池平衡



BMS / 电池集成与结果

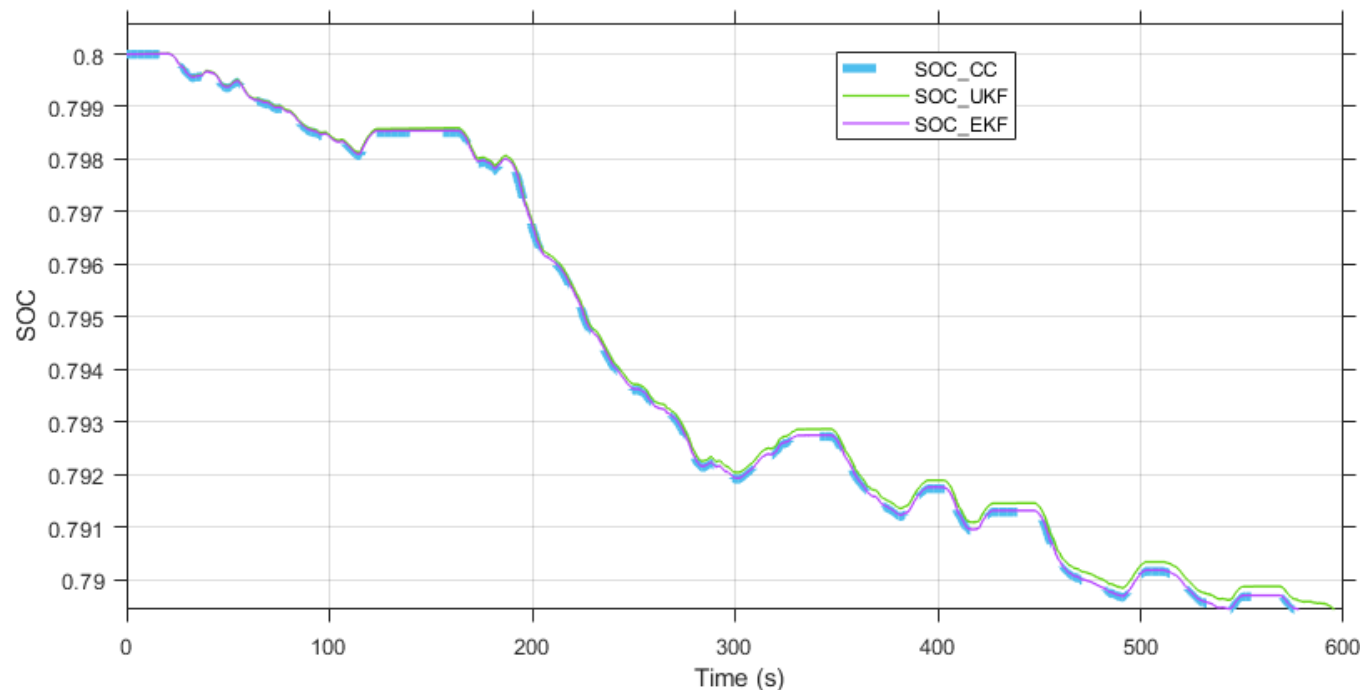
集成

- BMS 模型引用
 - 重用BUS对象
- 电池变体
- 将参数添加到数据字典 (Data Dictionary)



