MATLAB EXPO

5月28日, 2024 | 北京

基于模型设计助力高效电机驱动控制算法的仿真和实现

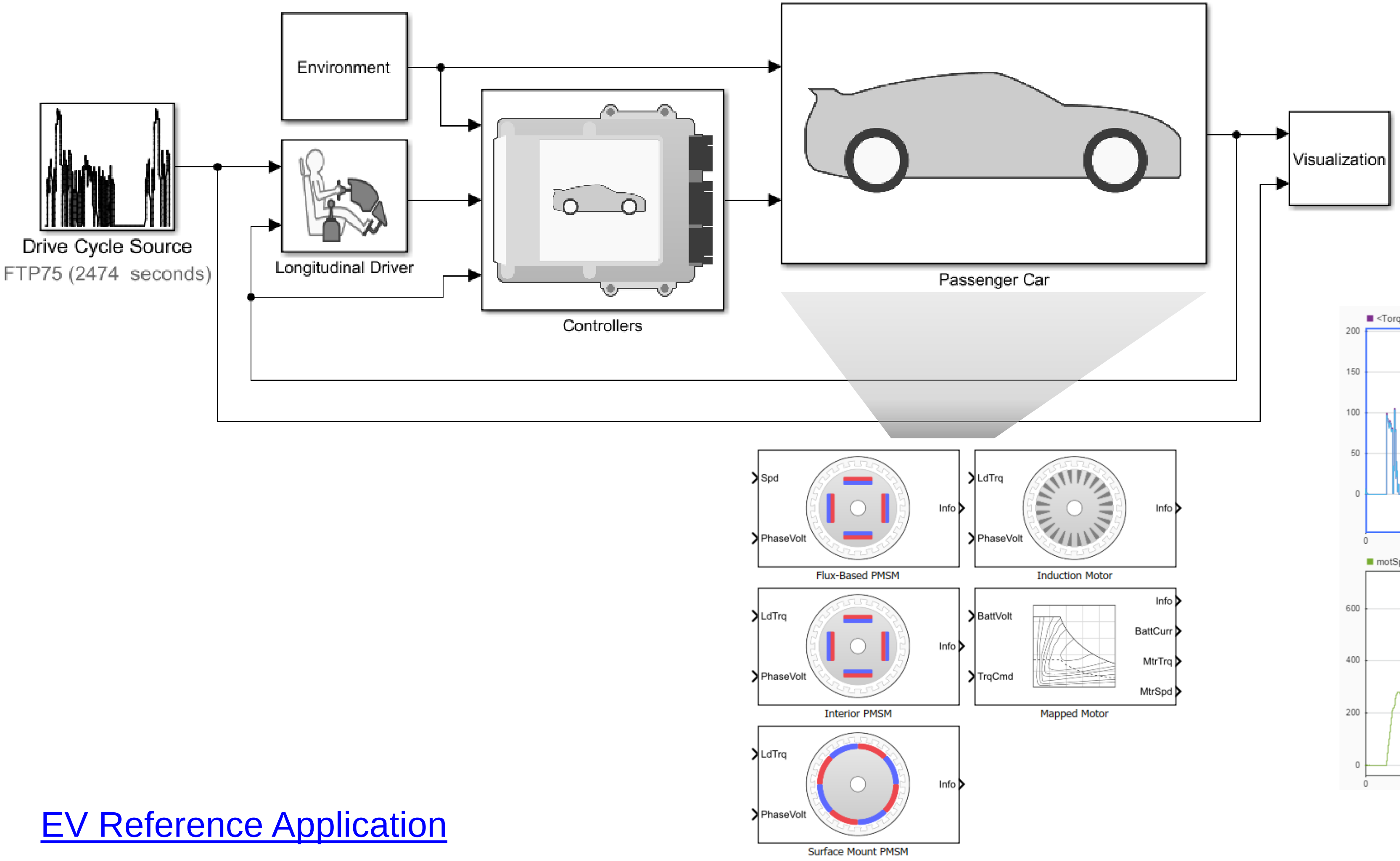
徐浩, MathWorks高级咨询顾问

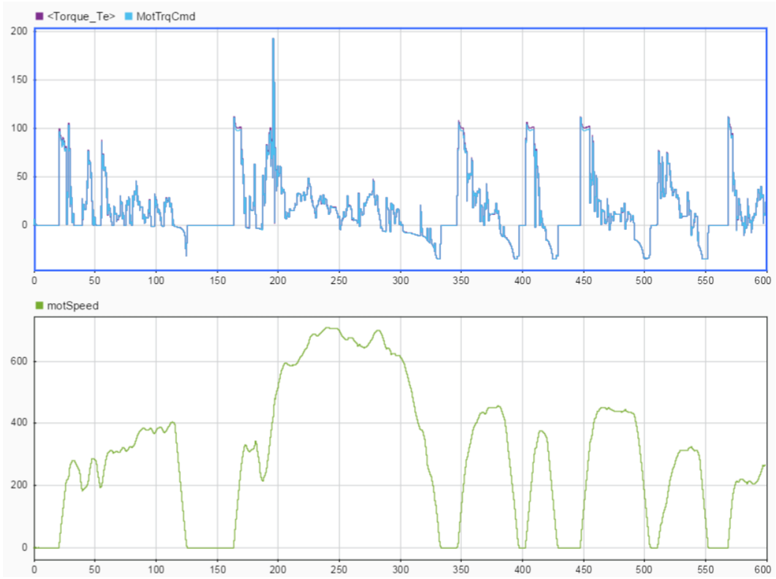
MathWorks

电动动力总成的核心：电机

- 组件选择?
- 组件选型?
- 权衡研究?

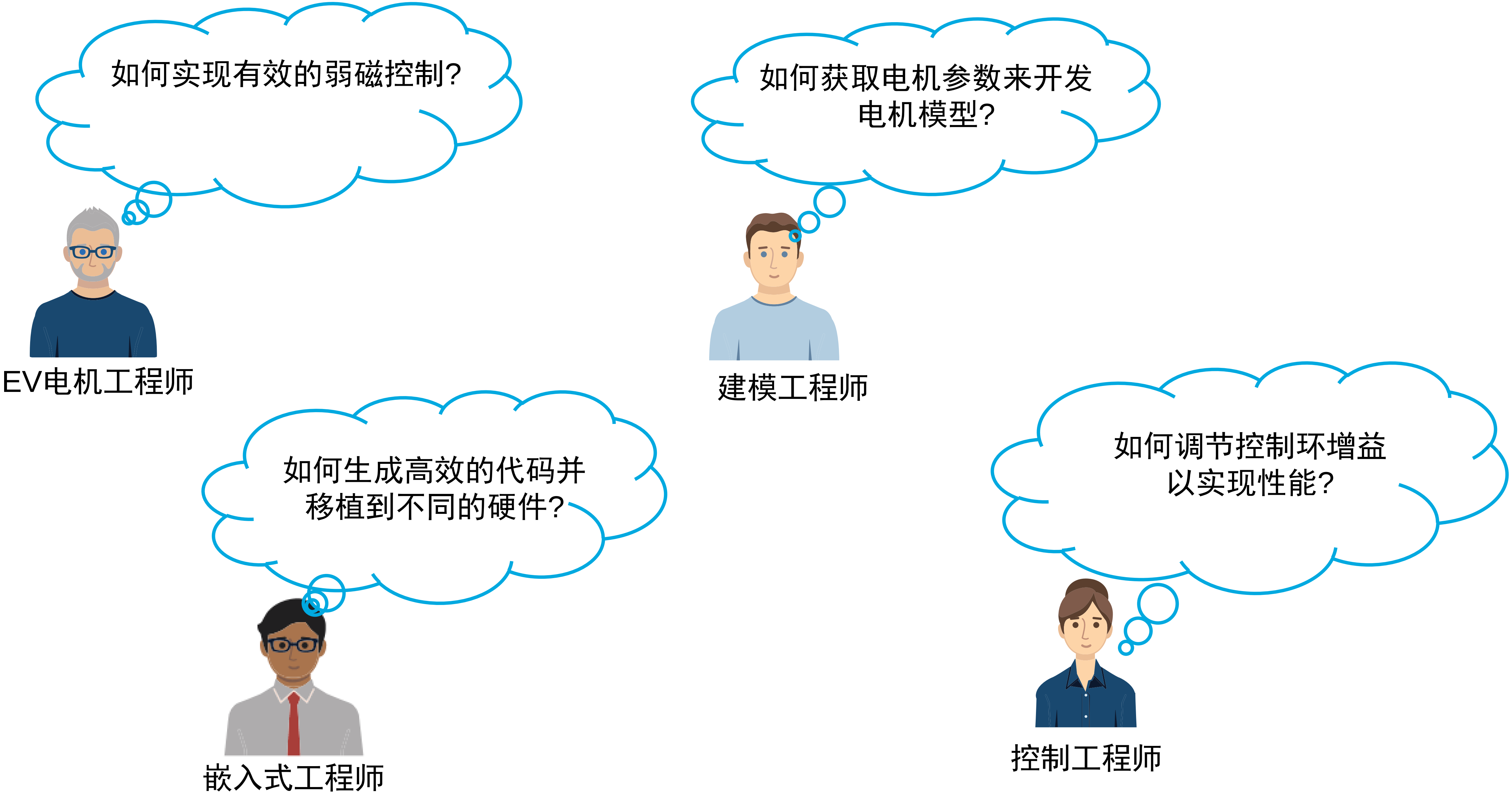
- 详细的组件建模和控制设计?





