

# 2020 MathWorks 中国汽车年会

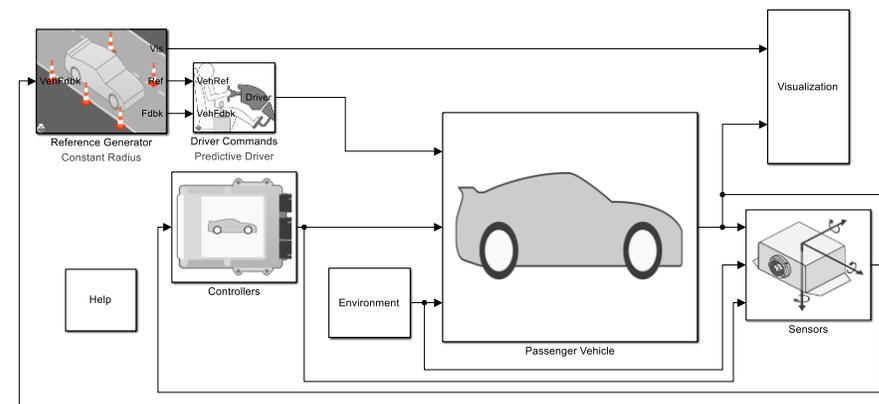
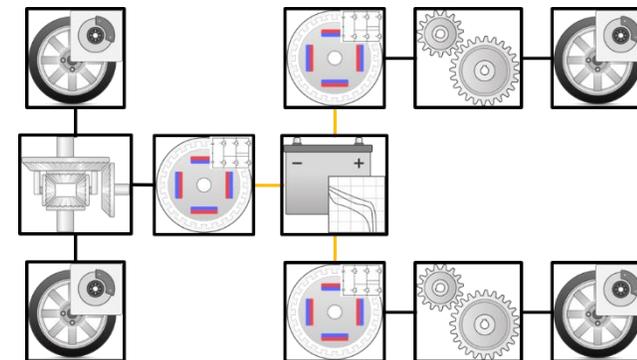
基于参考应用程序  
快速开发虚拟电动汽车模型

楚骏楠  
MathWorks 中国区高级应用工程师

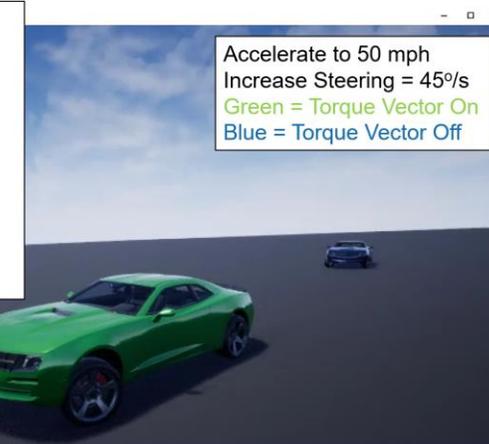
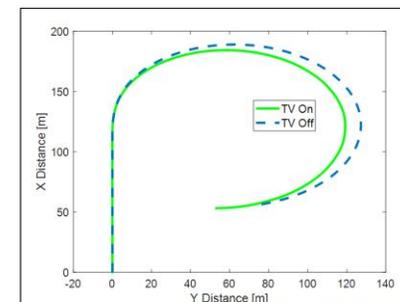


# 内容提要

- 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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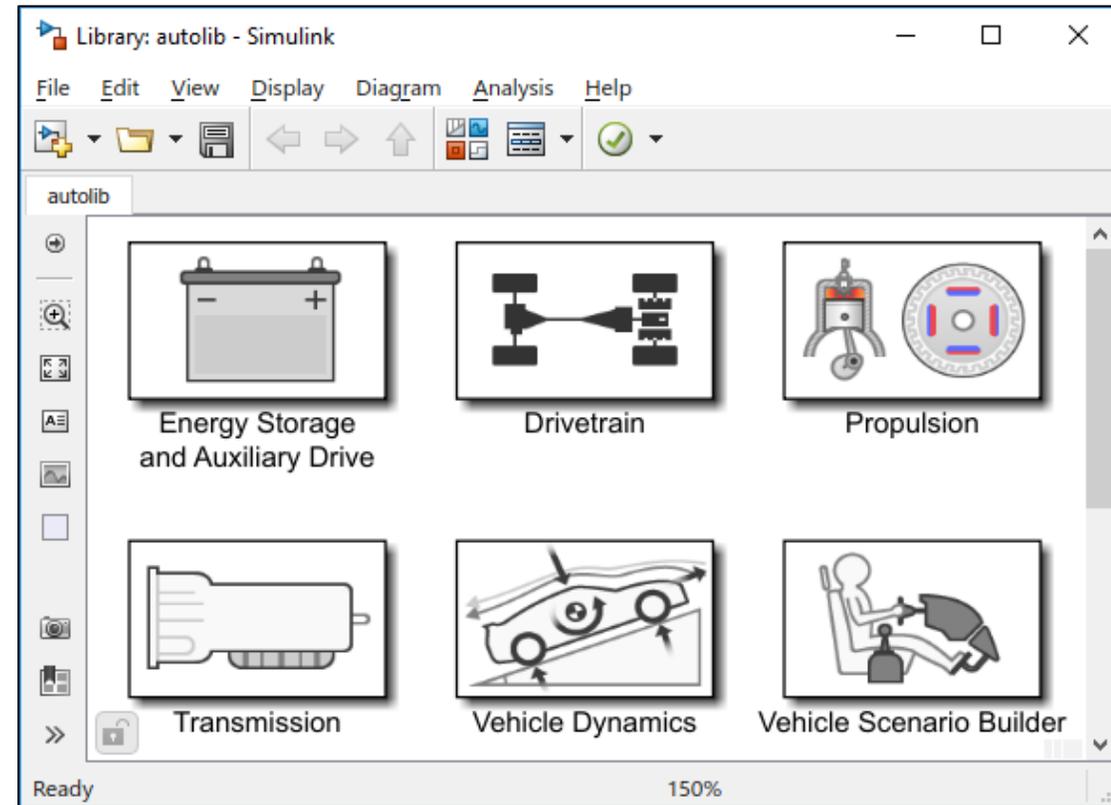


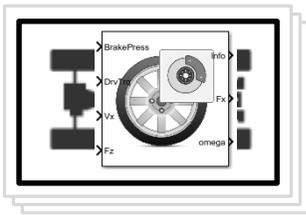
# Powertrain Blockset

- 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

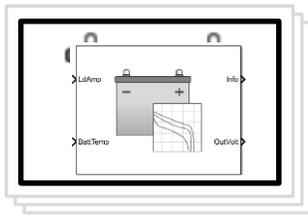
**降低基于模型设计的准入门槛**

## 模块库

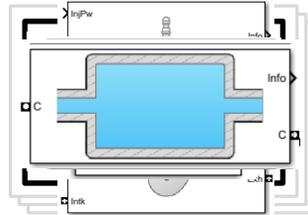




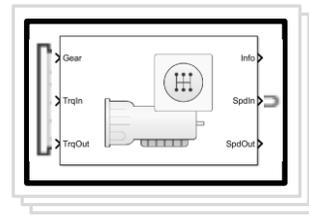
Drivetrain



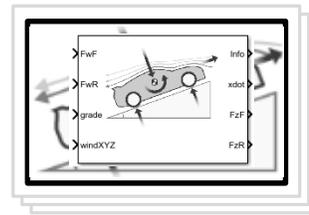
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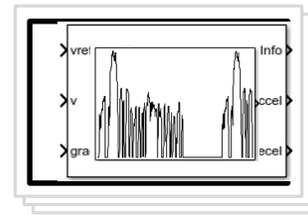
Propulsion



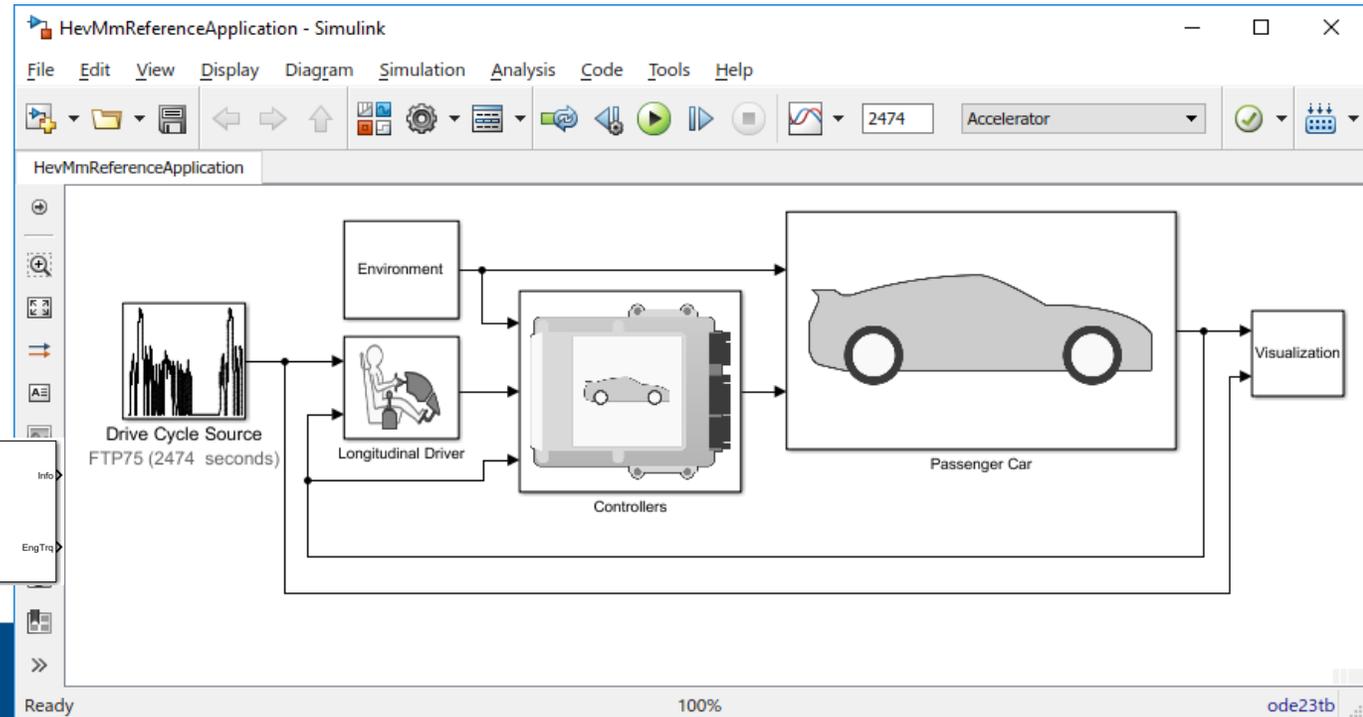
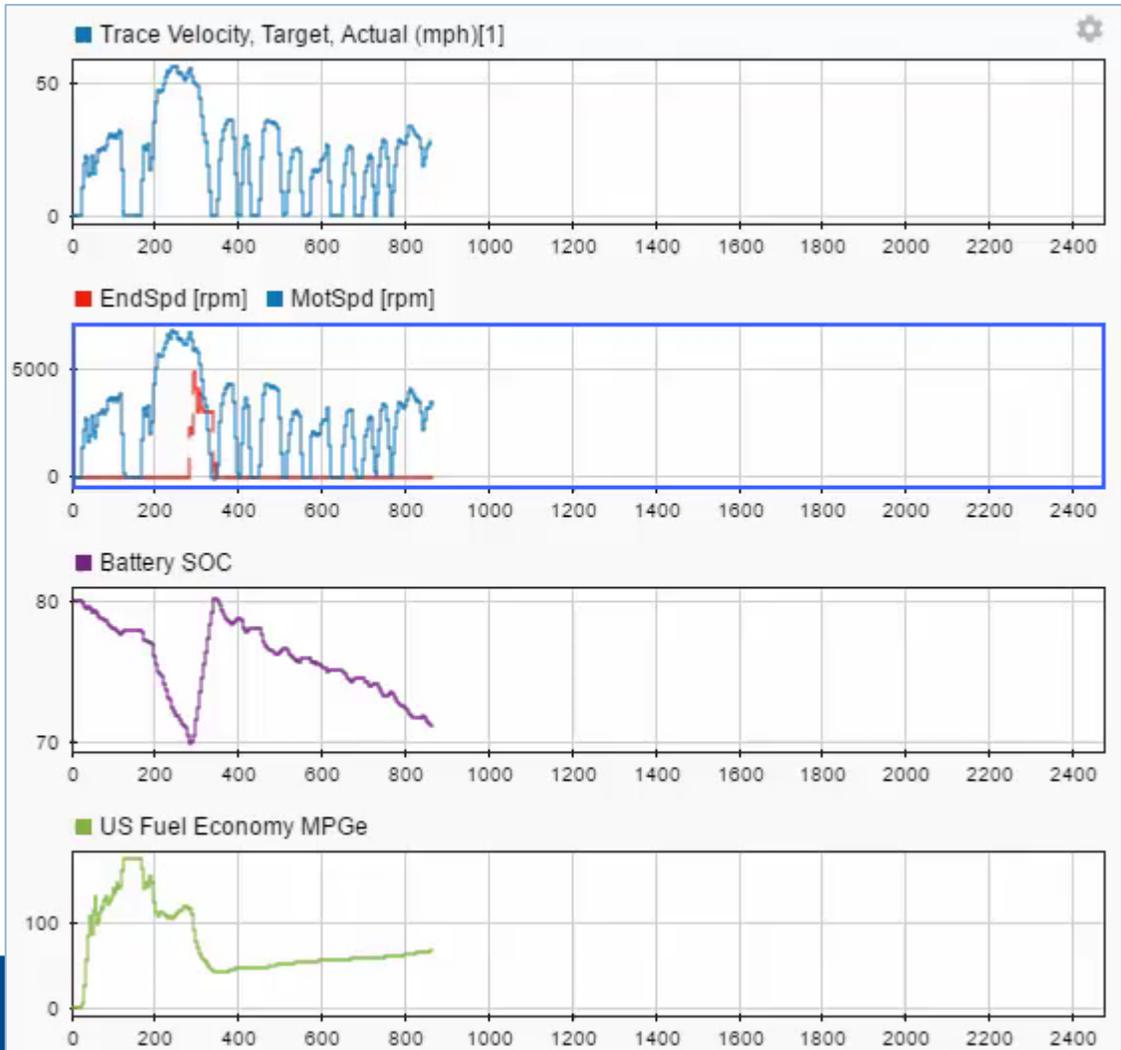
Transmission