结果

- 直接集成
- 使用整车模型测试BMS / 电池



5. 驾驶员在环功能

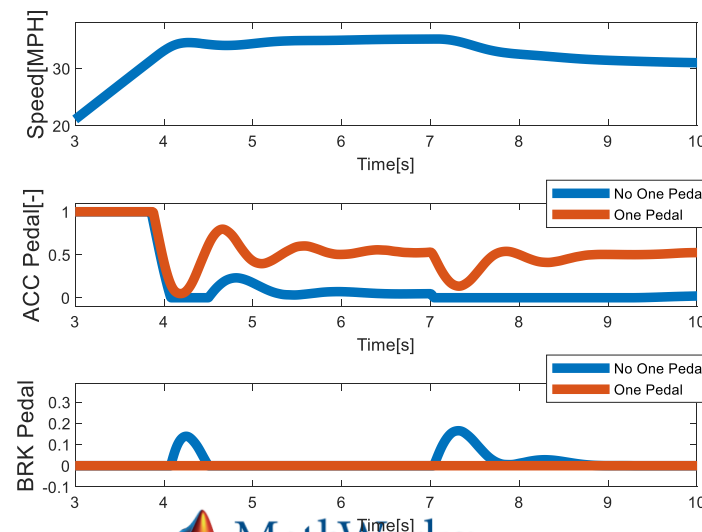
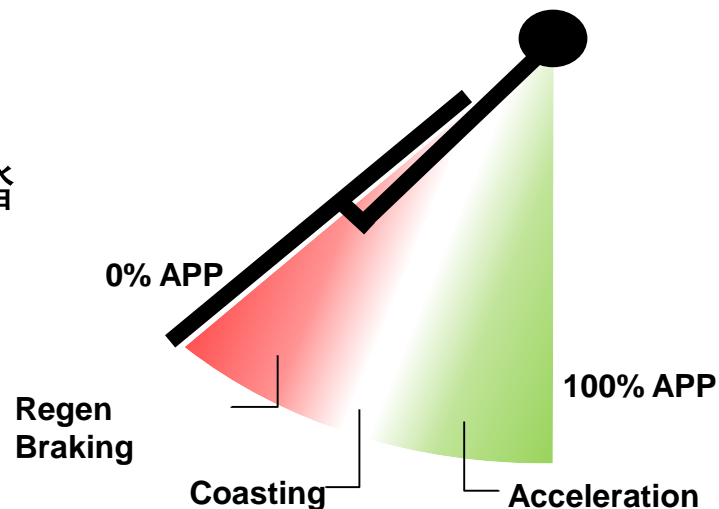
通过驾驶员在环功能增强车辆模型