EV Reference Application

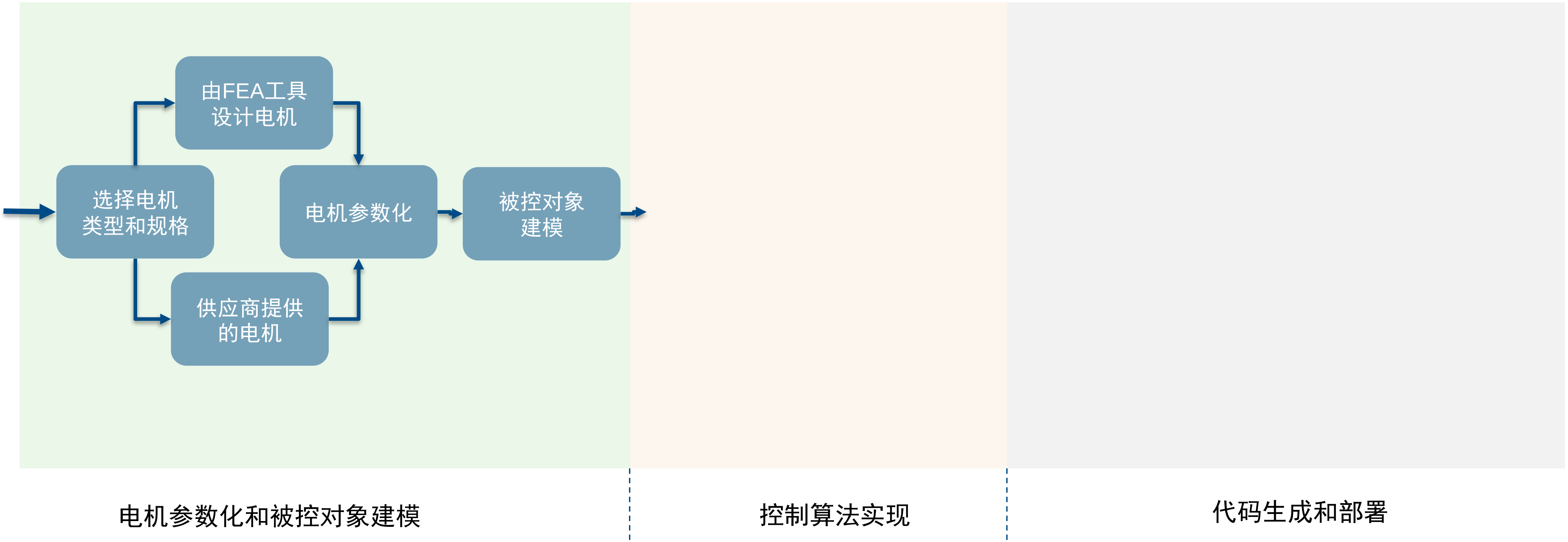
电动汽车电机控制开发面临的挑战



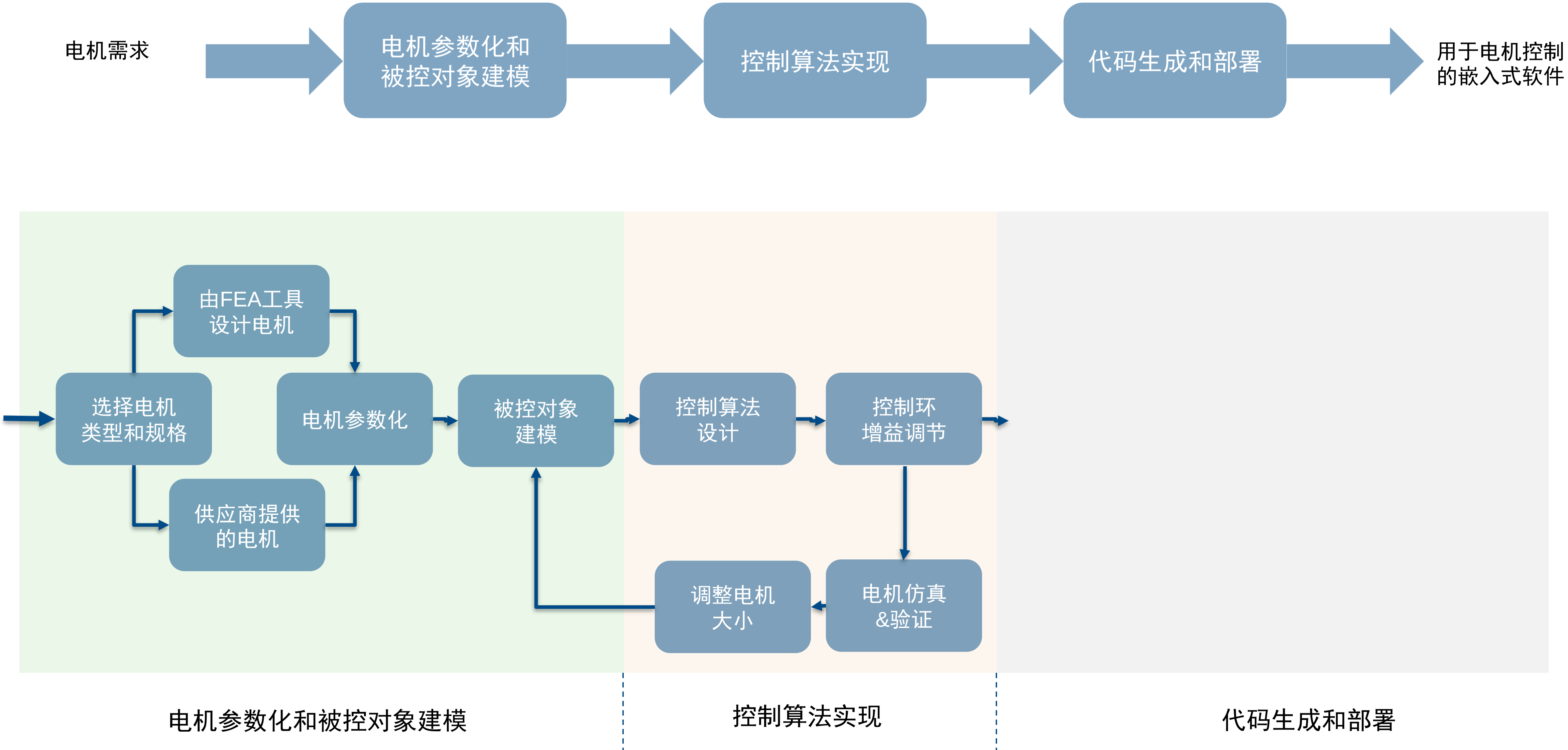
建议的电动车驱动电机控制软件开发流程

电机需求 → 电机参数化和被控对象建模 → 控制算法实现 → 代码生成和部署 → 用于电机控制的嵌入式软件

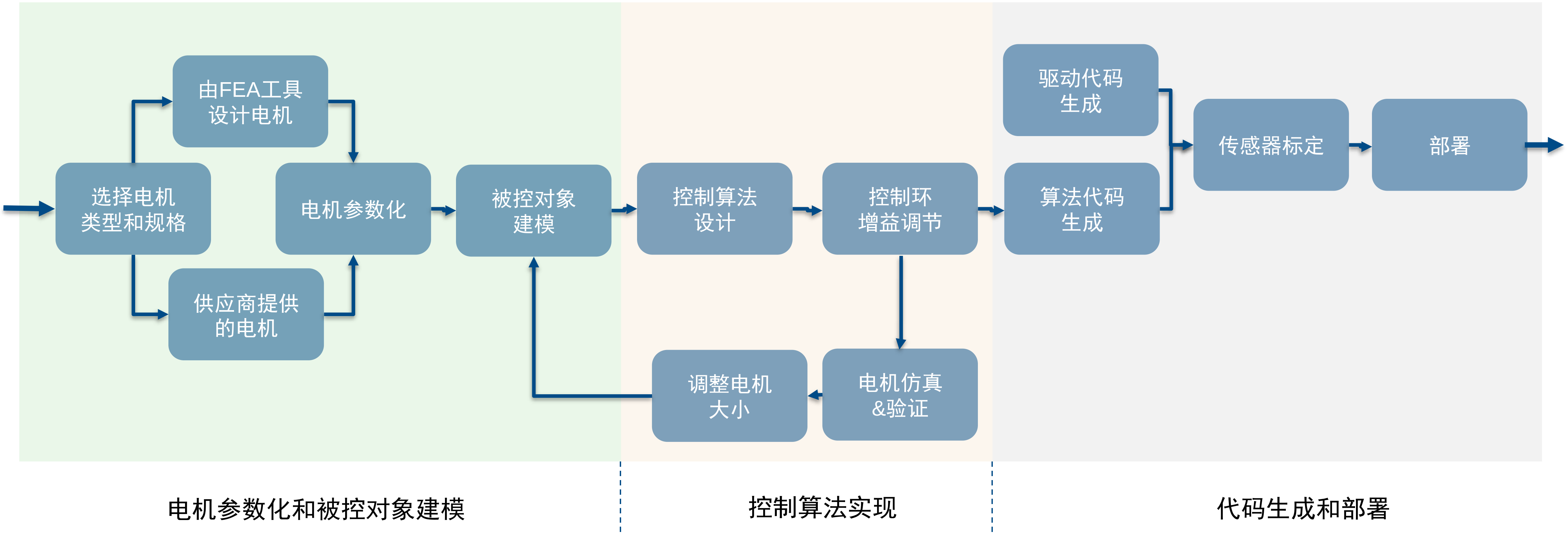
建议的电动车驱动电机控制软件开发流程



建议的电动车驱动电机控制软件开发流程



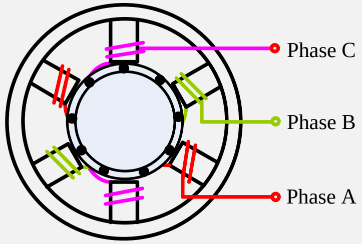
建议的电动车驱动电机控制软件开发流程

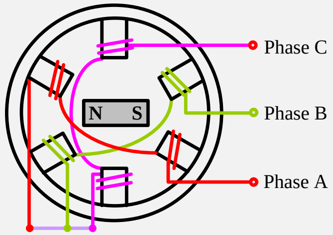


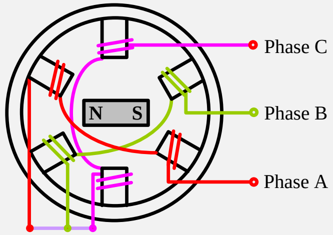
电机选型

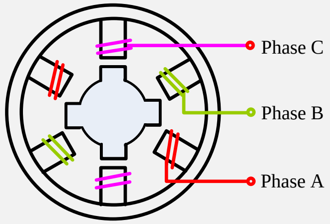
- 选择电机类型和规格
- 电机参数化
- 被控对象建模

电机概览







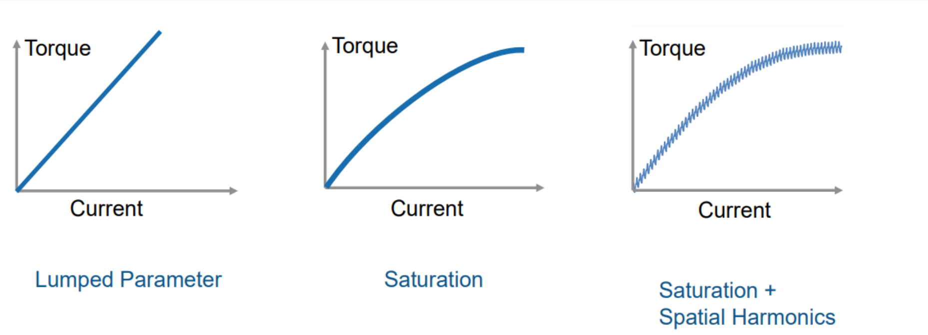


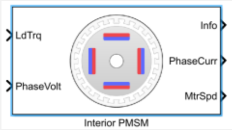
异步电机(IM)	无刷电机(BLDC)	永磁同步电机 (PMSM)	开关磁阻电机(SRM)
Advantages			
– Low material cost/ kg – Robust, reliable, Simple Control – Less maintenance	– Efficient, reliable – High Power Density and High torque at low speed	– Low noise, smooth operation – High performance and efficiency over operating range	– Simple and robust construction – Low cost, long constant power range
Disadvantages			
– Low efficiency, low power factor specially at light loads, Heavy, High Copper loss	– Higher torque ripples and cogging torque leads to vibration, noise and poor position control	– High Cost – Demagnetizing risk – Requires complex control	– High noise, torque ripples – Complex Control – High Switching losses
Industry Examples			
Tesla model X, Toyota RAV4 EV, Renault Zoe	Ather, Toyota Prius	Tesla Model S, Chevrolet Bolt, Hyundai Kona Electric	Jaguar I-PACE Concept, Ford Fiesta EV Prototype

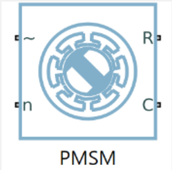
电机参数化和模型保真度

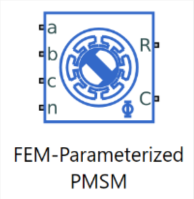
- 选择电机类型和规格
- 电机参数化
- 被控对象建模

Motor Model Fidelity Level

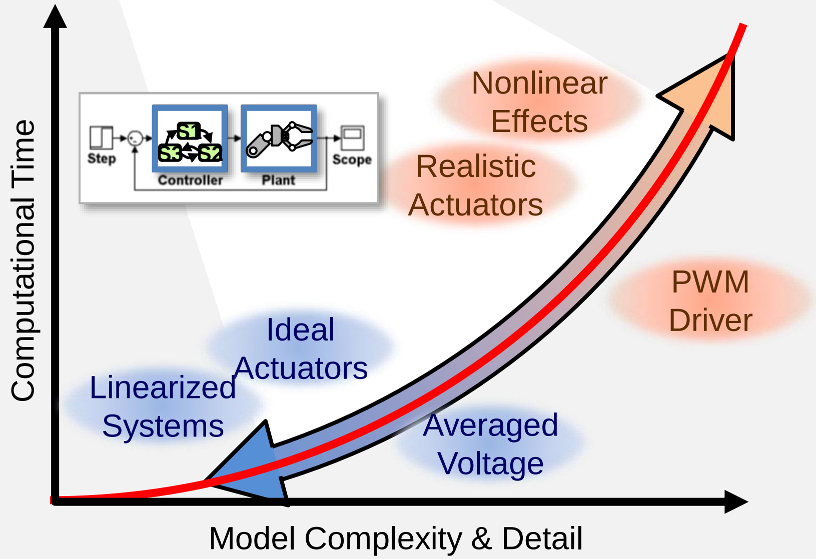








Computational Time vs. Model Complexity



Motor Control Blockset

Simscape Electrical

电机参数化和被控对象建模

- 选择电机类型和规格
- 电机参数化
- 被控对象建模

Motor Parameterization

被测电机

Estimate Motor Parameters Using Motor Control Blockset Parameter Estimation Tool

Motor Control Blockset™ provides a parameter estimation tool that estimates the motor parameters accurately. Use the estimated motor parameters to simulate the motor model and design the control system. Therefore, the simulation response with the estimated parameters for the motor model is close to the behavior of the motor under test.