Vehicle Dynamics

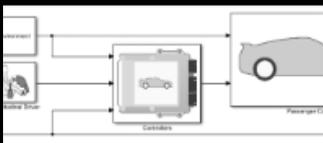
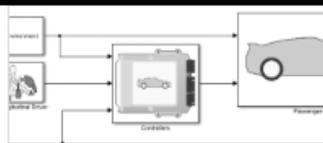
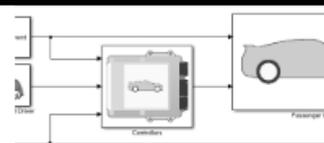
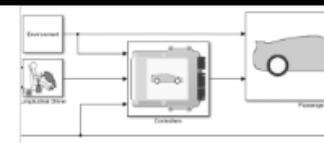
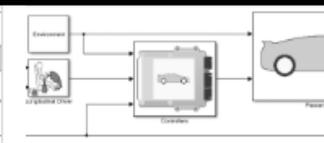
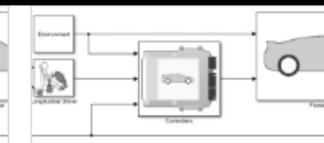
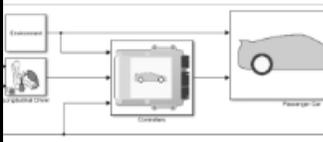
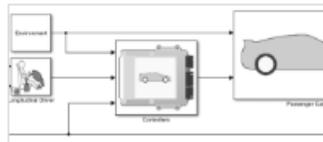
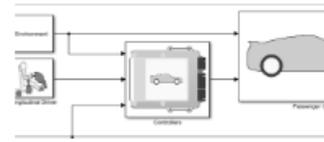
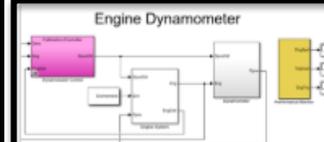
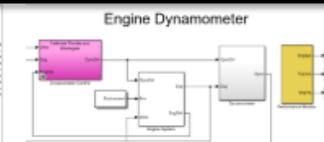


Vehicle Scenario Builder



# 参考应用

虚拟车  
辆模型

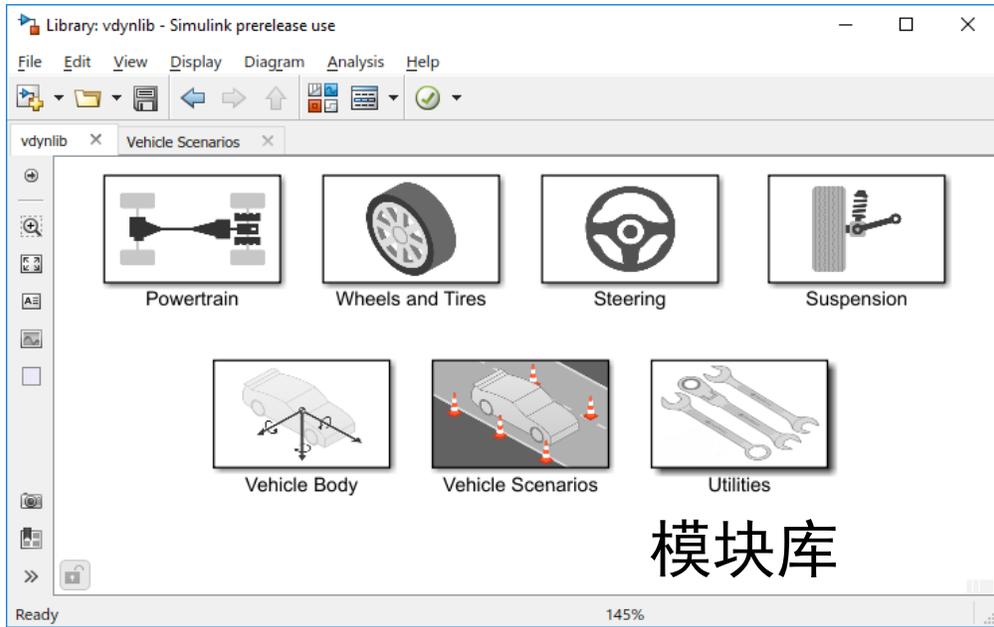
 <p><b>Conventional Vehicle Reference Application</b></p> <p>Simulate a full vehicle model with an internal combustion engine, transmission, and associated powertrain control algorithms. Use</p> <p><a href="#">Open Example</a></p>	 <p><b>HEV Multimode Reference Application</b></p> <p>Simulate a full multimode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

虚拟发动机  
台架

# Vehicle Dynamics Blockset

# R2018a

## 预制的参考应用



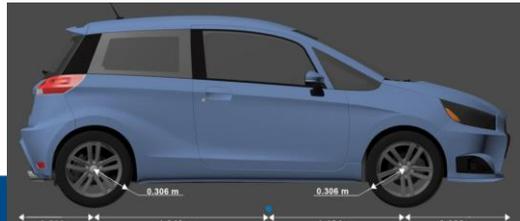
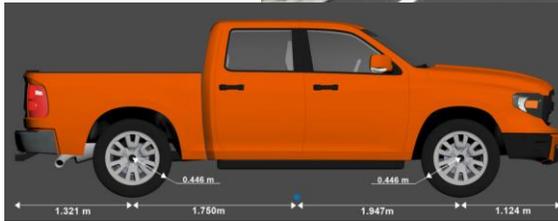
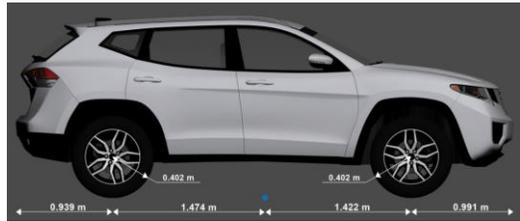
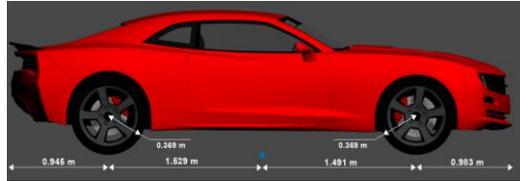
- Double-Lane Change Reference Application**  
Simulate a full vehicle dynamics model undergoing a double-lane change maneuver according to standard ISO 3888-2. You can [Open Example](#)
- Increasing Steering Reference Application**  
Simulate a full vehicle dynamics model undergoing a slowly increasing 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...**  
Generate optimized suspension parameters for the vehicle dynamics suspension blocks. [Open Example](#)
- Three-Axle Tractor Towing a Trailer**  
Simulate a three-axle tractor towing a three-axle trailer. [Open Example](#)

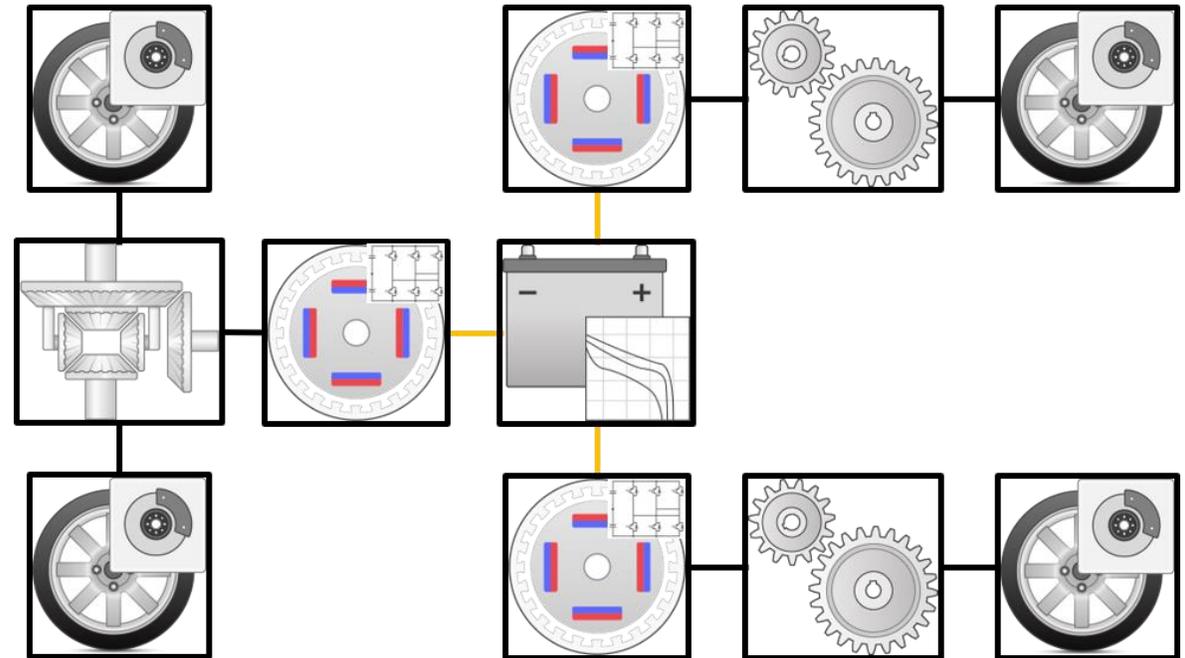
# Vehicle Dynamics Blockset

- 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

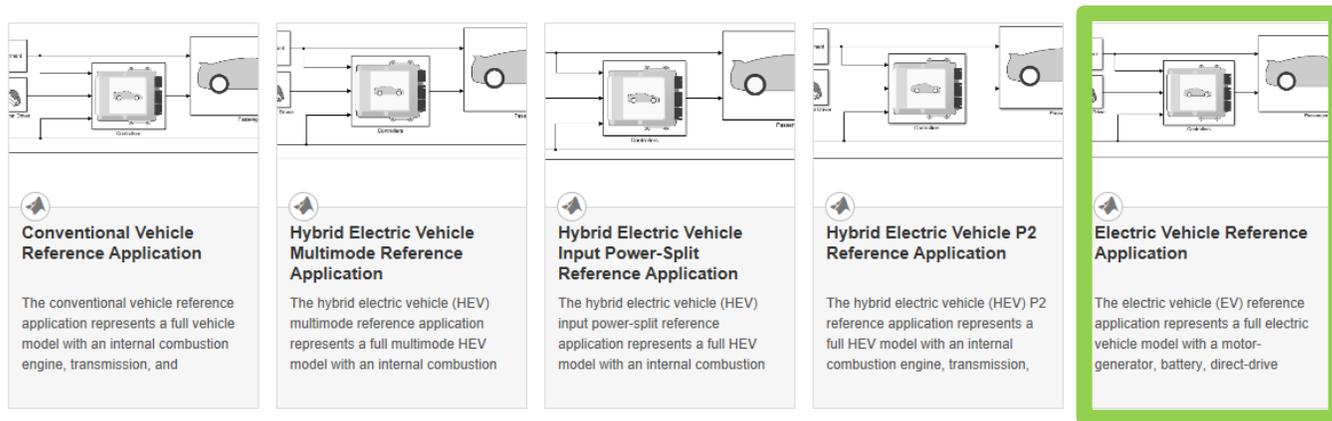
- 评估三电机纯电动汽车动力总成
- 使用一个模型开发和评估
  1. 整车能量管理的监督控制
  2. 前后轴传动比的优化
  3. 同轴的两个轮毂电机扭矩分配
  4. 集成详细的BMS/电池模型到系统级模型中
  5. 使用单踏板驱动算法的驾驶员在环功能