- 驾驶模拟器功能
 - [Logitech G29](#) 方向盘/ 踏板
 - Unreal Engine 显示
- 控制算法的开环测试

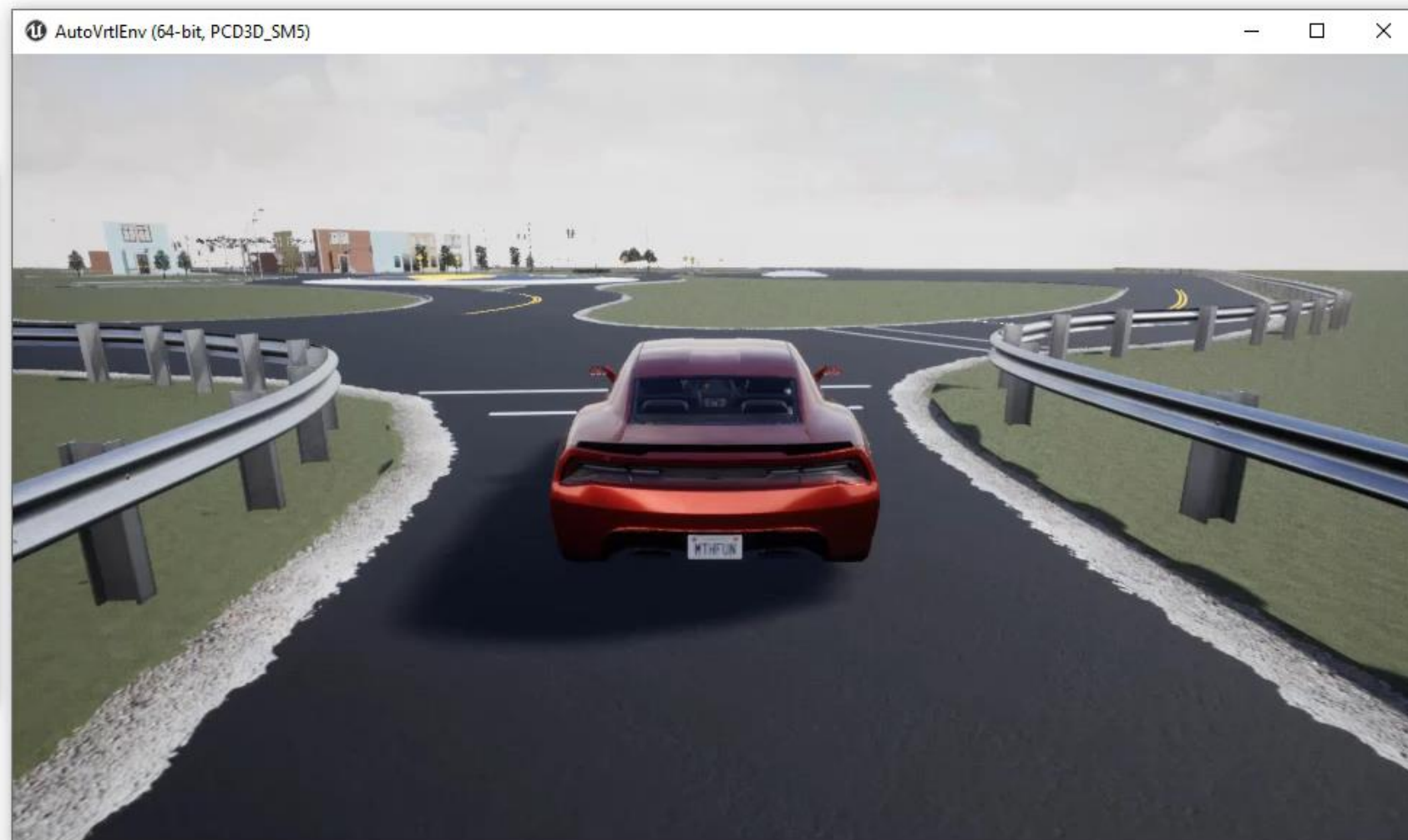
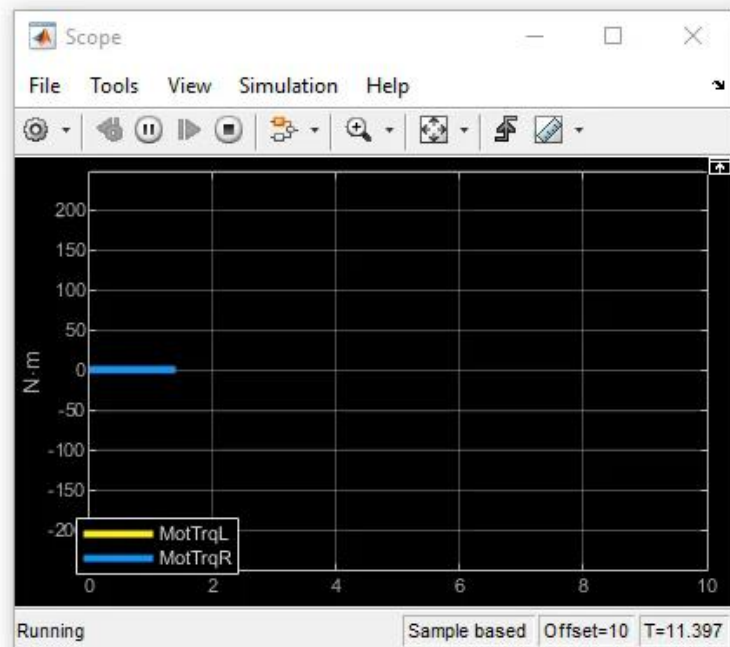