The parameter estimation tool determines these motor parameters for a Permanent Magnet Synchronous Motor:

Motor parameters	Units
Phase resistance (R_s)	Ohm
d and q axis inductances (L_d and L_q)	Henry
Back-EMF constant (K_e)	Vpk_LL/krpm (where Vpk_LL is the peak voltage line-to-line measurement)
Motor inertia (J)	Kg.m^2
Friction constant (F)	N.m.s

The parameter estimation tool accepts the minimum required inputs, runs tests on the target hardware, and displays the estimated parameters.

来自产品规格书或电机试验

集总参数模型

电机和测功机

Generate Parameters for Flux-Based PMSM Block

Using MathWorks tools, you can create lookup tables for an interior permanent magnet synchronous motor (PMSM) controller that characterizes the d-axis and q-axis current as a function of d-axis and q-axis flux.

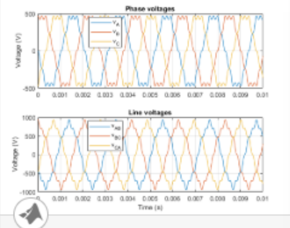
To generate the flux parameters for the Flux-Based PMSM block, follow these workflow steps. Example script `CreatingIdqTable.m` calls `gridfit` to model the current surface using scattered or semi-scattered flux data.

Workflow	Description
Step 1: Load and Preprocess Data	Load and preprocess this nonlinear motor flux data from dynamometer testing or finite element analysis (FEA): • d- and q- axis current • d- and q- axis flux • Electromagnetic motor torque
Step 2: Generate Evenly Spaced Table Data From Scattered Data	Use the `gridfit` function to generate evenly spaced data. Visualize the flux surface plots.
Step 3: Set Block Parameters	Set workspace variables that you can use for the Flux-Based PM Controller block parameters.

来自测功机试验

饱和效应模型

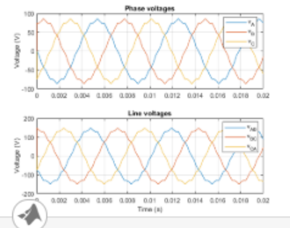
电机FEA模型



Import IPMSM Flux Linkage Data from ANSYS Maxwell

Import a motor design from ANSYS® Maxwell® into a Simscape™ simulation.

Open Model



Import IPMSM Flux Linkage Data from Motor-CAD

Import a motor design from Motor-CAD into a Simscape™ simulation.

Open Model

来自FEA工具如 ANSYS Maxwell, JMAG, Motor-CAD

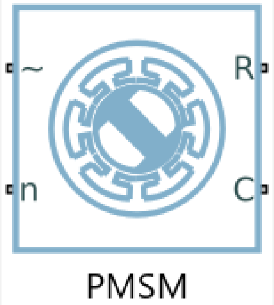
饱和效应+空间谐波模型

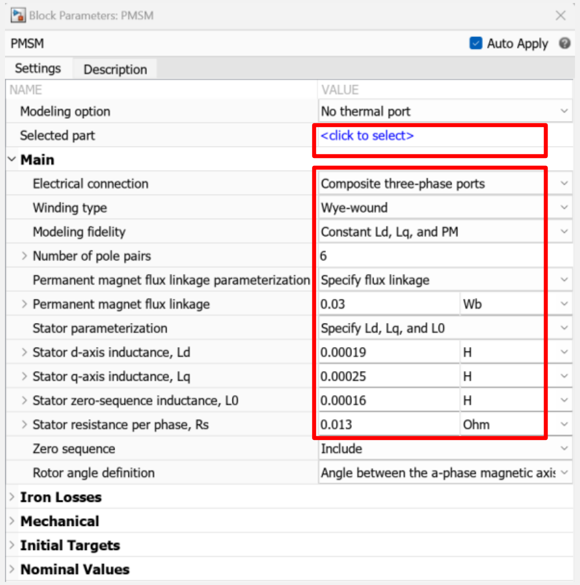
参数化有助于电机建模，从而获取电机动态，帮助我们进行控制设计

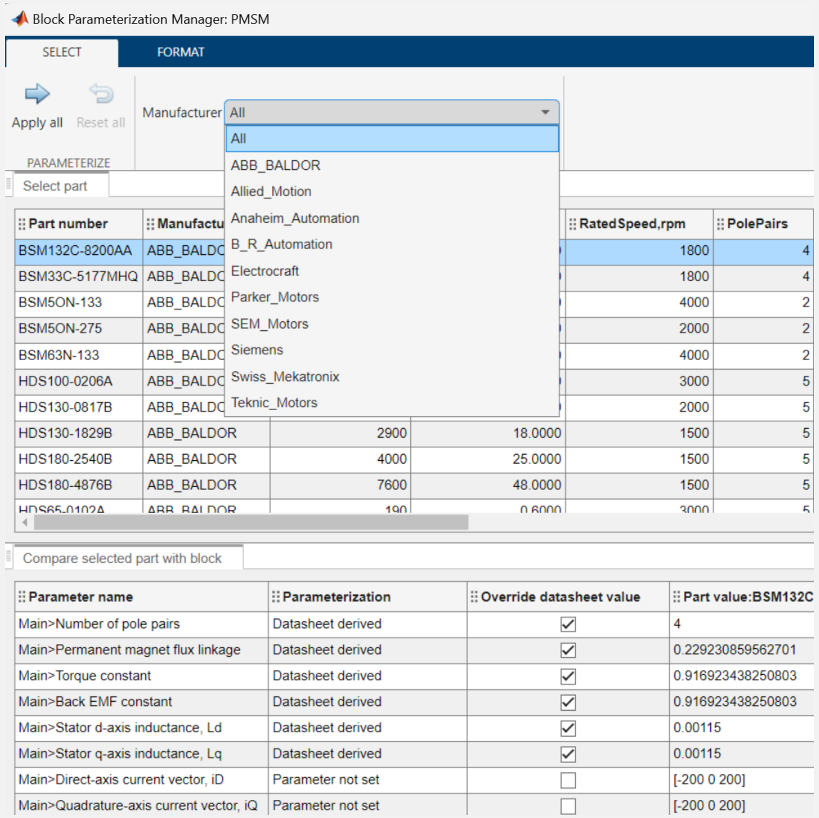
电机参数化和被控对象建模

根据电机规格书定义电机参数

- 选择电机类型和规格
- 电机参数化
- 被控对象建模



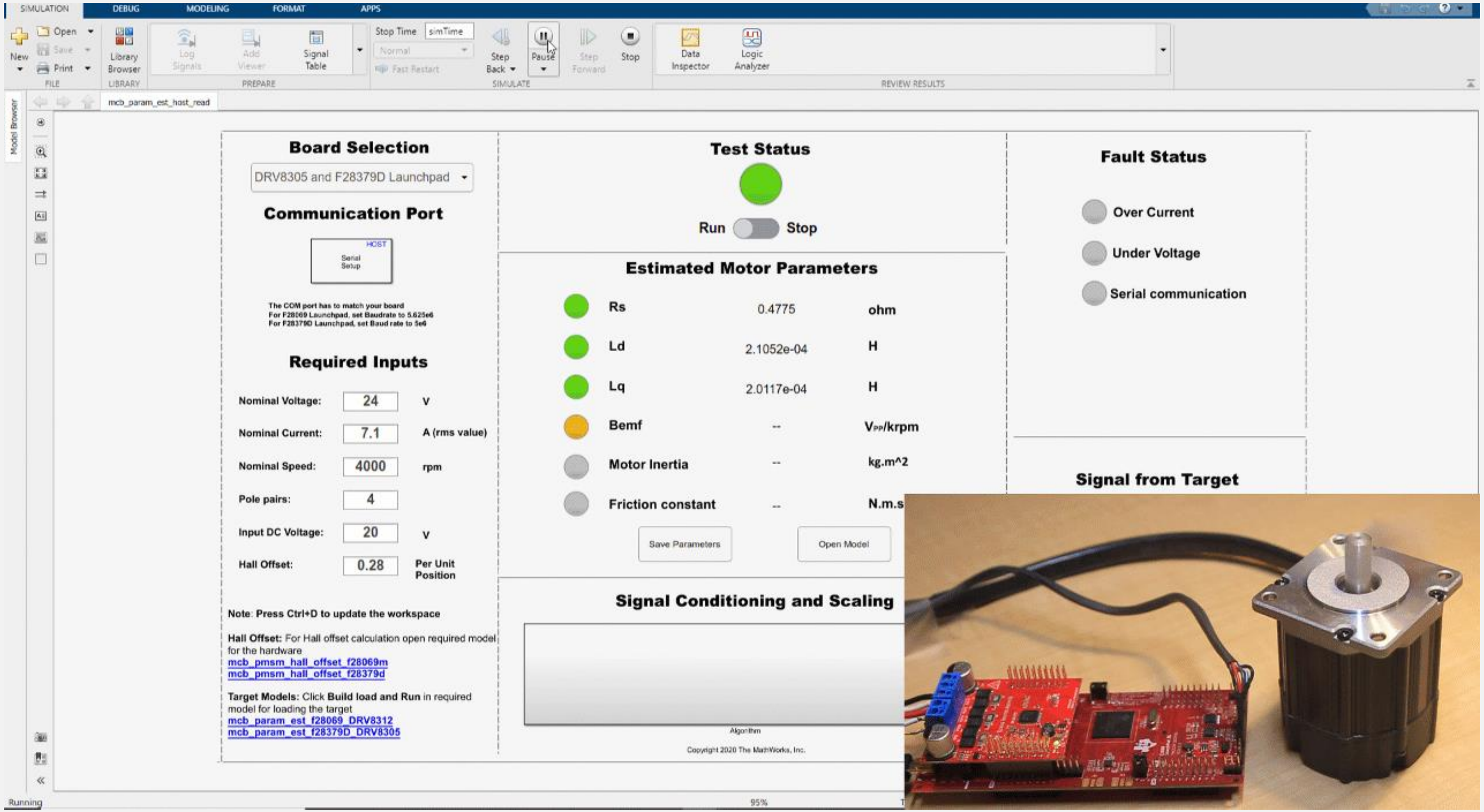




电机参数化和被控对象建模

基于实验测试估计电机参数

- 选择电机类型和规格
- 电机参数化
- 被控对象建模

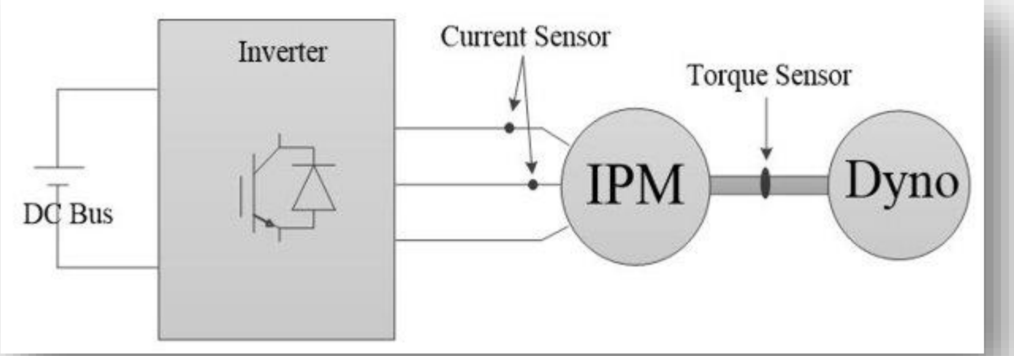


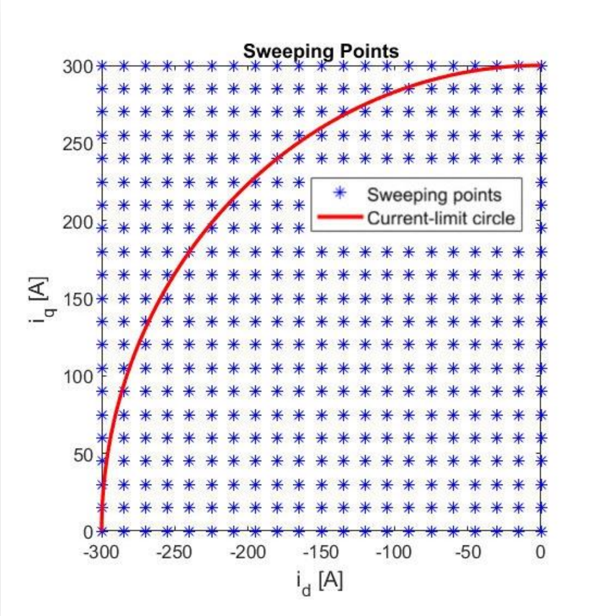
- 运行在目标上测试
- 提供参考示例模型
- 支持有/无速度传感器
- 支持PMSM和异步电机