# 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

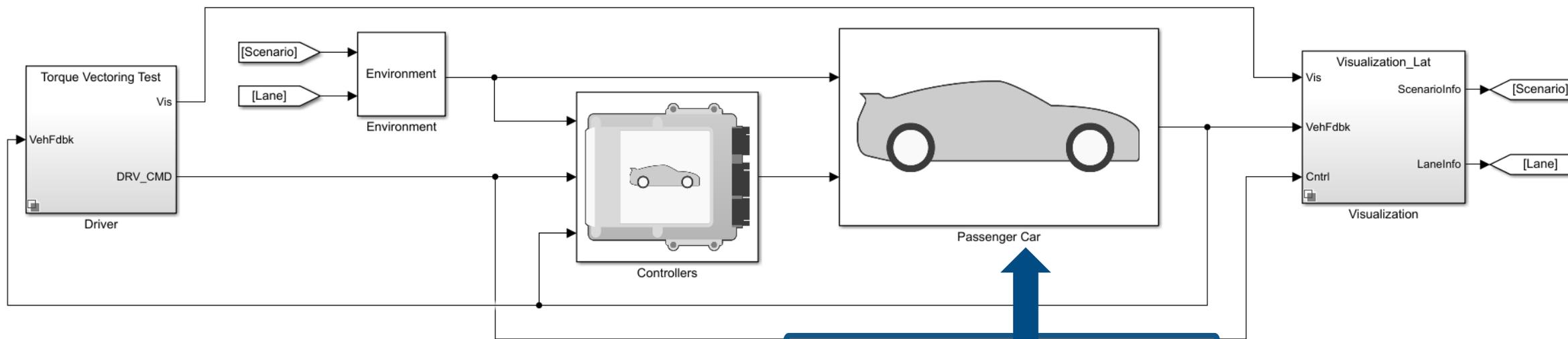
## 3. 自定义控制器

- 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

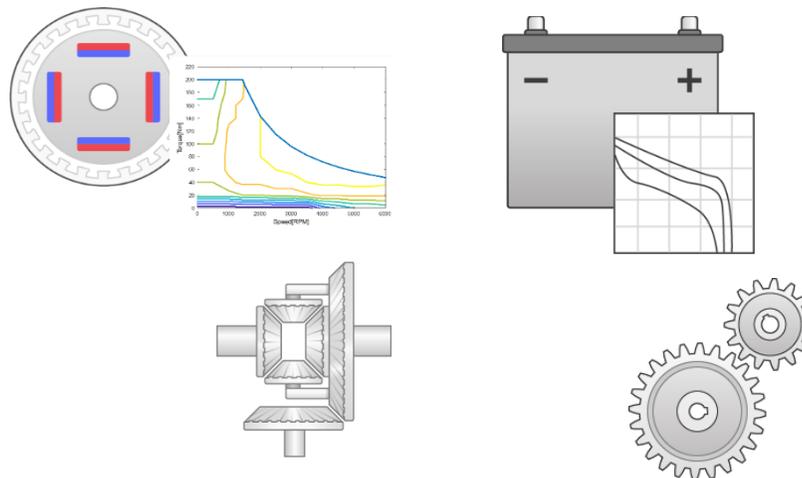
- 敏感度分析
- 设计优化
- MIL / SIL / HIL 测试

# 动力总成被控对象模型



## ■ 修改EV的参考应用案例

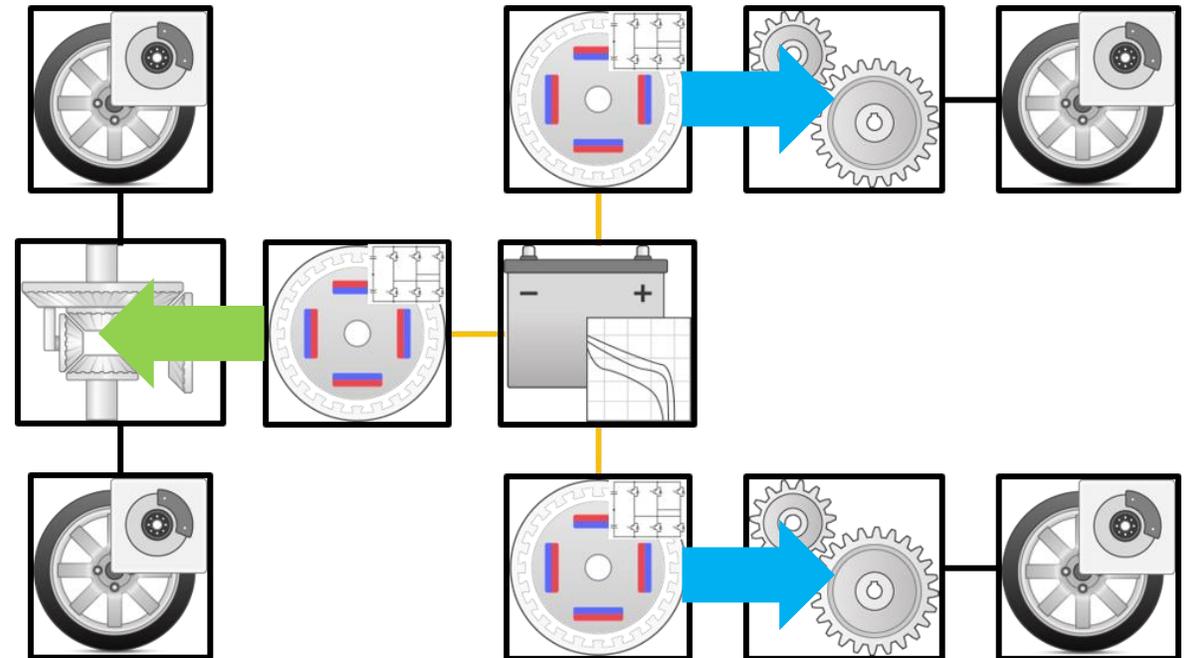
- 3个永磁同步电机
- 电池
- 前差速器/后轴齿轮组



# 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:

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

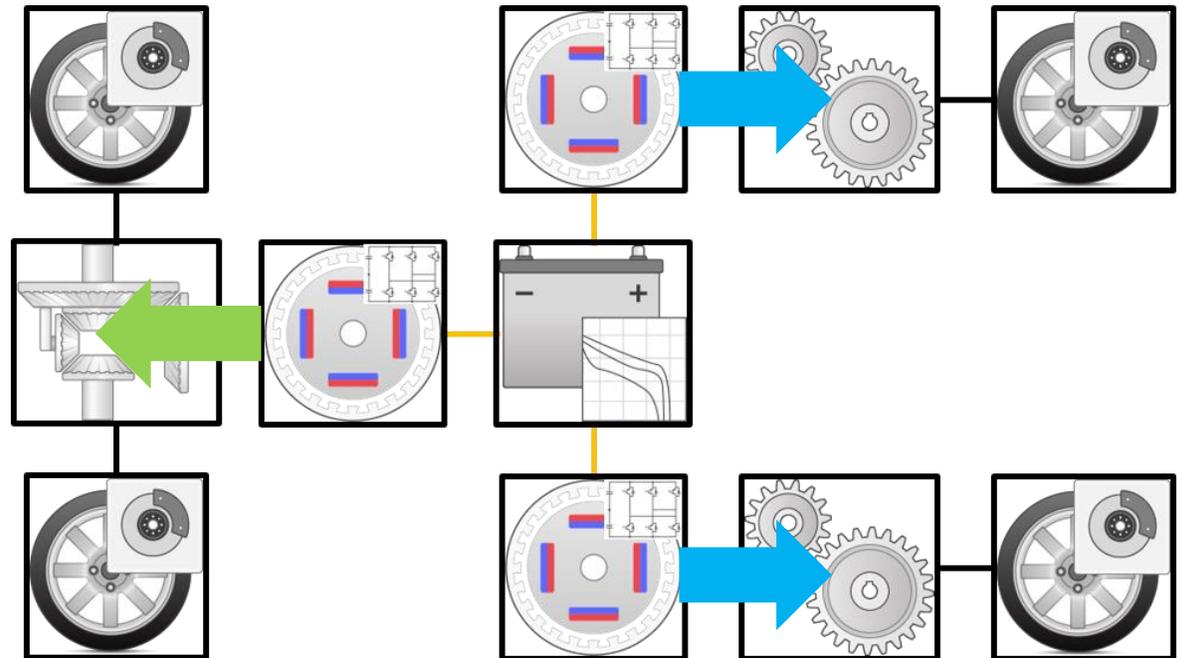
$$P_{chg}(SOC) \leq P_{batt} \leq P_{dischg}(SOC)$$

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

- 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)