单踏板驱动算法

- 将原先油门踏板信号映射到单踏板对应的信息上
- 区间标定影响驾驶性与“驾驶乐趣”特性

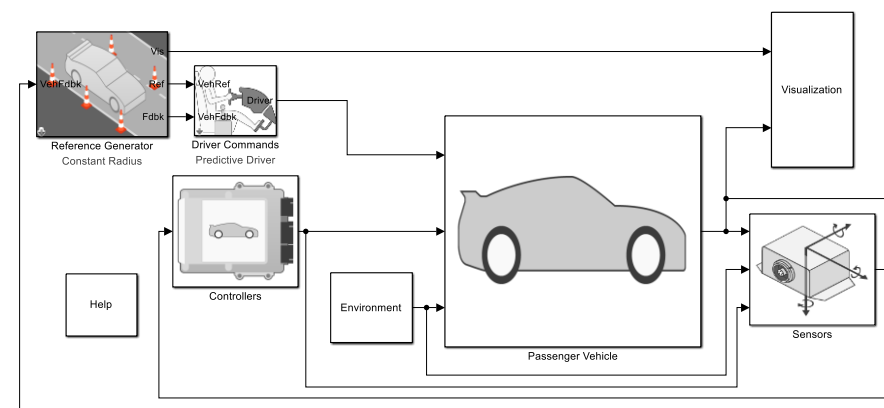
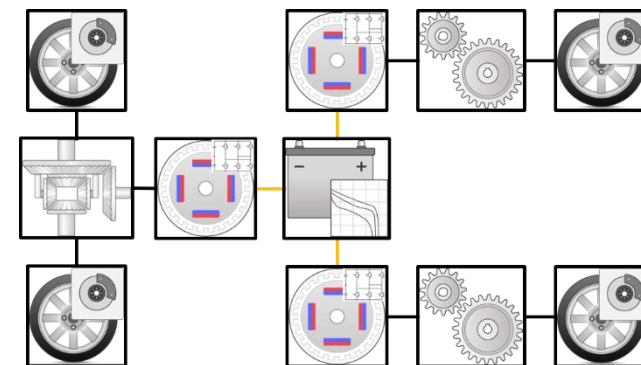


驾驶员在环功能

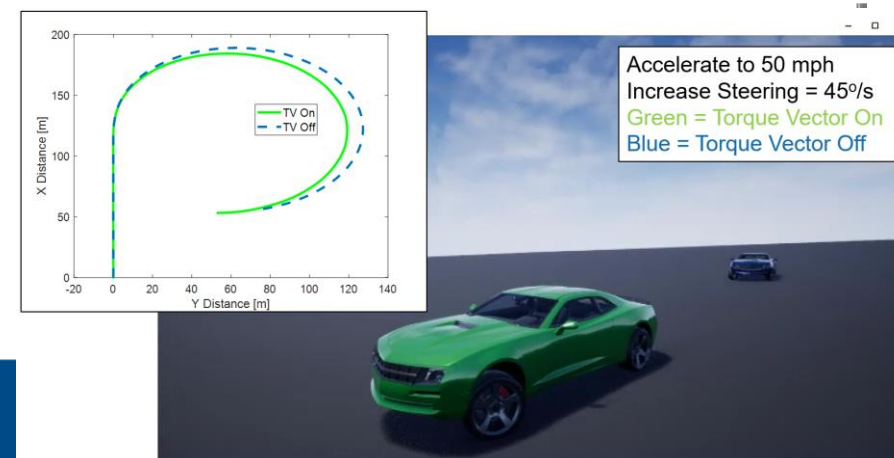


总结

- MathWorks 在虚拟车辆仿真上的应用：
 - 使用Powertrain Blockset 和 Vehicle Dynamics Blockset快速评估电气化动力总成
 - 参考应用提供了模型构架和测试用例的模板
 - 单个模型用于支持多种基于模型设计的活动



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Q & A

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