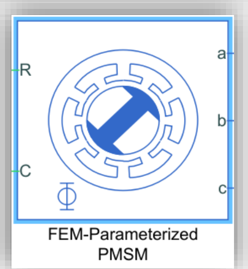
电机参数化和被控对象建模

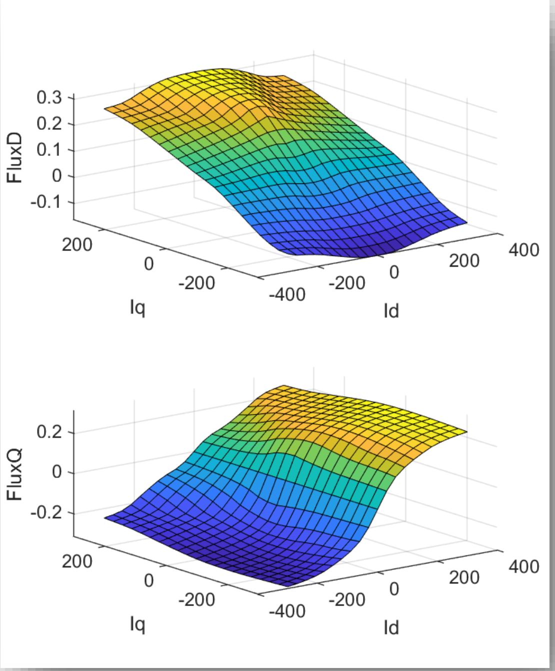
- 选择电机类型和规格
- 电机参数化
- 被控对象建模

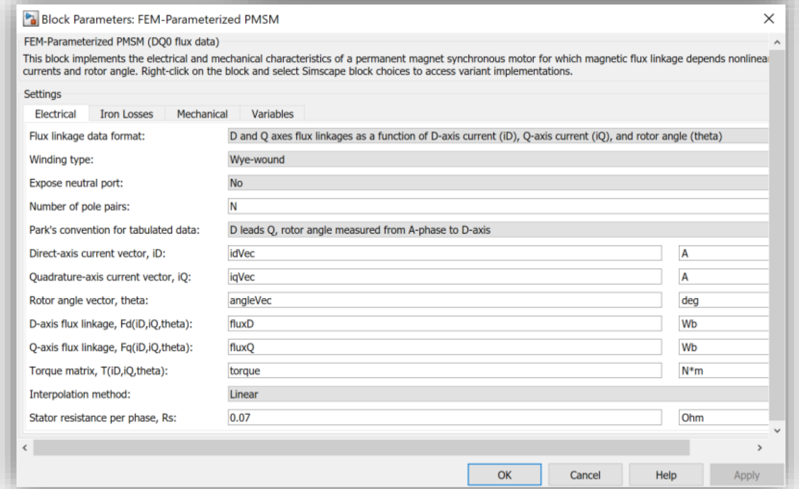
基于测功机试验获得Flux-I曲面







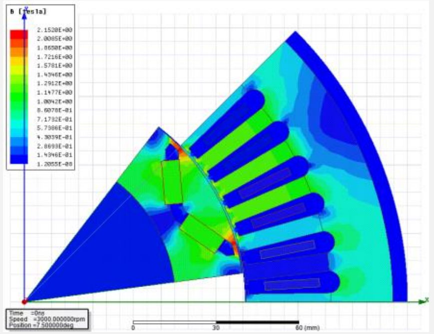


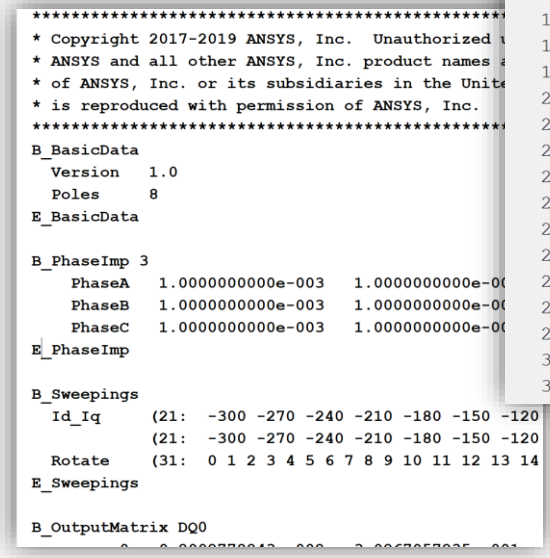


电机参数化和被控对象建模

- 选择电机类型和规格
- 电机参数化
- 被控对象建模

来自FEA电机设计工具





```
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* is reproduced with permission of ANSYS, Inc.
****************************************************
B_BasicData
  Version    1.0
  Poles      8
E_BasicData

B_PhaseImp 3
    PhaseA   1.0000000000e-003   1.0000000000e-00
    PhaseB   1.0000000000e-003   1.0000000000e-00
    PhaseC   1.0000000000e-003   1.0000000000e-00
E_PhaseImp

B_Sweepings
  Id_Iq      (21:  -300 -270 -240 -210 -180 -150 -120
             (21:  -300 -270 -240 -210 -180 -150 -120
  Rotate     (31:  0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
E_Sweepings

B_OutputMatrix DQ0
```
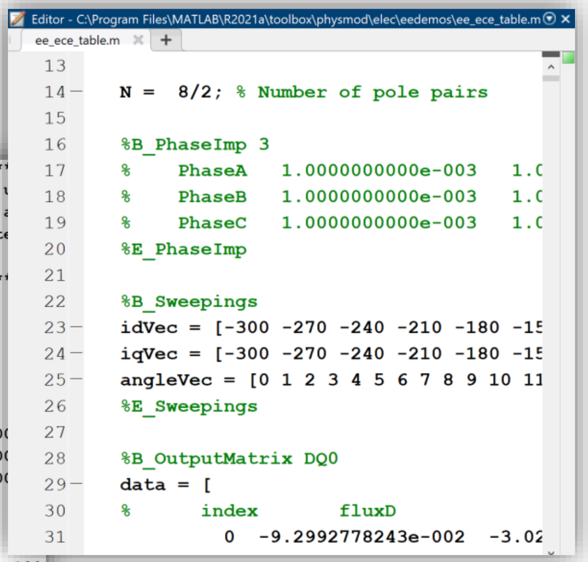
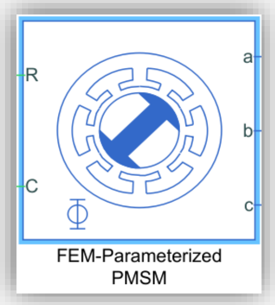
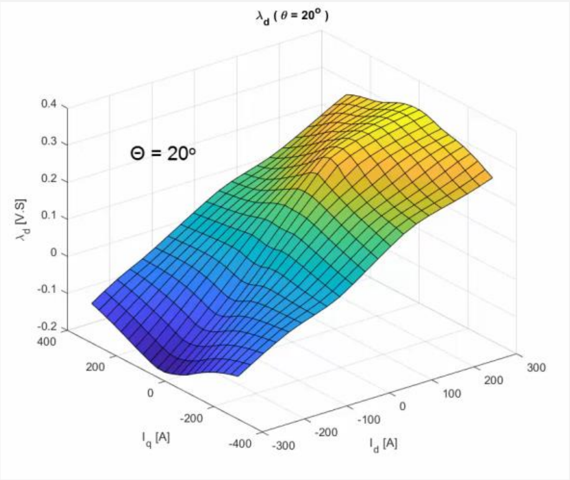




```
N =  8/2; % Number of pole pairs

%B_PhaseImp 3
%     PhaseA   1.0000000000e-003   1.(
%     PhaseB   1.0000000000e-003   1.(
%     PhaseC   1.0000000000e-003   1.(
%E_PhaseImp

%B_Sweepings
idVec = [-300 -270 -240 -210 -180 -15
iqVec = [-300 -270 -240 -210 -180 -15
angleVec = [0 1 2 3 4 5 6 7 8 9 10 11
%E_Sweepings

%B_OutputMatrix DQ0
data = [
%        index         fluxD
           0  -9.2992778243e-002   -3.02
```