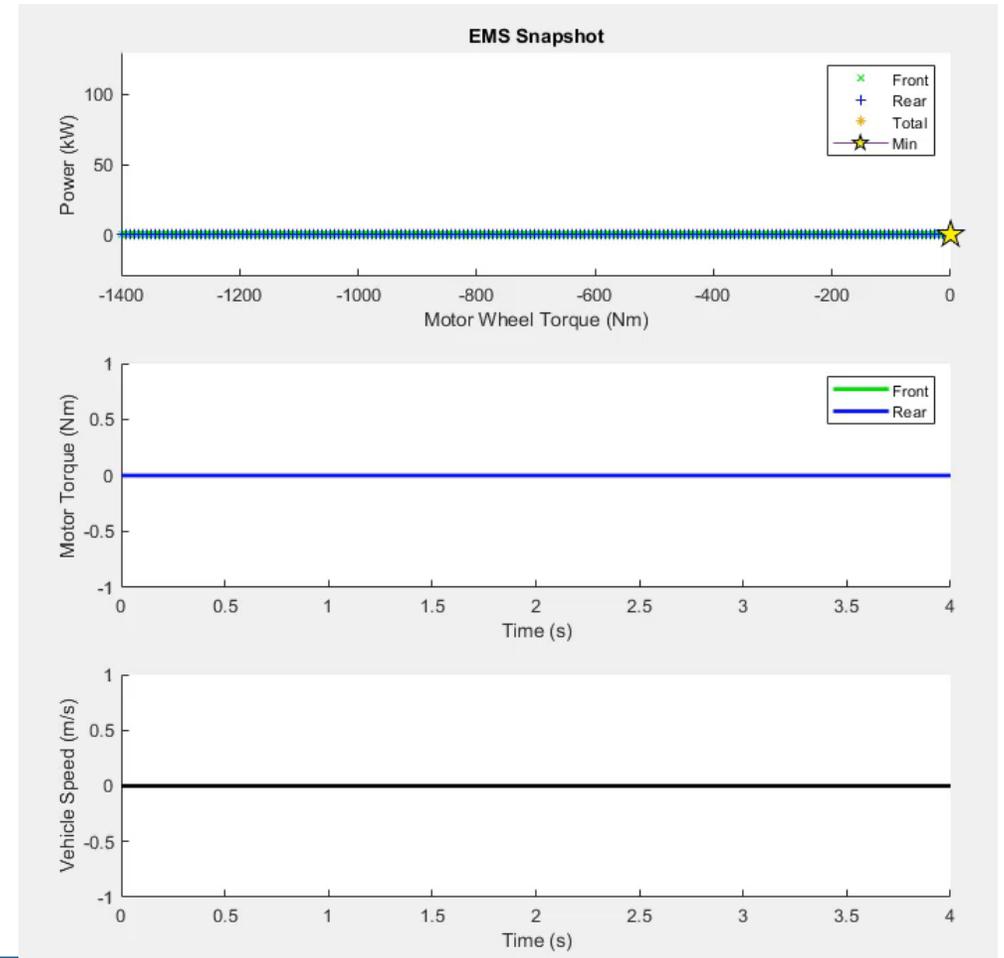
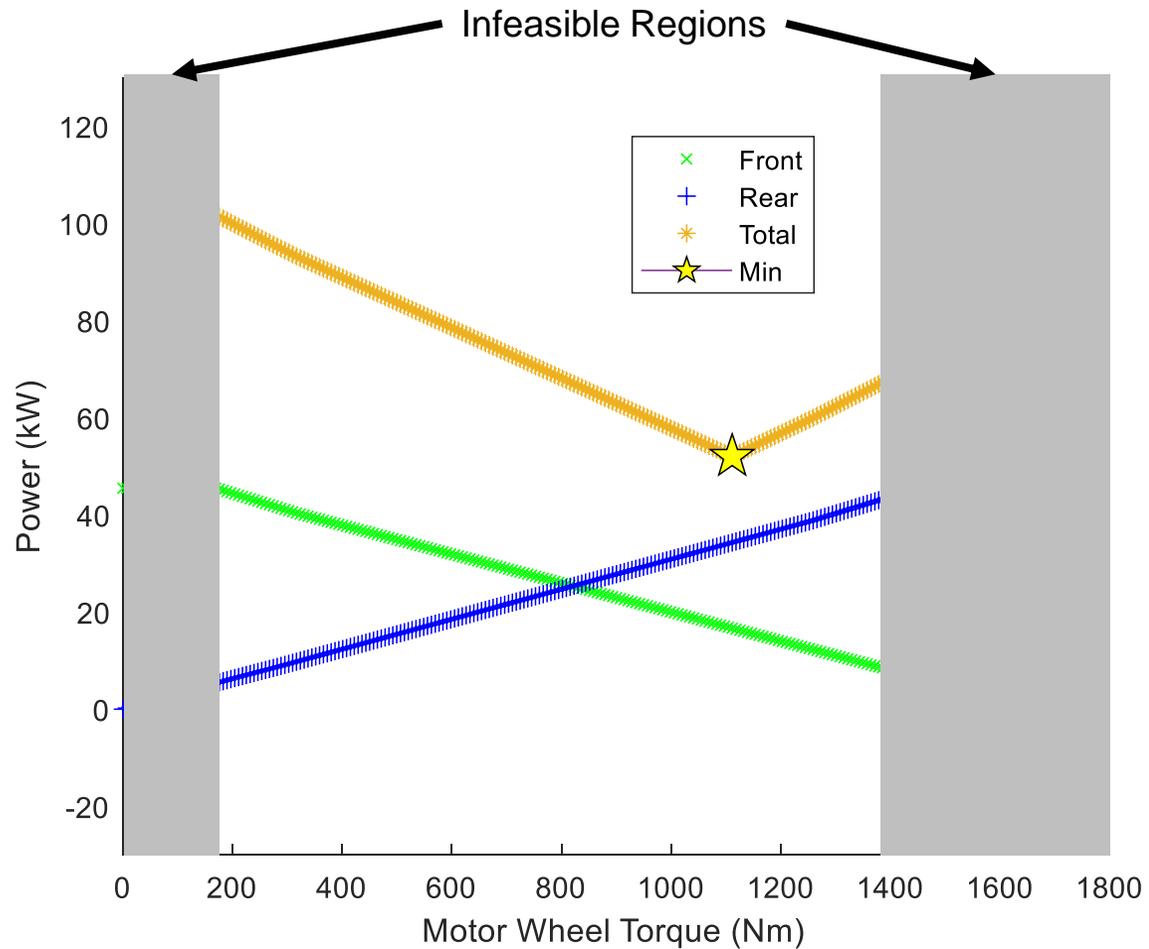
$$\begin{bmatrix} -Min\ Rear\ Torque \\ \vdots \\ +Max\ Rear\ Torque \end{bmatrix}$$

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

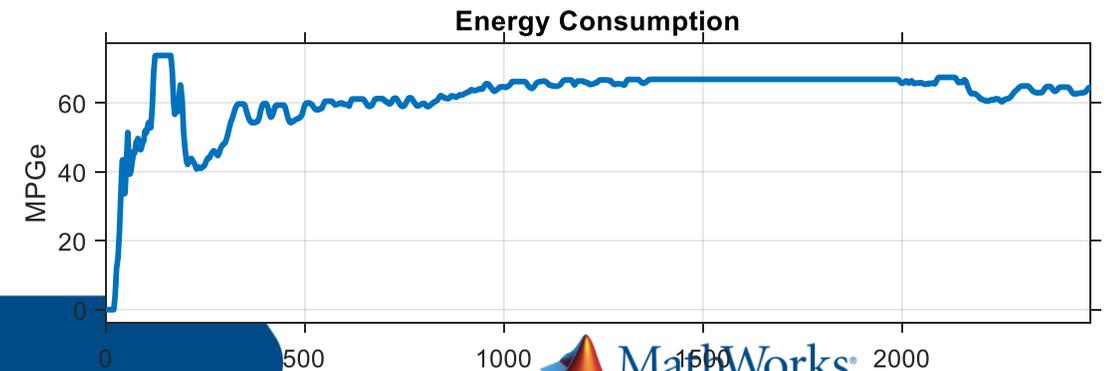
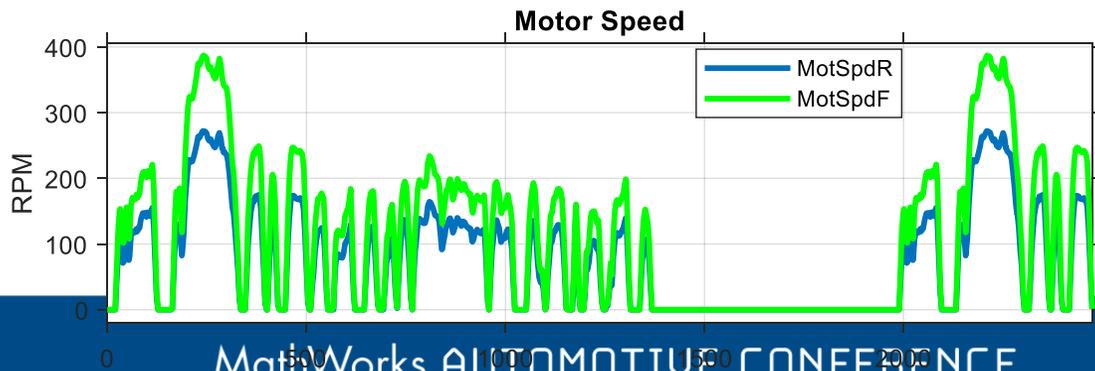
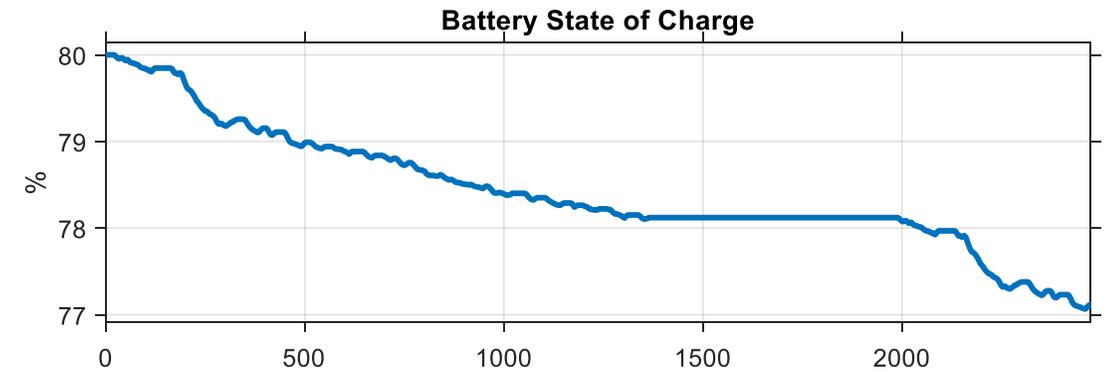
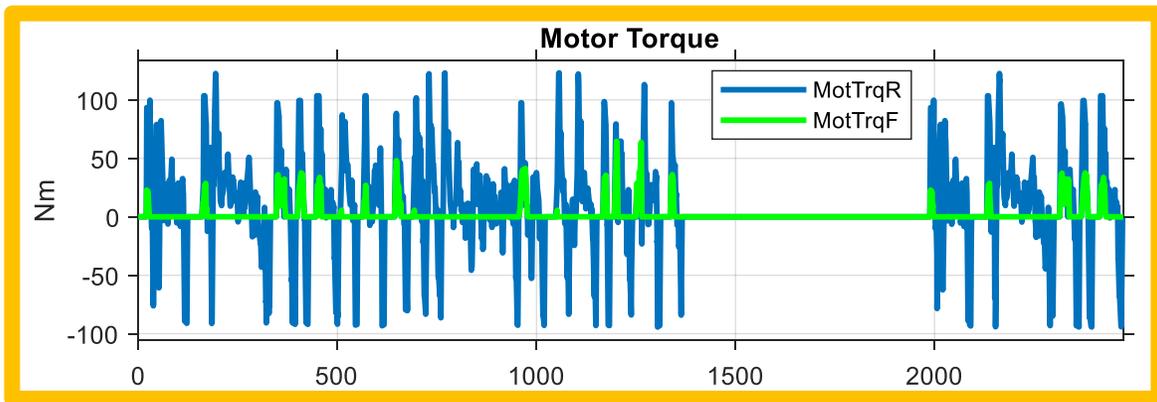
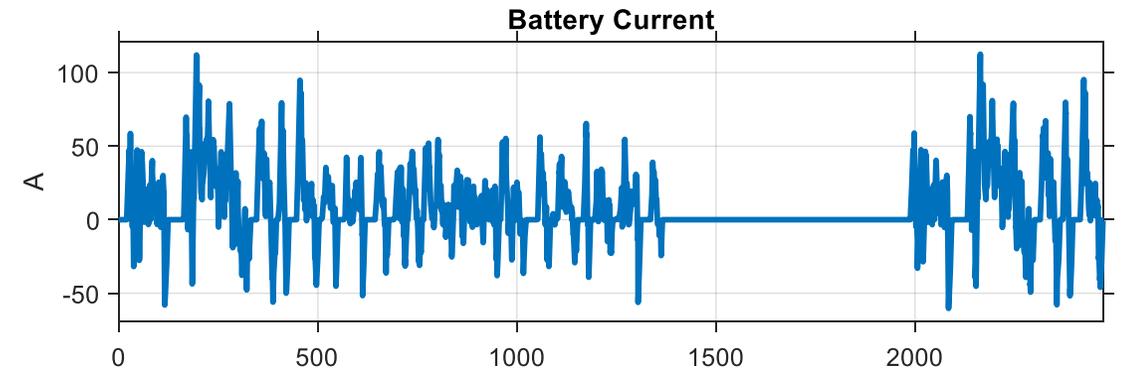
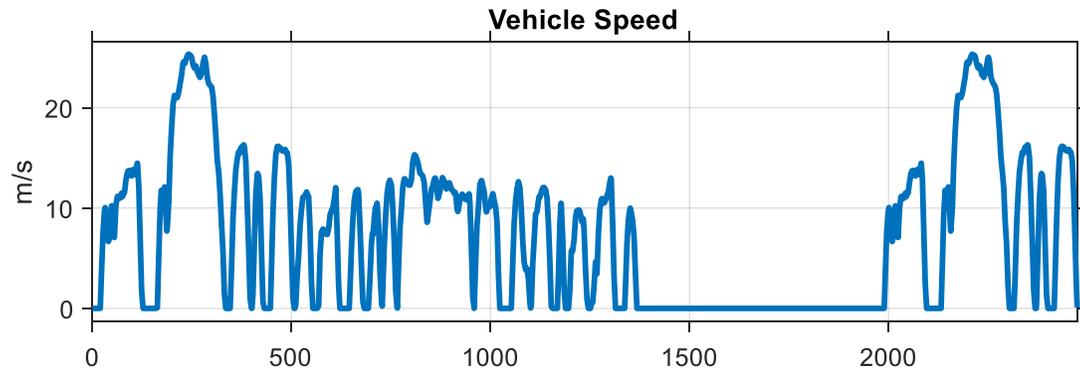
$$\min_{\tau_{rear}} P_b(\tau_{rear})$$