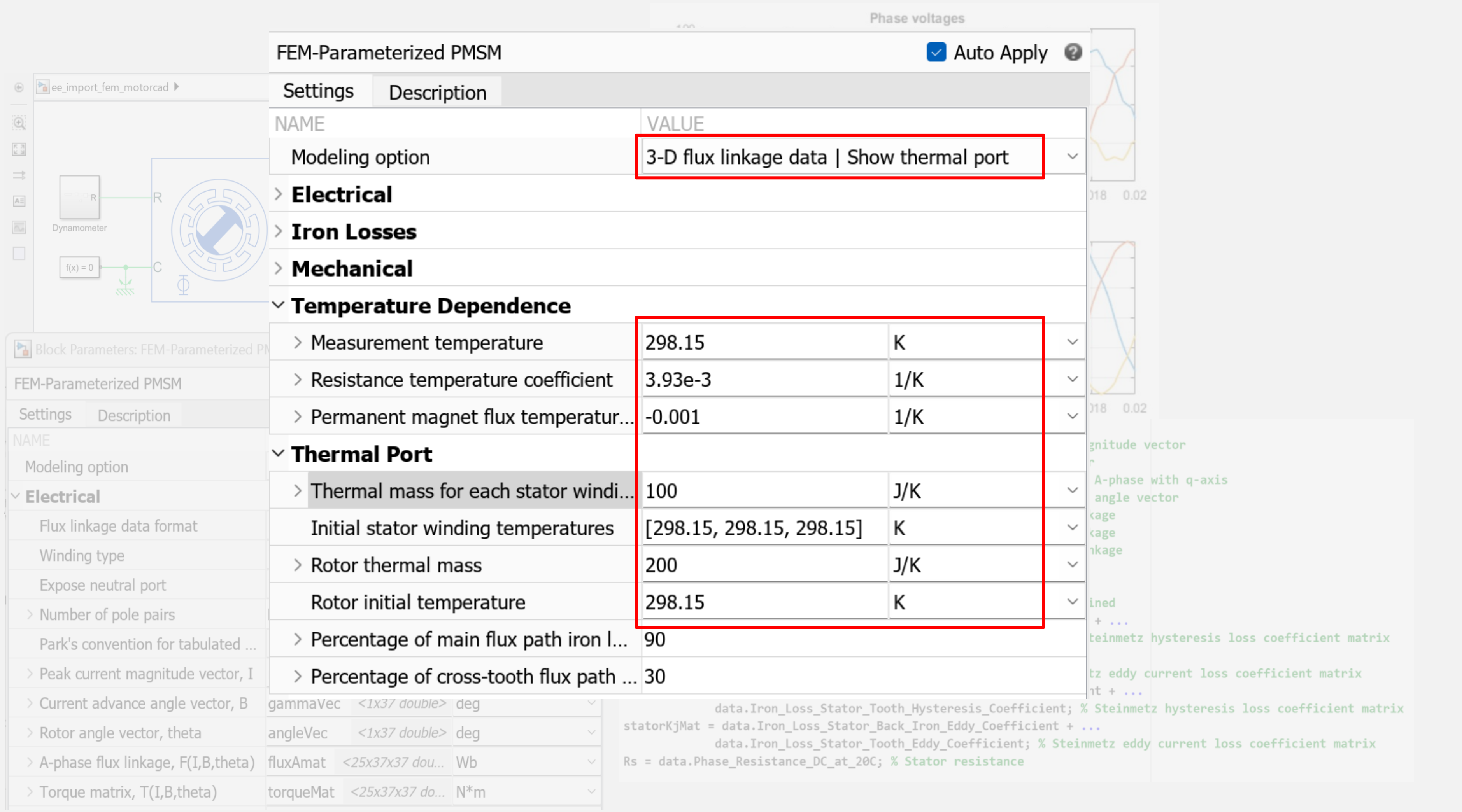




电机参数化和被控对象建模

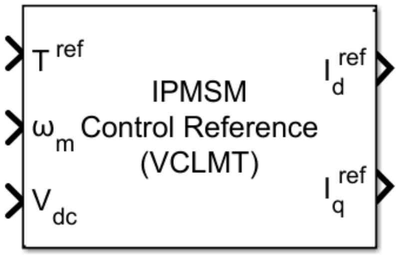
- 选择电机类型和规格
- 电机参数化
- 被控对象建模

来自FEA电机设计工具



电机约束曲线和外特性

- 绘制电机约束曲线
  - MTPA 曲线 (最大转矩电流比)
  - MTPV 曲线(最大转矩电压比)
  - 电压约束
  - 电流约束
- 电机特性



LUT based PMSM Control Reference

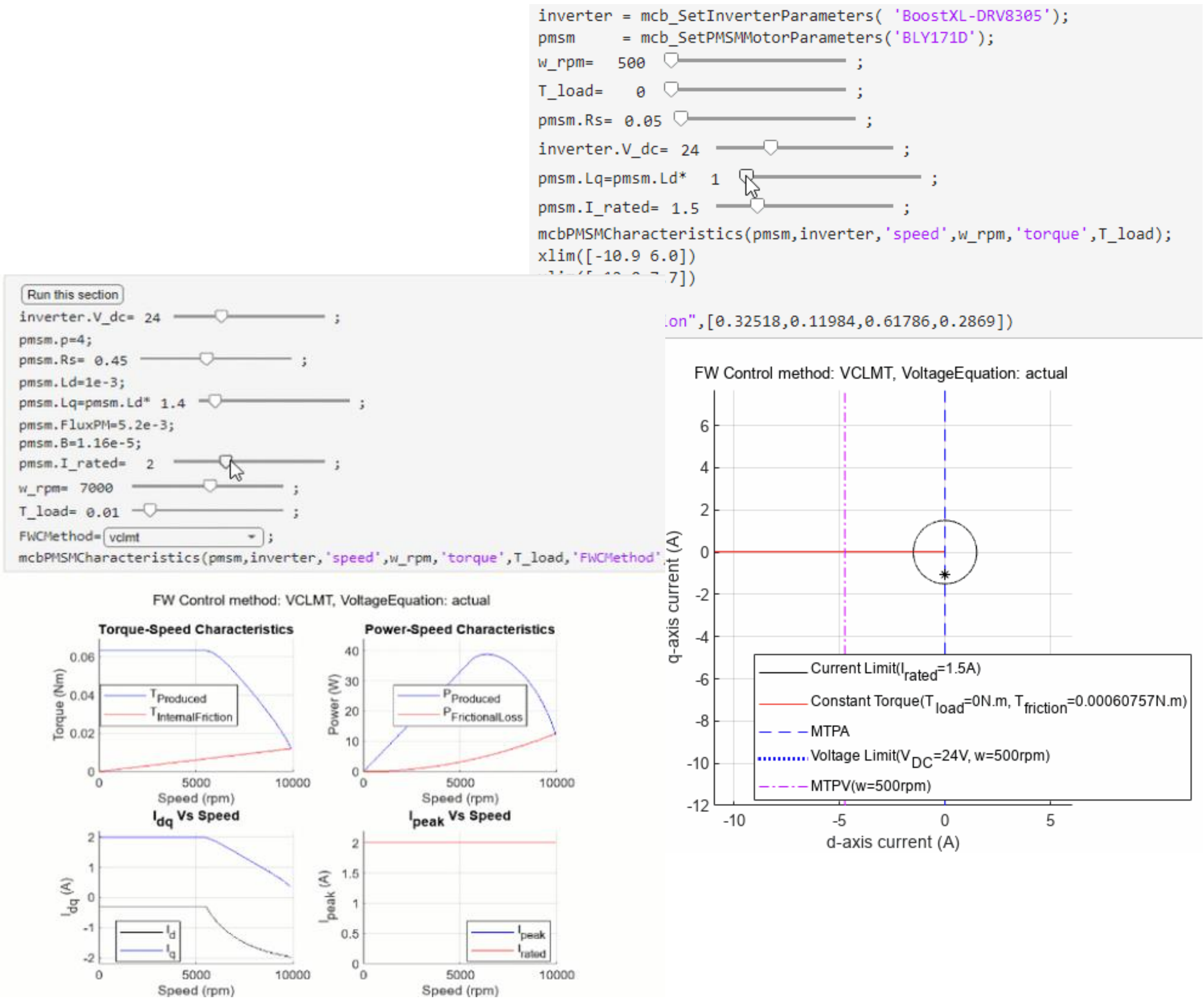
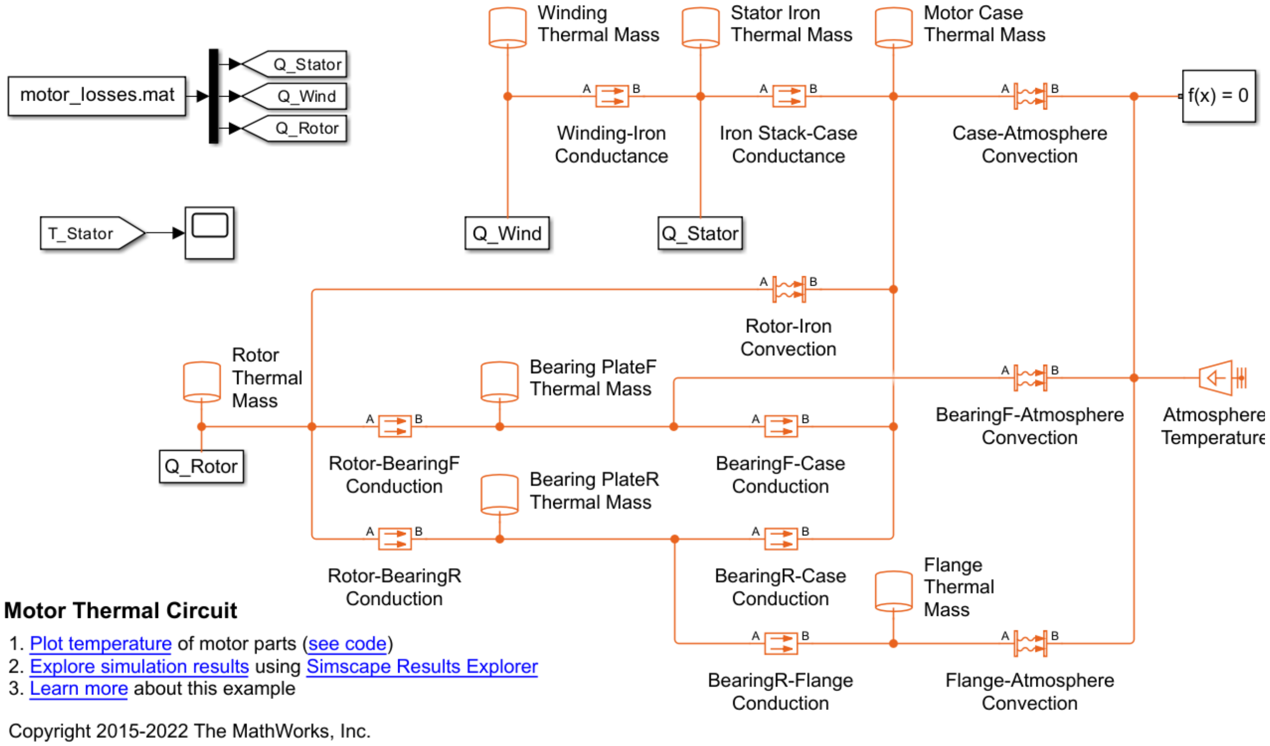


Figure : Dependency of curves and characteristics on parameters changes

Ref: https://www.mathworks.com/help/mcb/ug/pmsm-characteristics-constraint-curves.html

电机热路模型


motor_losses.mat
Q_Stator
Q_Wind
Q_Rotor
T_Stator
Winding Thermal Mass
Stator Iron Thermal Mass
Motor Case Thermal Mass
Winding-Iron Conductance
Iron Stack-Case Conductance
Case-Atmosphere Convection
f(x) = 0
Q_Wind
Q_Stator
Rotor-Iron Convection
Rotor Thermal Mass
Bearing PlateF Thermal Mass
BearingF-Atmosphere Convection
Atmosphere Temperature
Q_Rotor
Rotor-BearingF Conduction
BearingF-Case Conduction
Bearing PlateR Thermal Mass
Rotor-BearingR Conduction
BearingR-Case Conduction
Flange Thermal Mass
BearingR-Flange Conduction
Flange-Atmosphere Convection
Motor Thermal Circuit
1. Plot temperature of motor parts (see code)
2. Explore simulation results using Simscape Results Explorer
3. Learn more about this example
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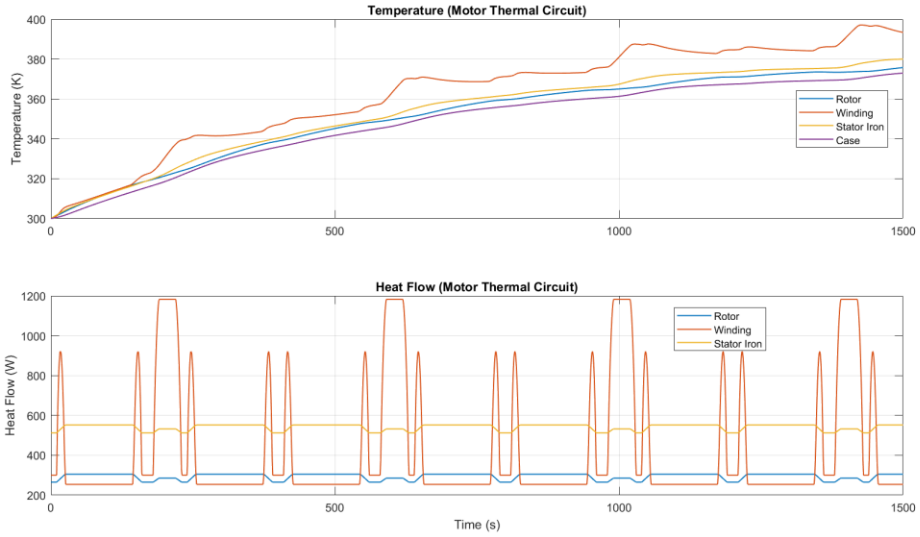

Temperature (Motor Thermal Circuit)
Temperature (K)
400
380
360
340
320
300
0
500
1000
1500
Rotor
Winding
Stator Iron
Case
Heat Flow (Motor Thermal Circuit)
Heat Flow (W)
1200
1000
800
600
400
200
Rotor
Winding
Stator Iron
Time (s)

电机参数化和被控对象建模

- 选择电机类型和规格
- 电机参数化
- 被控对象建模

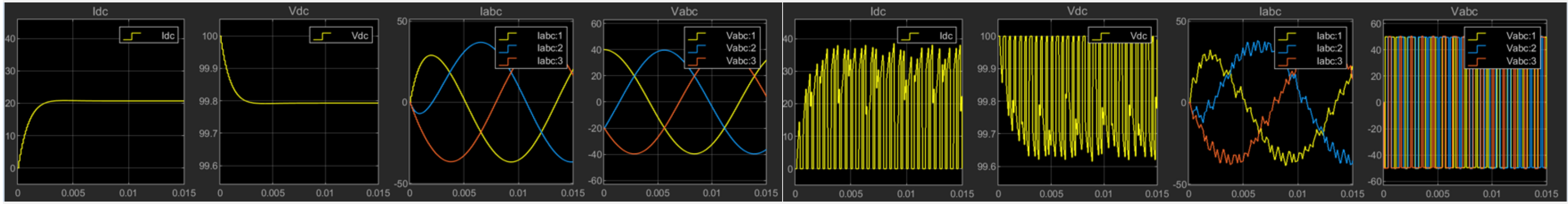
电力电子变流器模型保真度

系统行为	部件验证	组件设计

Low Fidelity **Composition** High Fidelity

Abstracted | Waveform Controlled | PWM Controlled | Individual Switches

Semiconductor Converter Models



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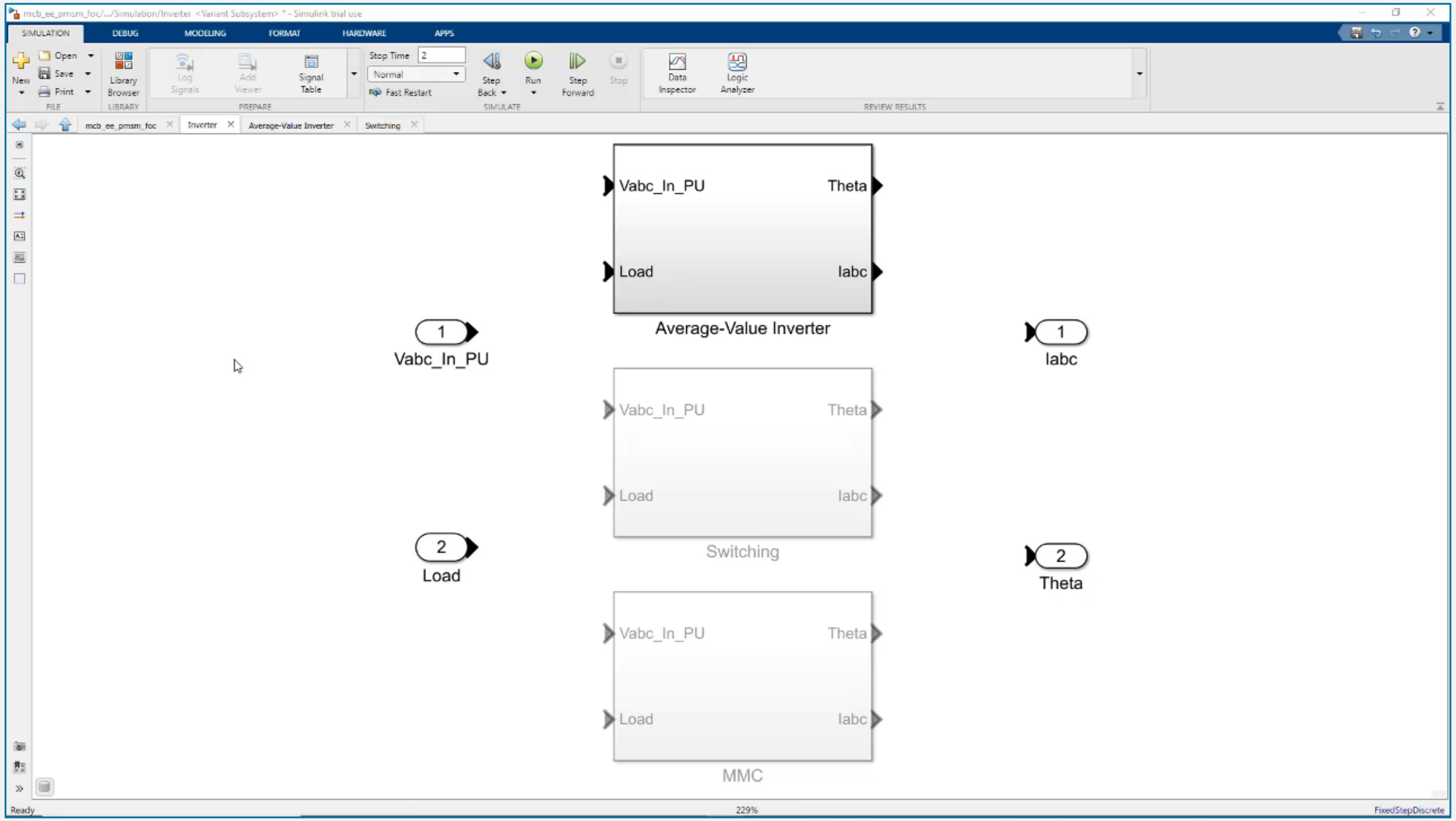
电机参数化和被控对象建模

- 选择电机类型和规格
- 电机参数化
- 被控对象建模

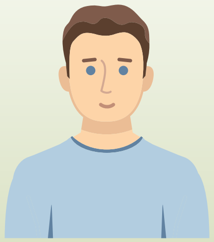
不同电力电子保真度的变体模型



电机参数化和被控对象建模

电机需求 → 电机参数化和被控对象建模 → Control algorithm implementation → Code generation and deployment → Embedded Software for Motor Control

- 选择电机类型和规格
- 电机参数化
- 被控对象建模



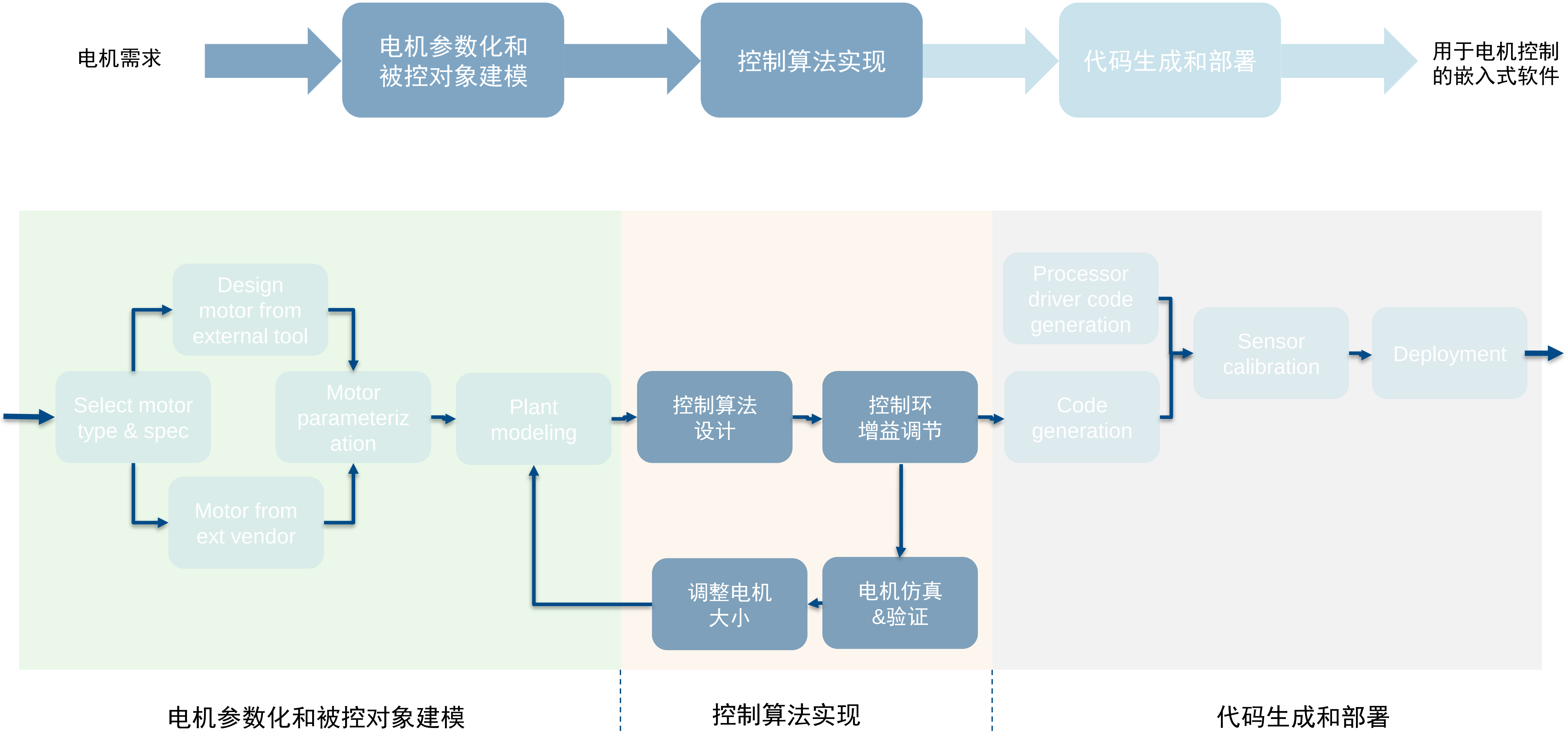
建模工程师

如何获取电机参数来开发电机模型?
使用电机测试、测功机测试或有FEA数据确定电机参数

小结

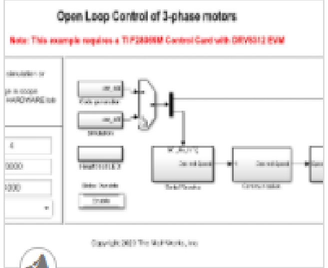
- 电机辨识
- 预定义的PMSM建模流程
- 使用电机规格书、实验测试、FEA工具或测功机数据对电机进行参数化
- 对具有不同保真度的电机和逆变器进行建模

建议的电动车驱动电机控制软件开发流程



常见电机控制算法

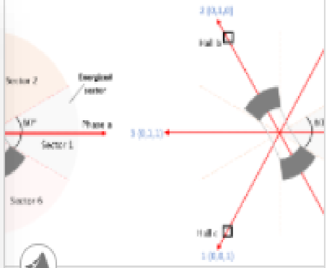
- 控制算法设计
- 控制环增益调节
- 电机仿真&验证
- 调整电机大小



Run 3-Phase AC Motors in Open-Loop Control and Calibrate ADC Offset

Uses open-loop control (also known as scalar control or Volts/Hz control) to run a motor. This technique varies the stator voltage

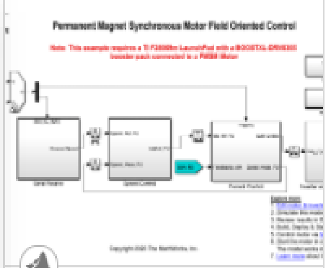
V/F控制



Six-Step Commutation of BLDC Motor Using Sensor Feedback

Uses 120-degree conduction mode to implement the six-step commutation technique to control speed and direction of rotation of a

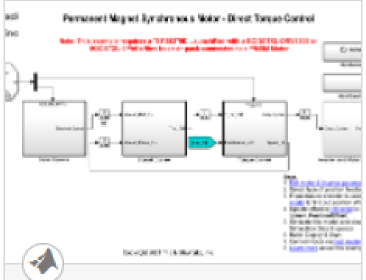
BLDC六步换相



Sensorless Field-Oriented Control of PMSM

Implements the field-oriented control (FOC) technique to control the speed of a three-phase permanent magnet synchronous

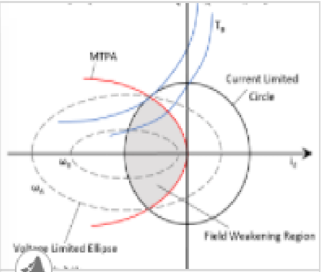
磁场定向控制



Direct Torque Control of PMSM Using Quadrature Encoder or Sensorless Flux...