# EV 能量管理策略(EMS)实现过程

## 某时间点的EMS快照

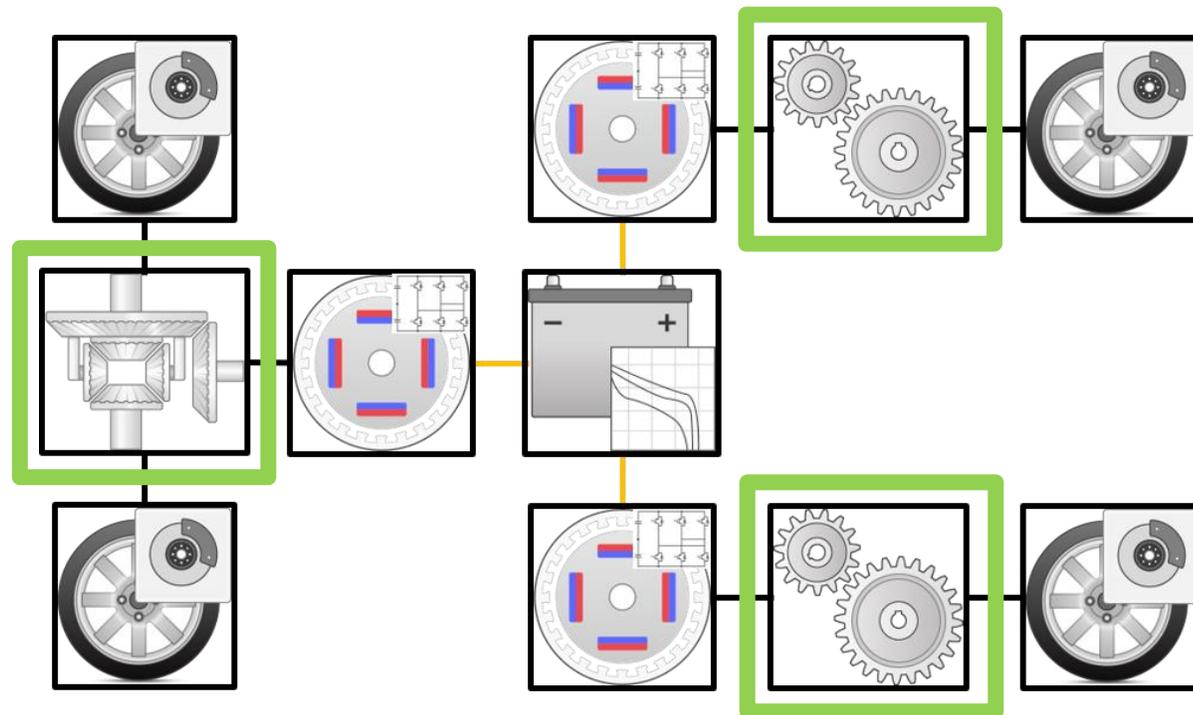


# EV 能量管理策略(EMS)实现过程

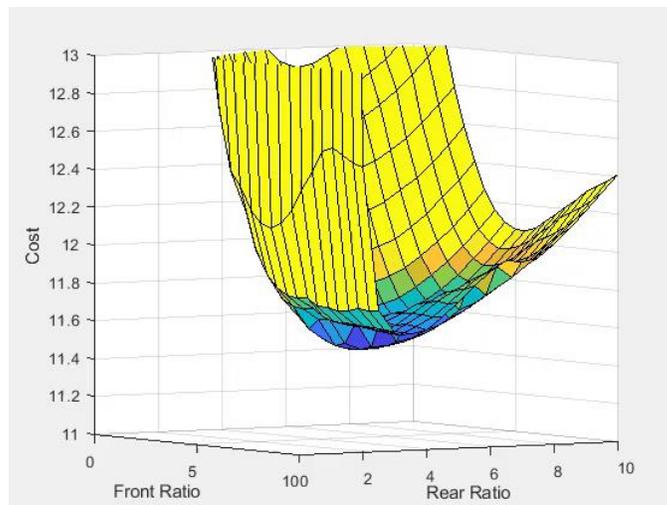
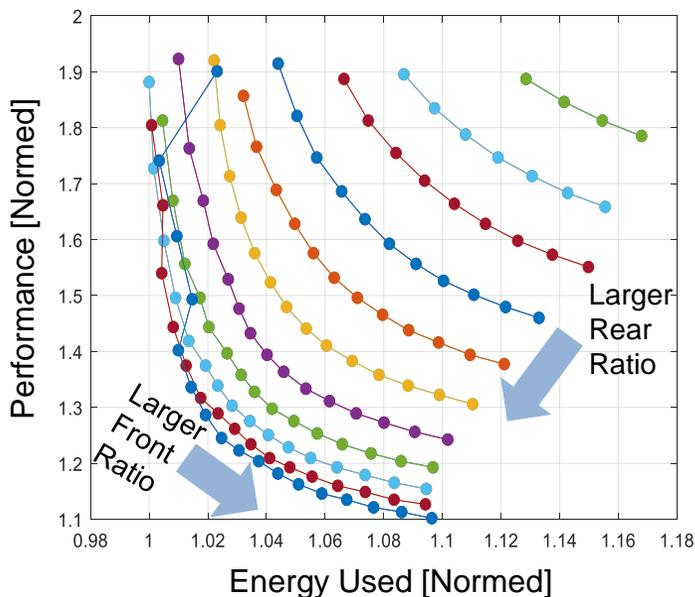


## 2. 优化前后轴的传动比

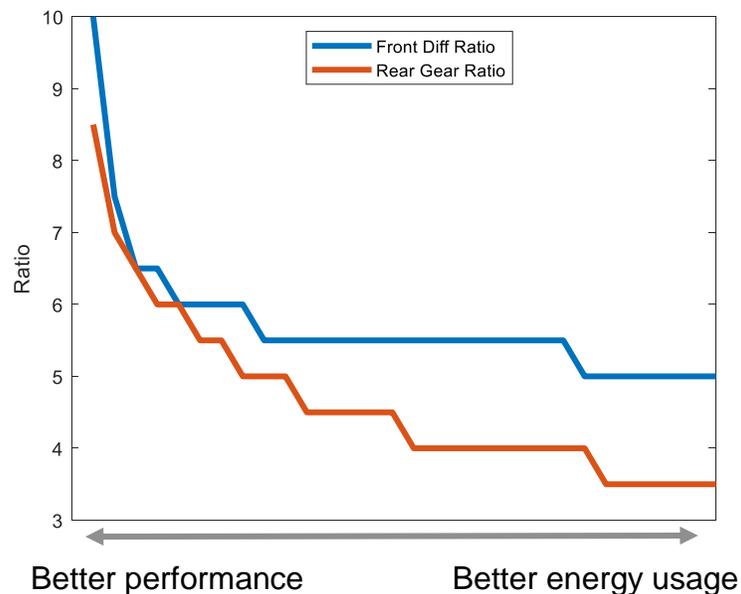
- 重用模型/EMS控制，支持调整各个部件参数的仿真
- 是否可以优化传动比？
  - 将多个驾驶循环的能耗降至最低
  - 优化车辆加速性能



## 2. 优化前后轴的传动比



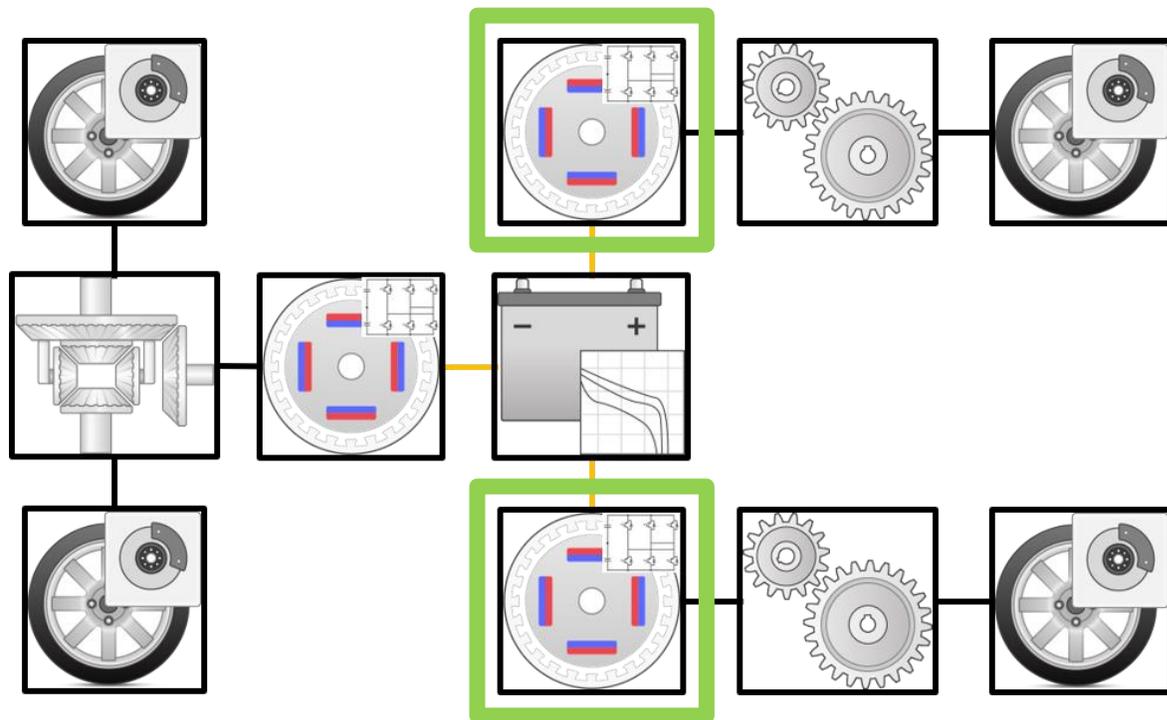
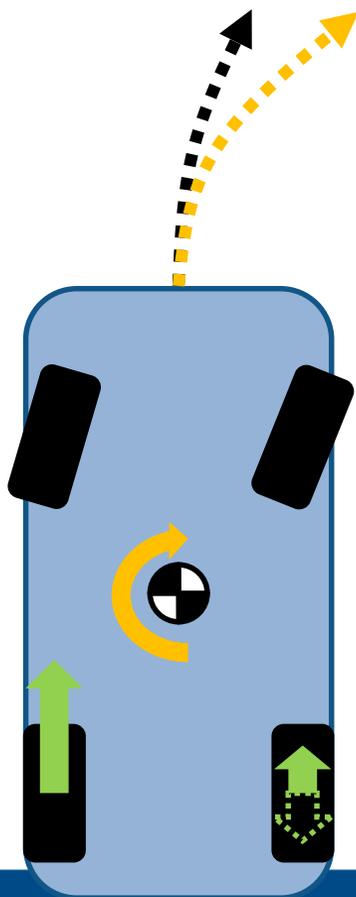
$$\min_{N_f, N_r} (0.55E_{FTP} + 0.45E_{HWY}) W_1 + W_2(T_{0-120KPH})$$



- 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

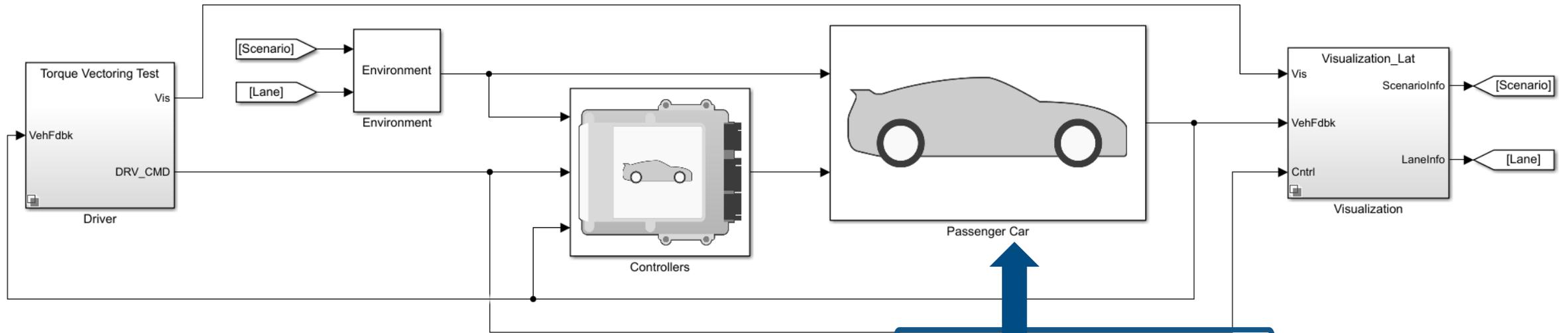
### 3. 轮毂电机扭矩分配

- 双后轮电机



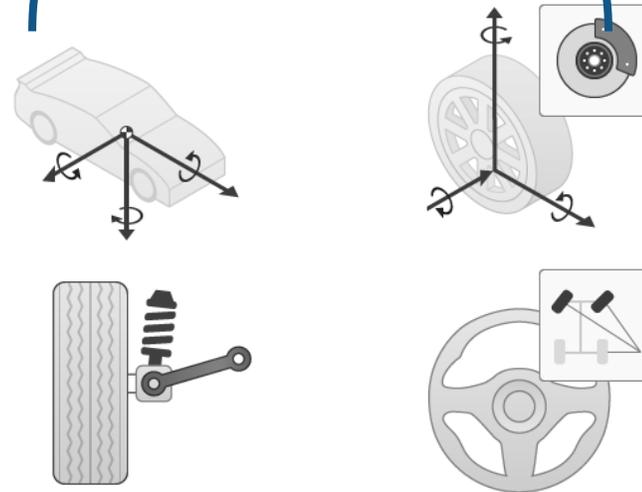
- 评估扭矩分配 (Torque Vectoring):
  - 详细的传动系统+ 横向车辆动力学模型
  - 扭矩控制策略可以与能量管理策略兼容
  - 确定改进目标

# 车辆动力学模型

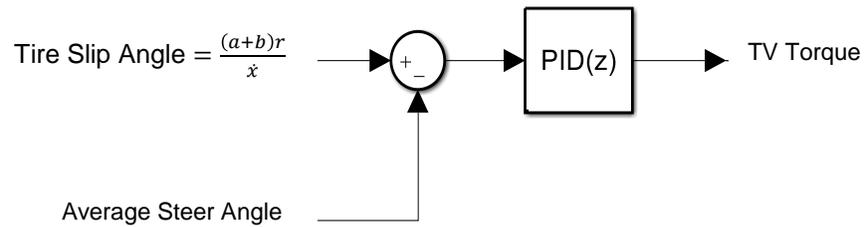


- 在车辆模型上添加可变子系统:
  - 6 DOF 车辆模型
  - 2 DOF 轮胎+制动模型
  - 悬架
  - 转向

} 14-DOF
- 沿用详细的传动控制和能量管理控制

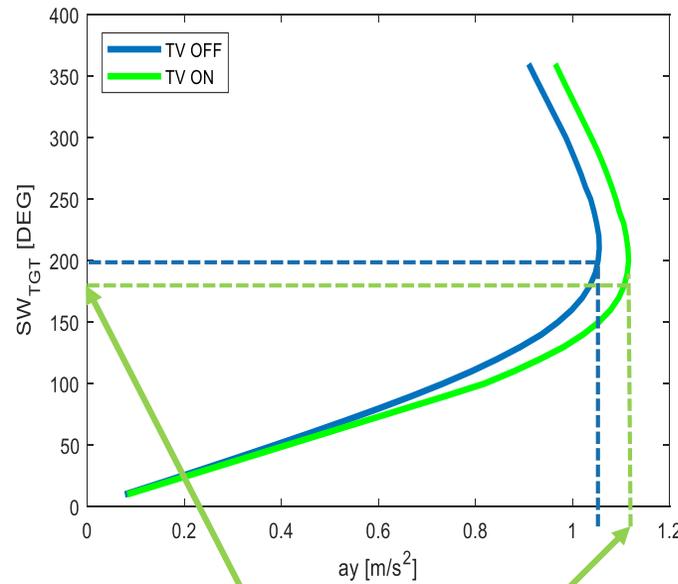
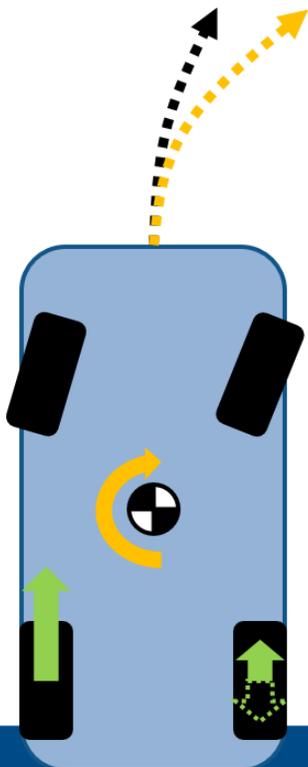


# 车身动态控制 – 轮毂电机扭矩分配

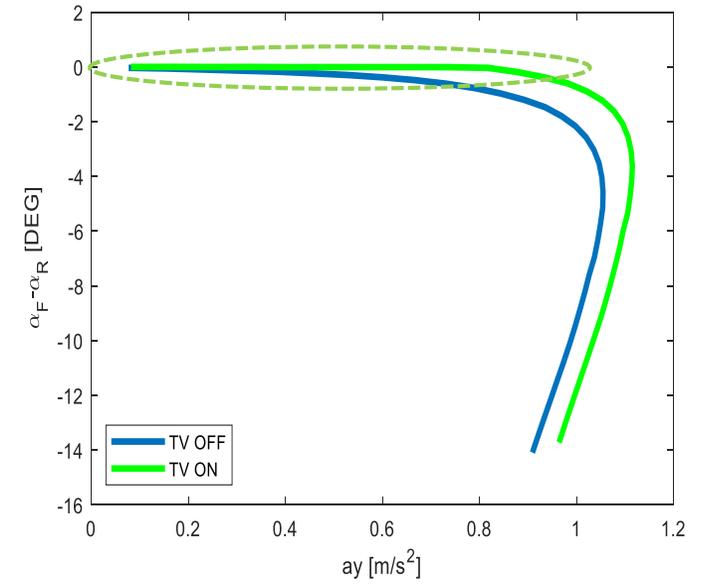


## A Torque Vectoring Strategy for Improving the Performance of a Rear Wheel Drive Electric Vehicle

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

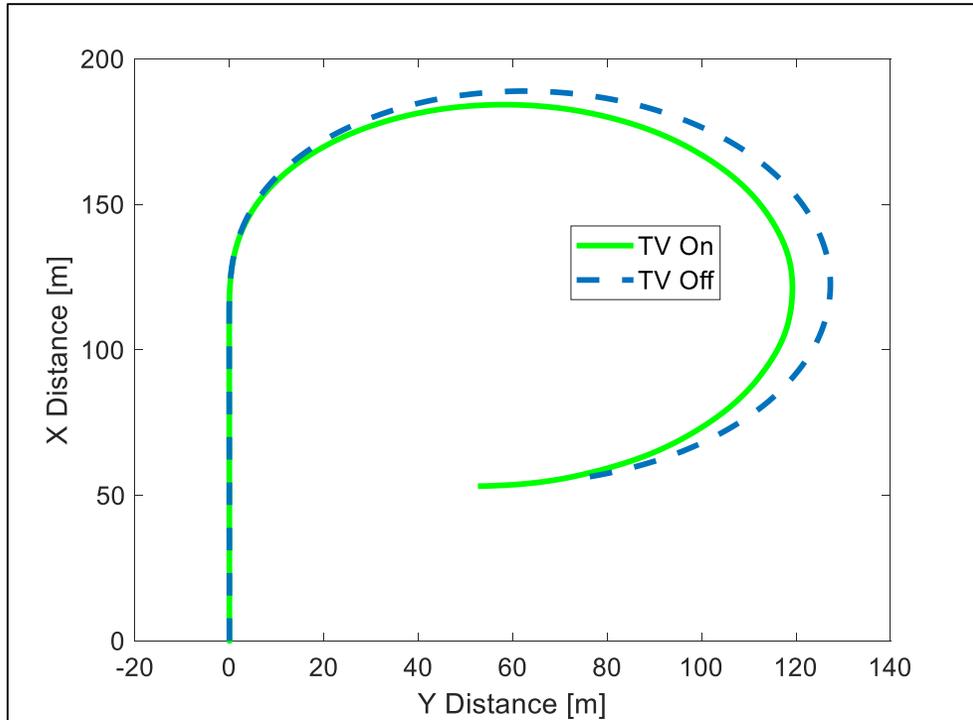


横向加速度更大，而转向输入减少8.7%



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 =  $45^\circ/s$   
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 prominently displayed in orange. Below the title, it indicates the version is 1.0.2 (8.89 MB) by Chirag, who is a staff member. A brief description states that the project can be used as a reference design for designing a Battery Management System with MATLAB and Simulink. On the right side, there are statistics: "Trial software", "3 Ratings" (represented by five stars), "386 Downloads", and "Updated 12 Nov 2019". There are also buttons for "+ Follow" and "Download". At the bottom left, there are tabs for "Overview", "Functions", and "Models".