Implements direct torque control (DTC) technique to control the speed of a three-phase permanent magnet synchronous motor (PMSM). Direct

直接转矩控制



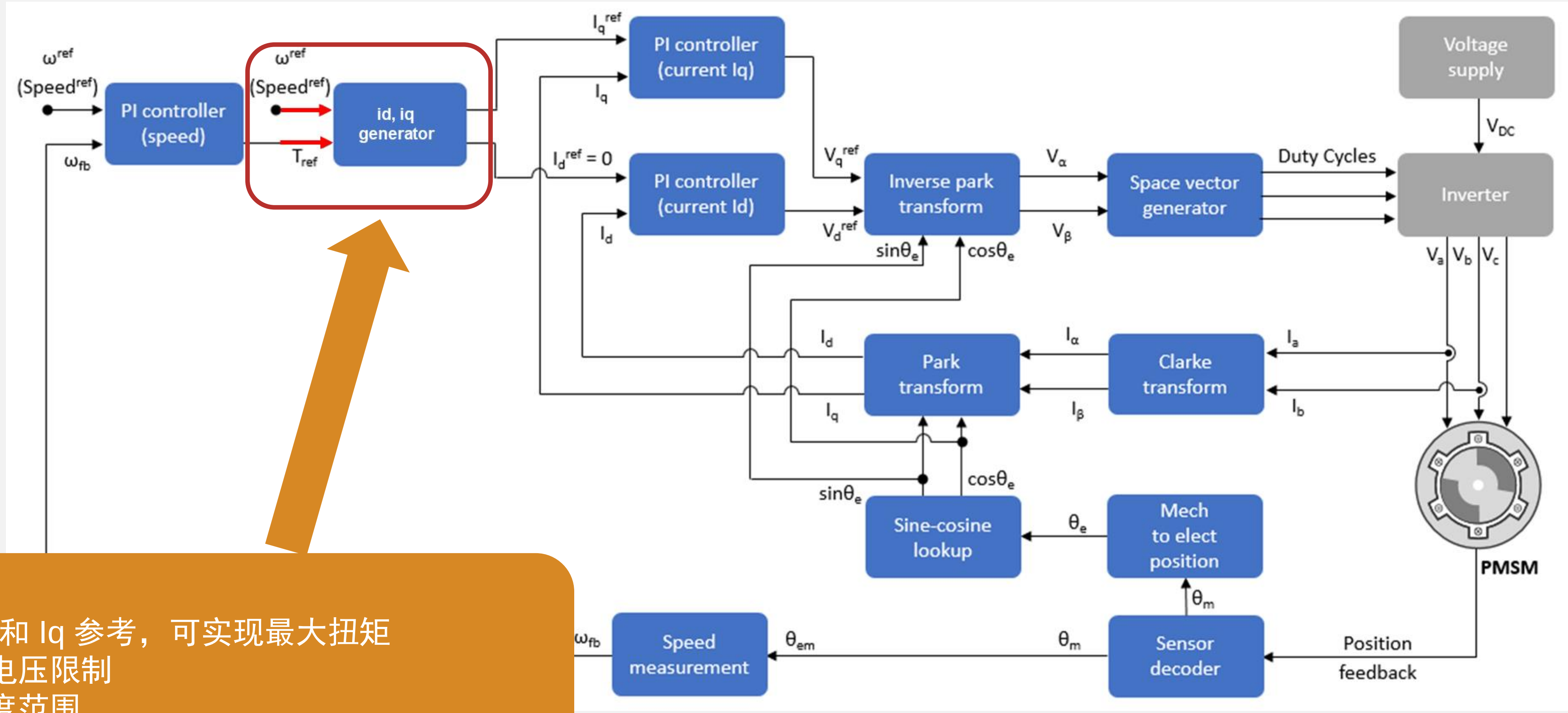
Field-Weakening Control (with MTPA) of PMSM

Implements the field-oriented control (FOC) technique to control the torque and speed of a three-phase permanent magnet