- 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

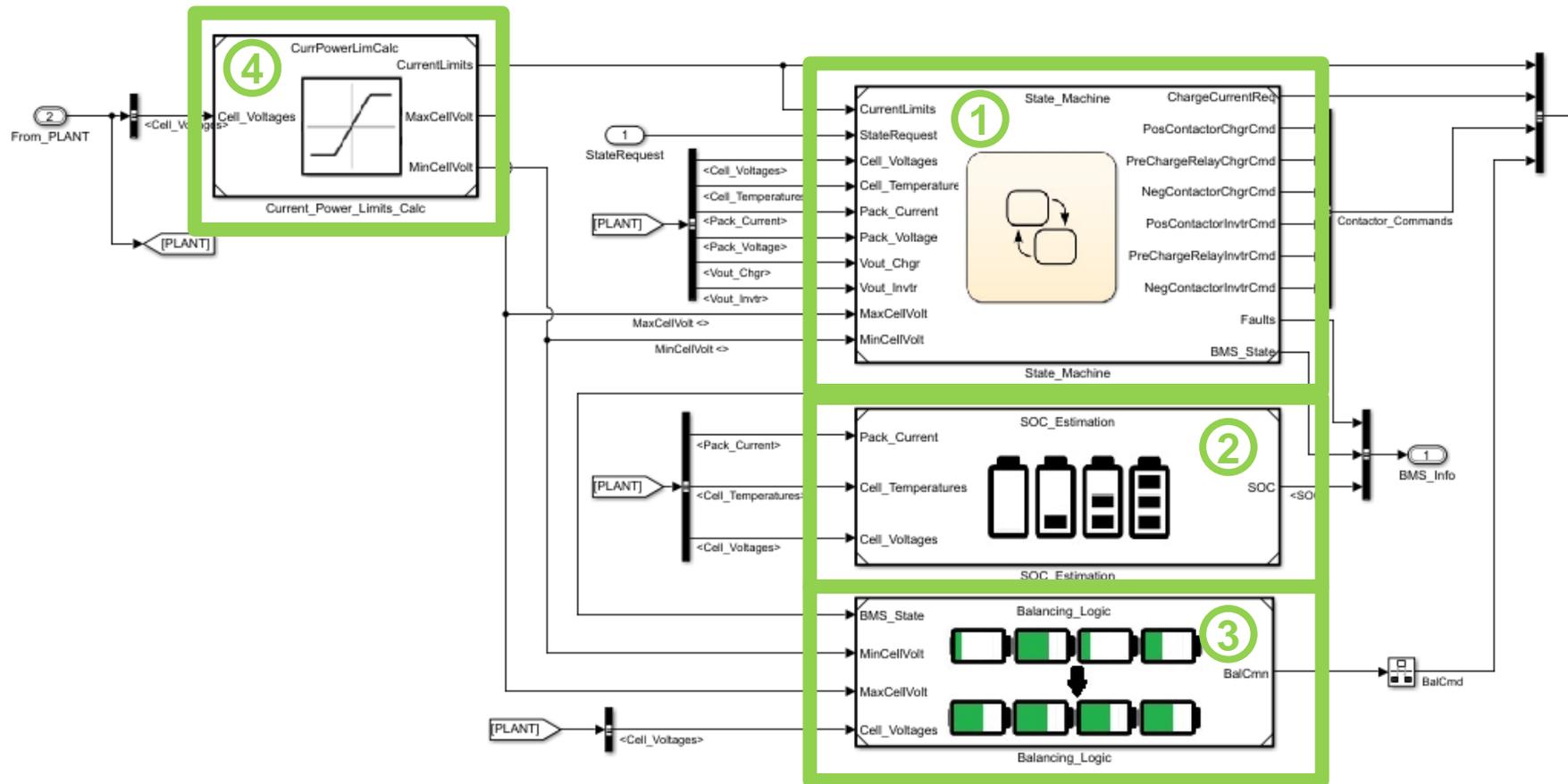
- BMS 状态
- 故障检测
- 接触器管理

## 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

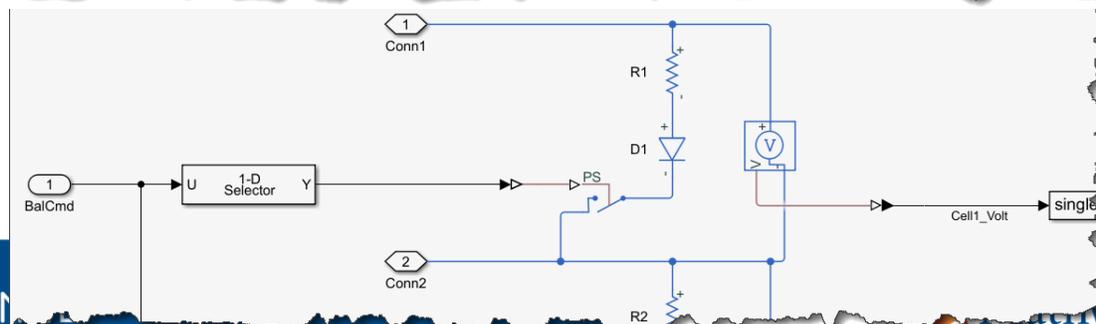
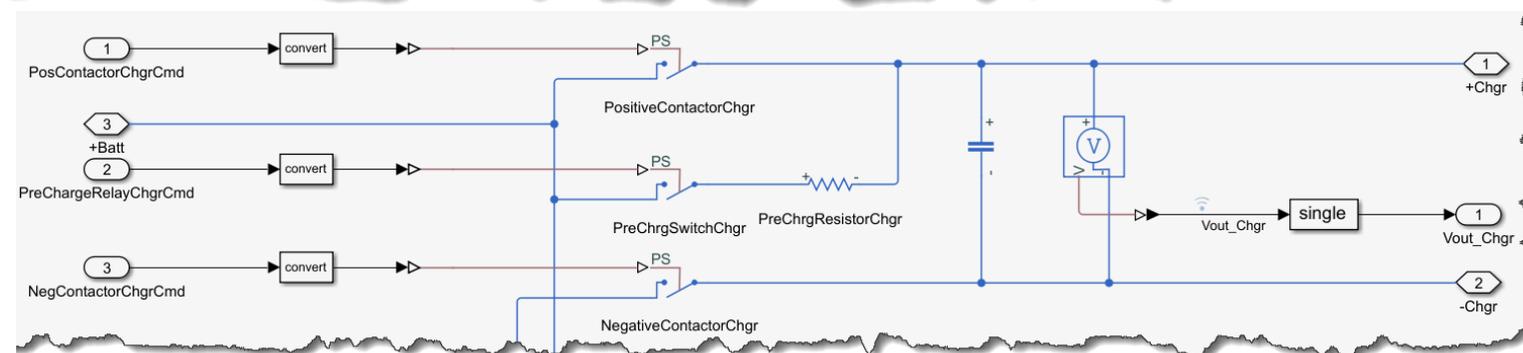
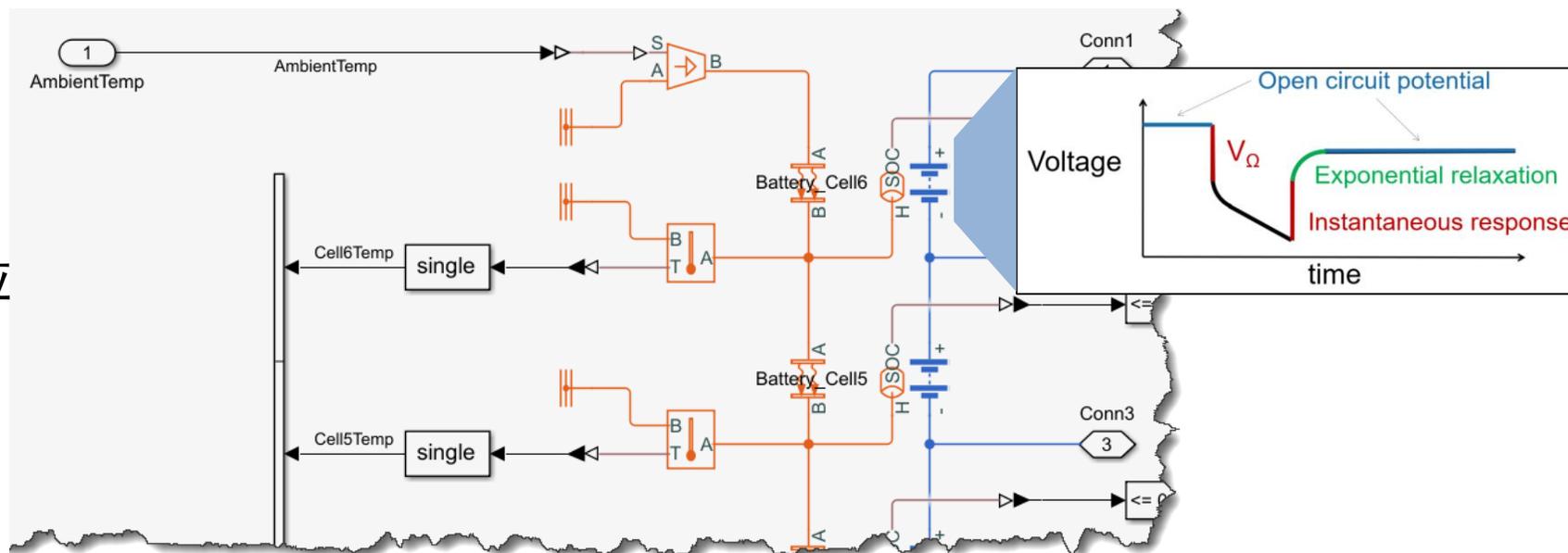
- Simscape

- RC 等效电路的动态响应
- 热效应

- 接触器

- 逆变器
- 充电器

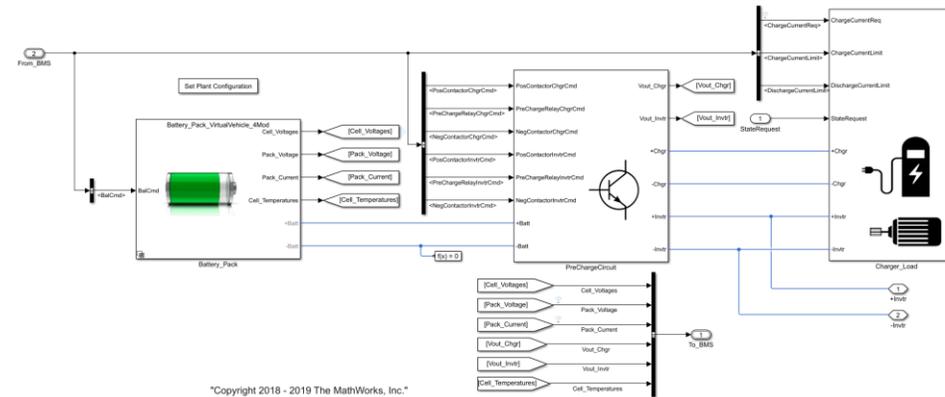
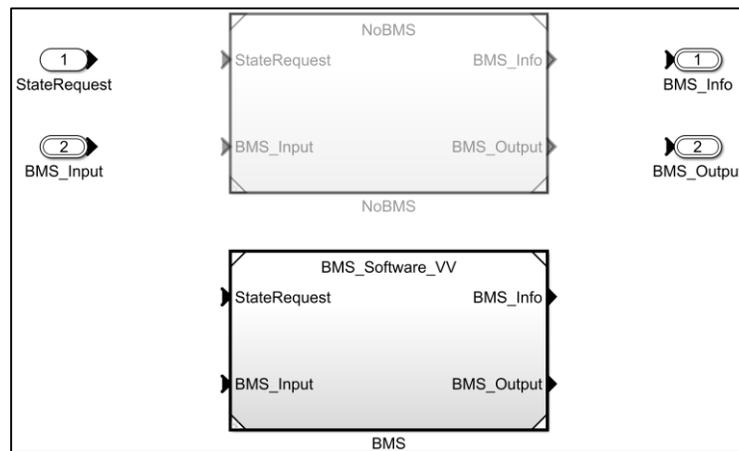
- 电池平衡



# BMS / 电池集成与结果

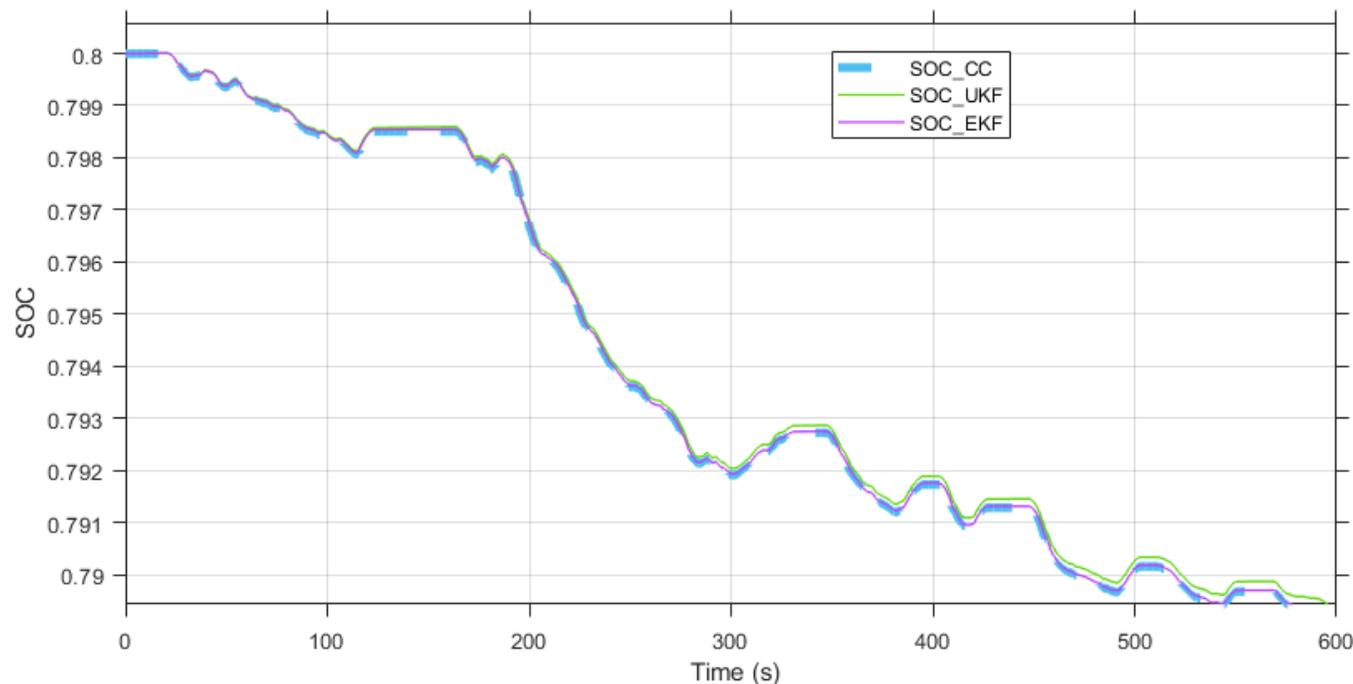
## 集成

- 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

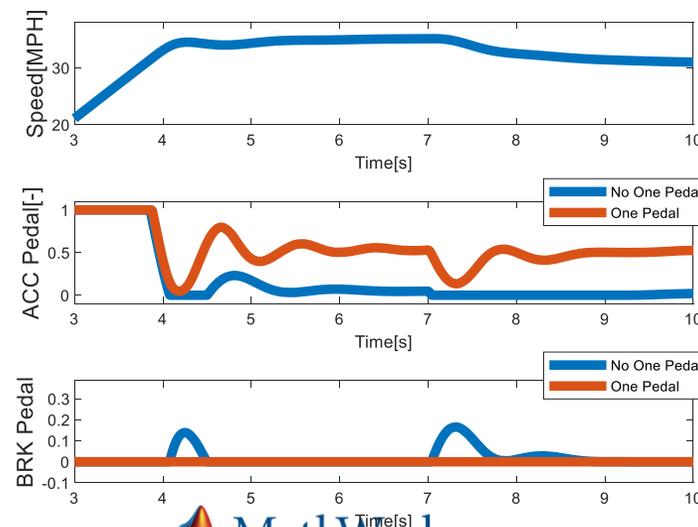
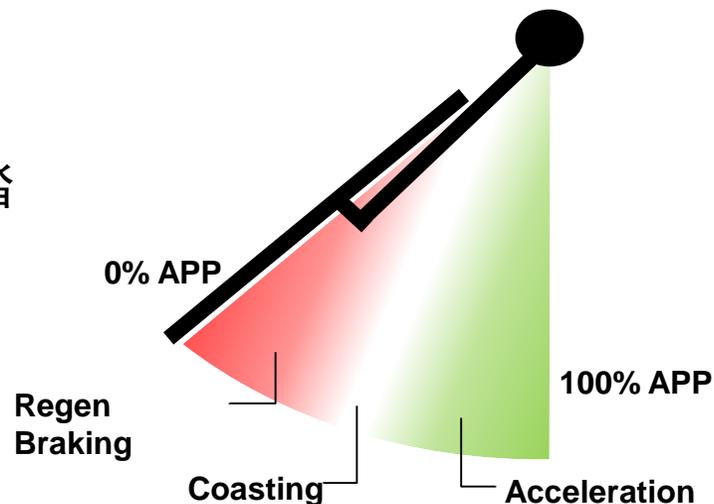
### 通过驾驶员在环功能增强车辆模型

- 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

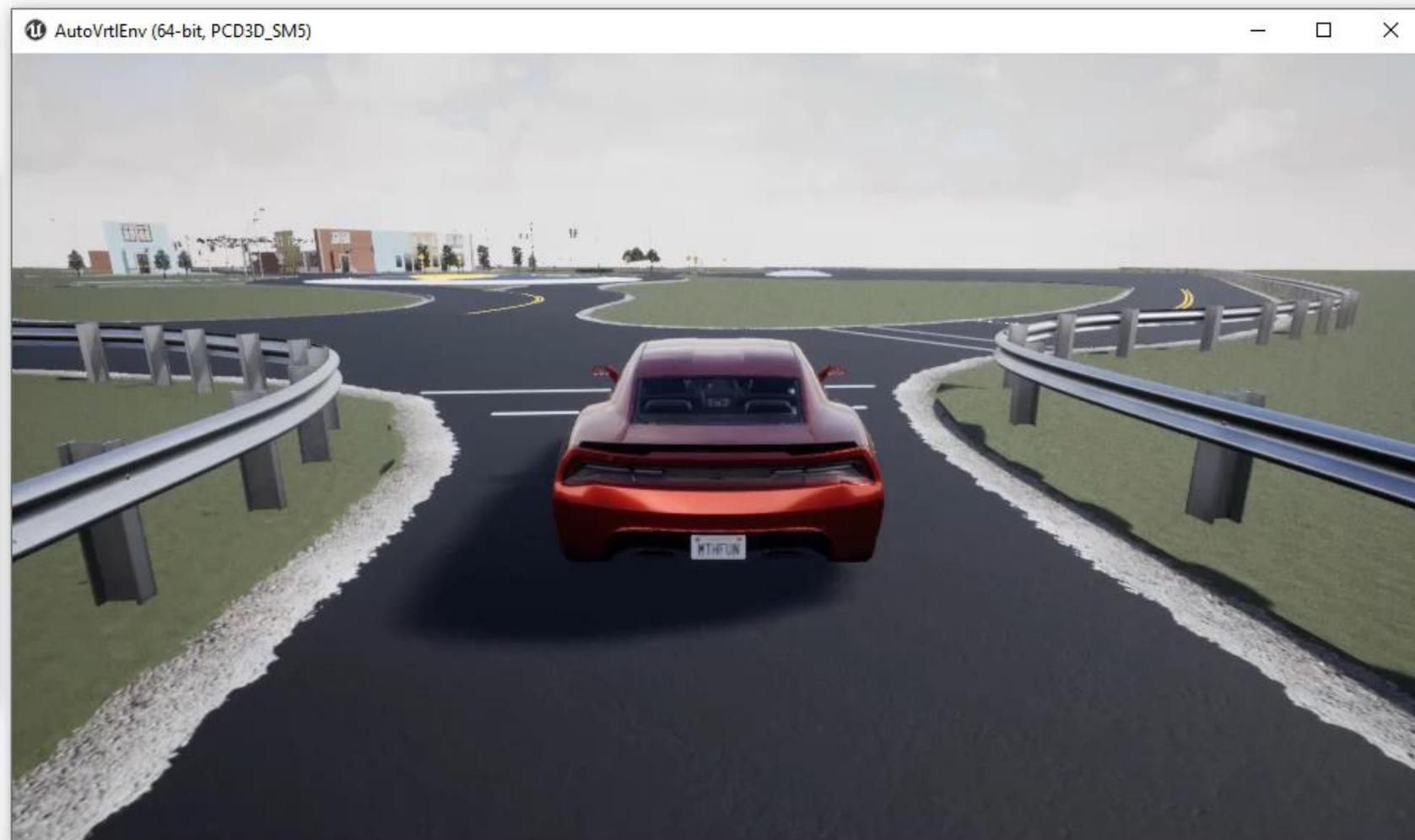
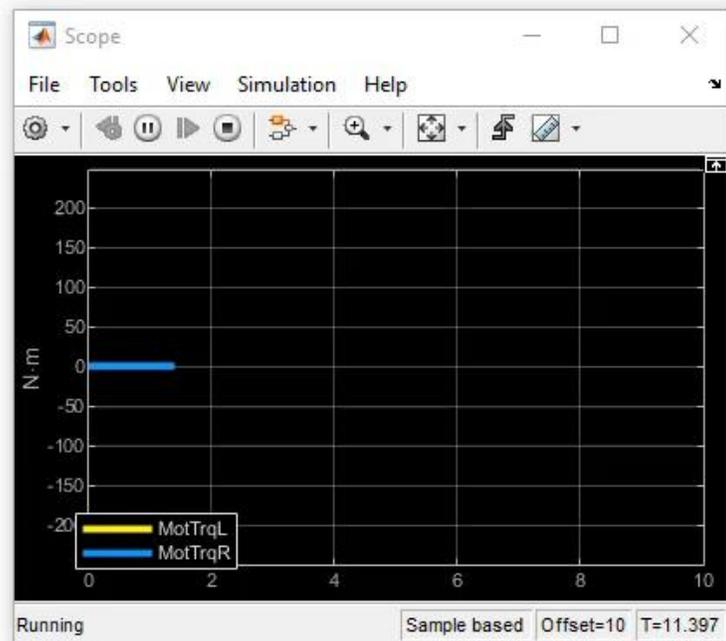


### 单踏板驱动算法

- 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

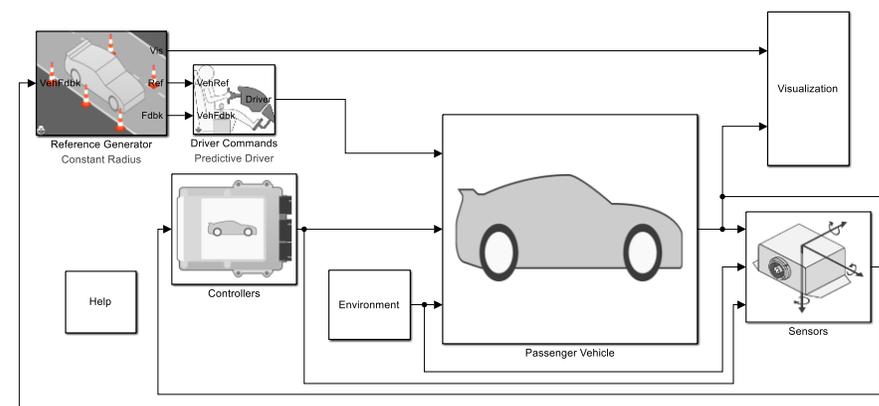
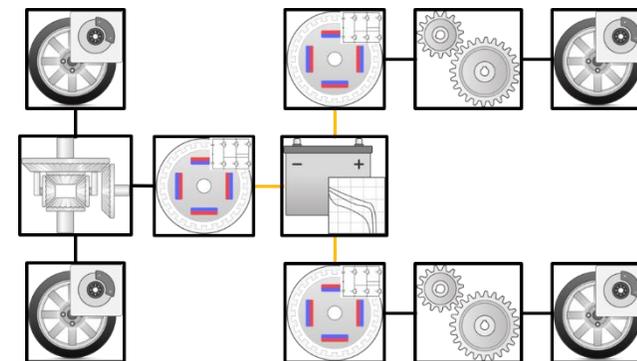


# 驾驶员在环功能

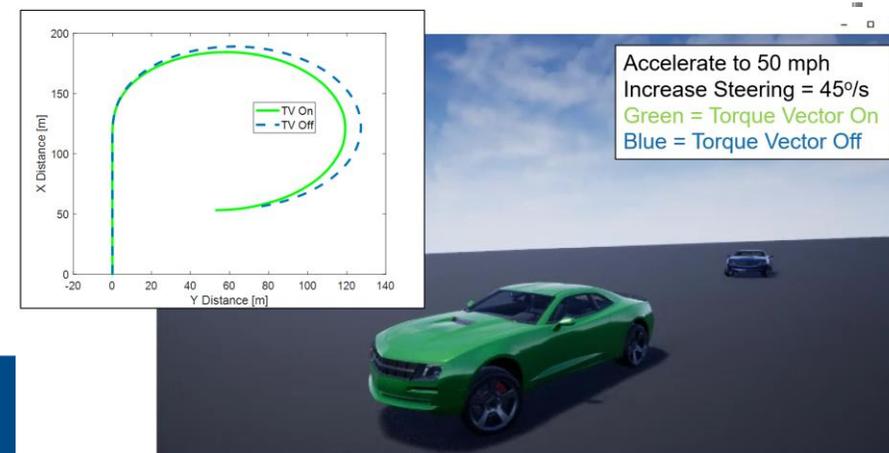


# 总结

- 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

如果您对所介绍的材料感兴趣，请与我们联系