弱磁控制

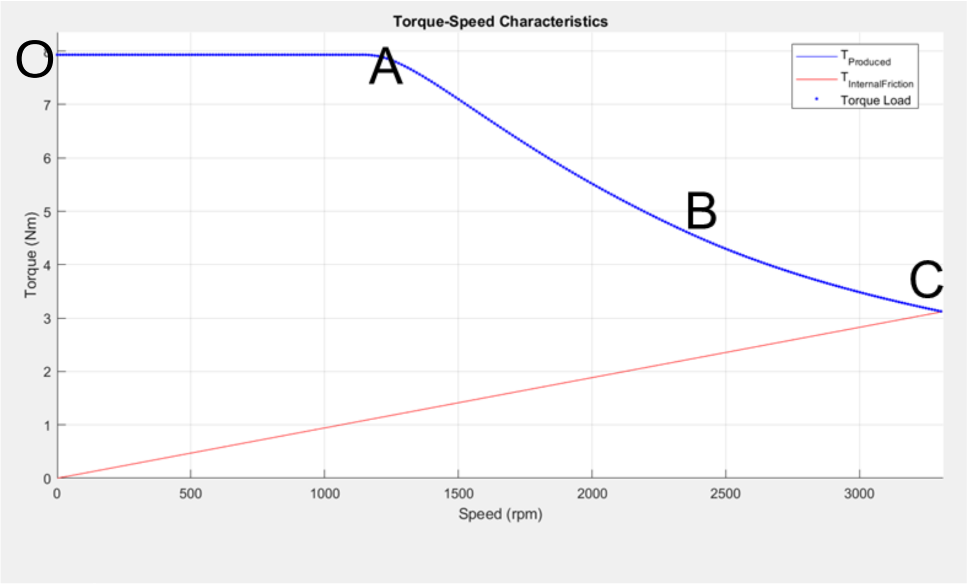
弱磁控制模块

- 控制算法设计
- 控制环增益调节
- 电机仿真&验证
- 调整电机大小

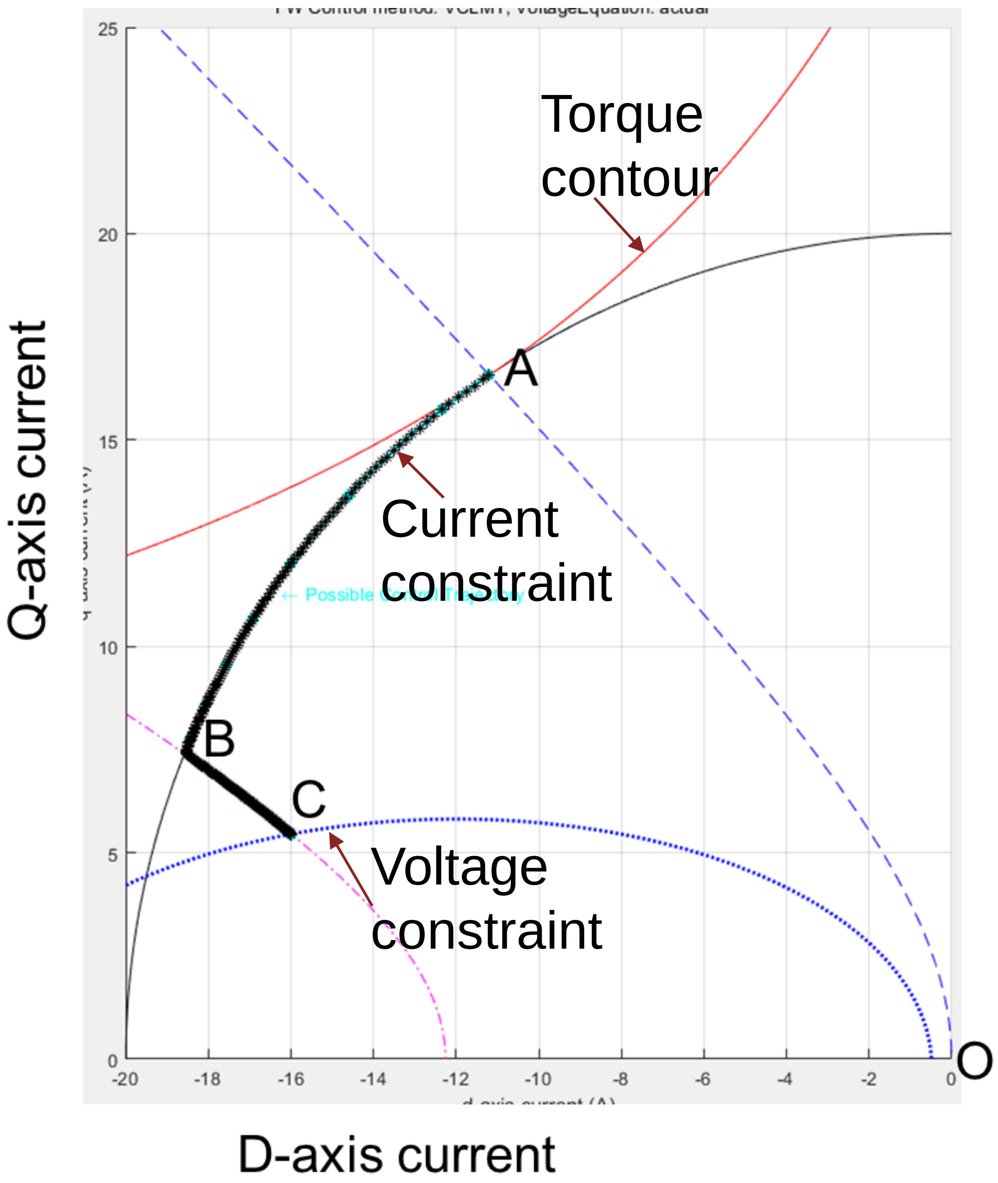


1. 输出右侧 Id 和 Iq 参考，可实现最大扭矩
2. 满足电流和电压限制
3. 扩大运行速度范围

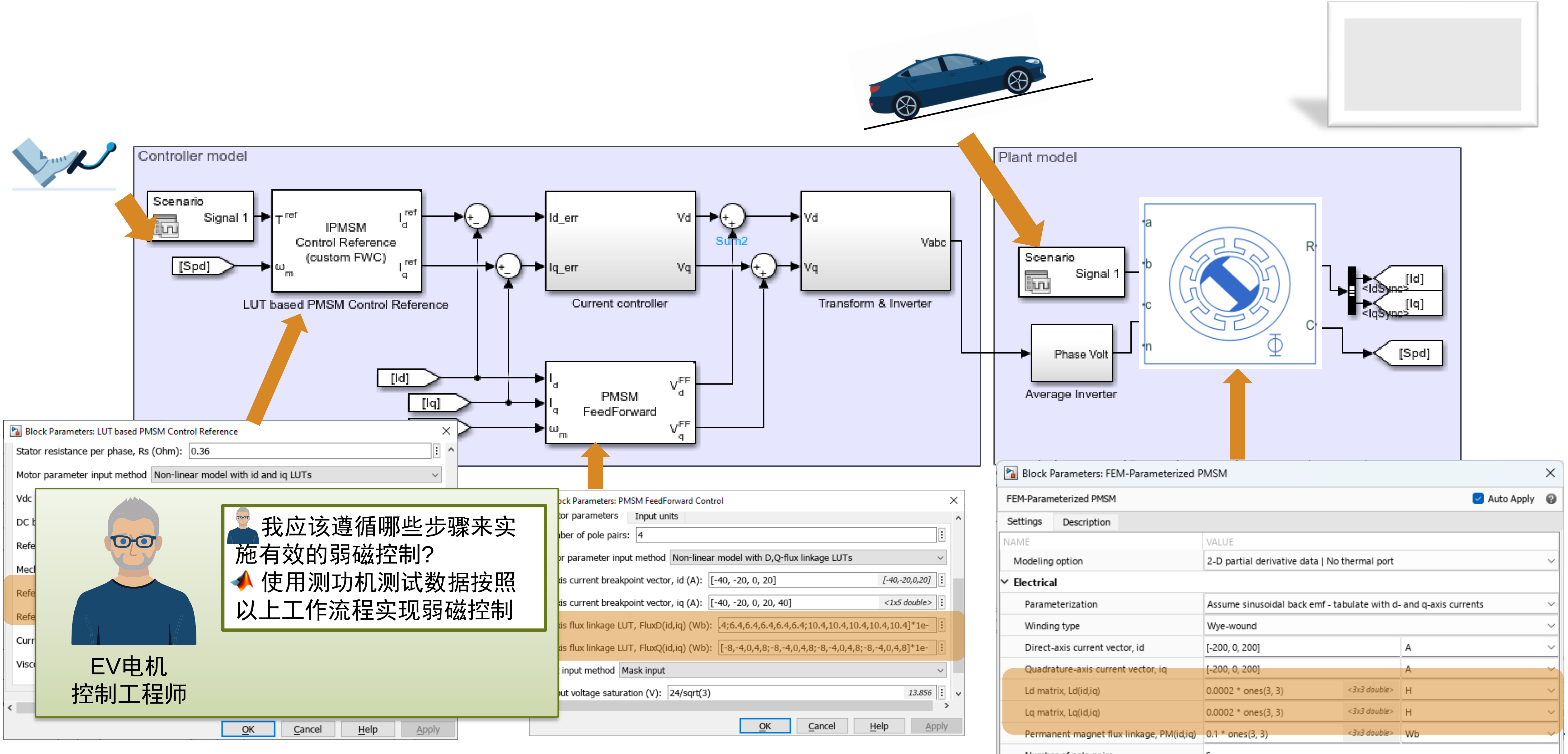
比较转矩-速度特性曲线和Id/Iq图谱中的关键运行点。



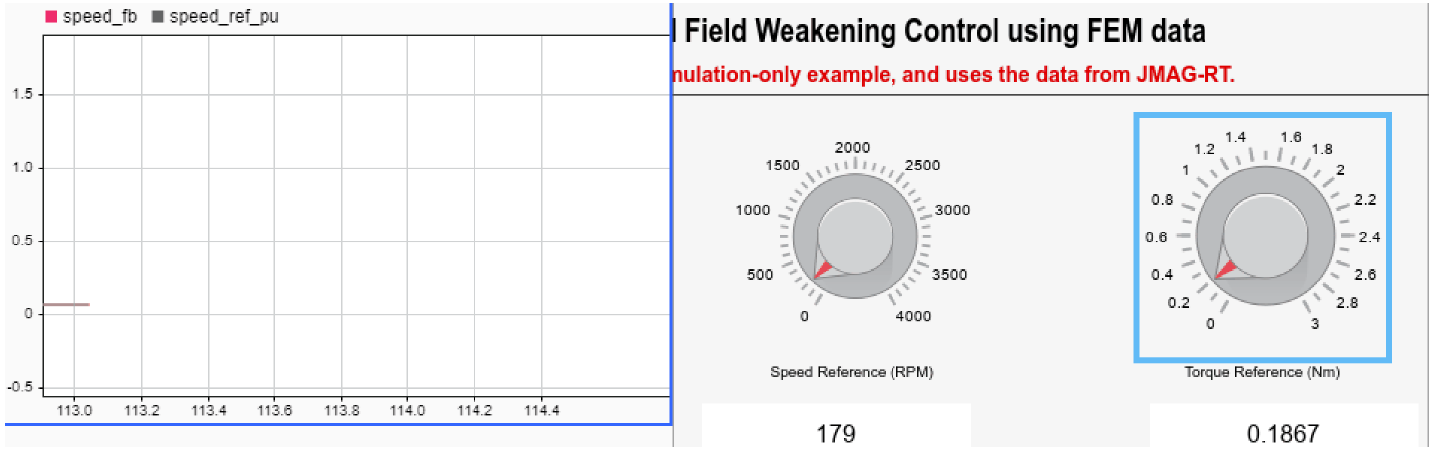
Region	Algorithm / Constraints
OA	MTPA运行区域
AB	弱磁运行区（满足电流约束）
BC	MTPV运行区域
CO	弱磁运行区（满足电压约束）
C	C 是最大运行速度（此时电机驱动扭矩与摩擦力矩相等）

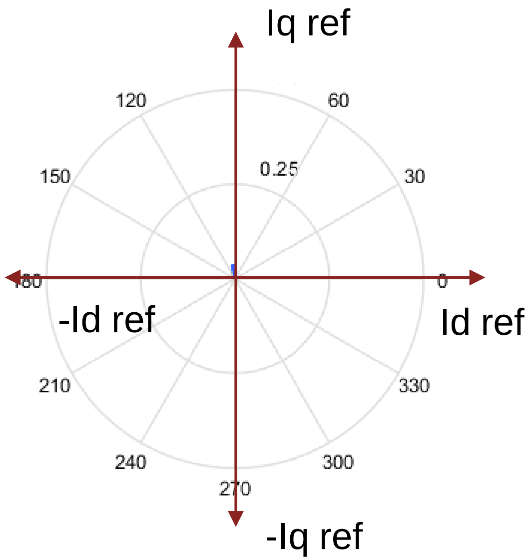


使用电机测功机数据实现弱磁控制



IPMSM的弱磁控制仿真

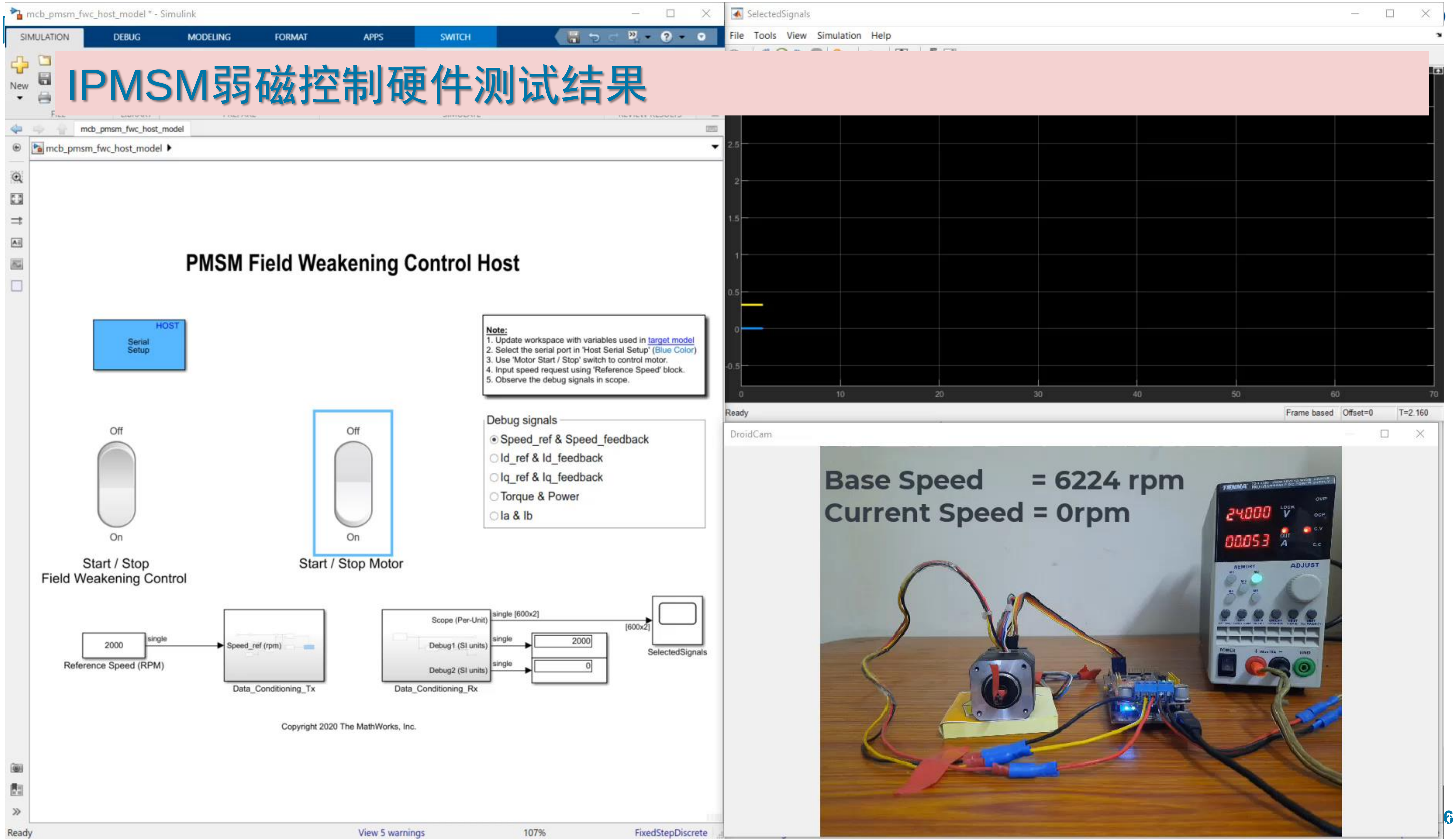




参考速度 vs. 实际速度（阶跃测试）

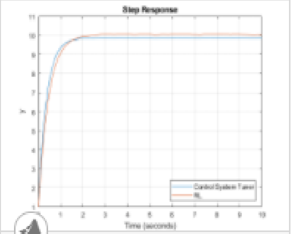
Id 和 Iq 图

IPMSM弱磁控制硬件测试结果



其它先进控制策略

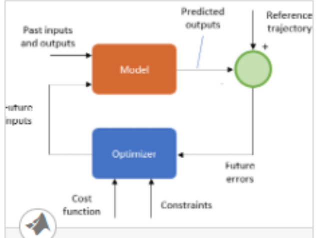
- 控制算法设计
- 控制环增益调节
- 电机仿真&验证
- 调整电机大小



Tune PI Controller using Reinforcement Learning

Tune the gains of a PI controller using a reinforcement learning agent.

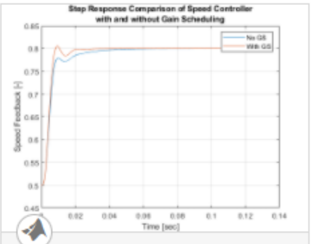
使用加强学习进行PID调参



Run Field Oriented Control of PMSM Using Model Predictive Control

Uses Model Predictive Control (MPC) to control the speed of a three-phase permanent magnet synchronous motor (PMSM). MPC is

模型预测控制

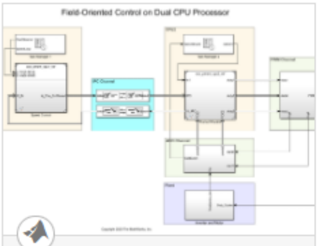


Tune Gain-Scheduled Controller for PMSM Model Using Closed-Loop PID...

Use Closed-Loop PID Autotuner block to tune gain-scheduled PI controller for a PMSM model in one simulation.

Open Live Script

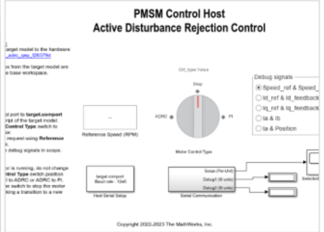
增益调度控制



Partition Motor Control for Multiprocessor MCUs

Partition real-time motor control application on to multiple processors to achieve design modularity and improved control performance.

多处理器 MCU 的电机控制仿真



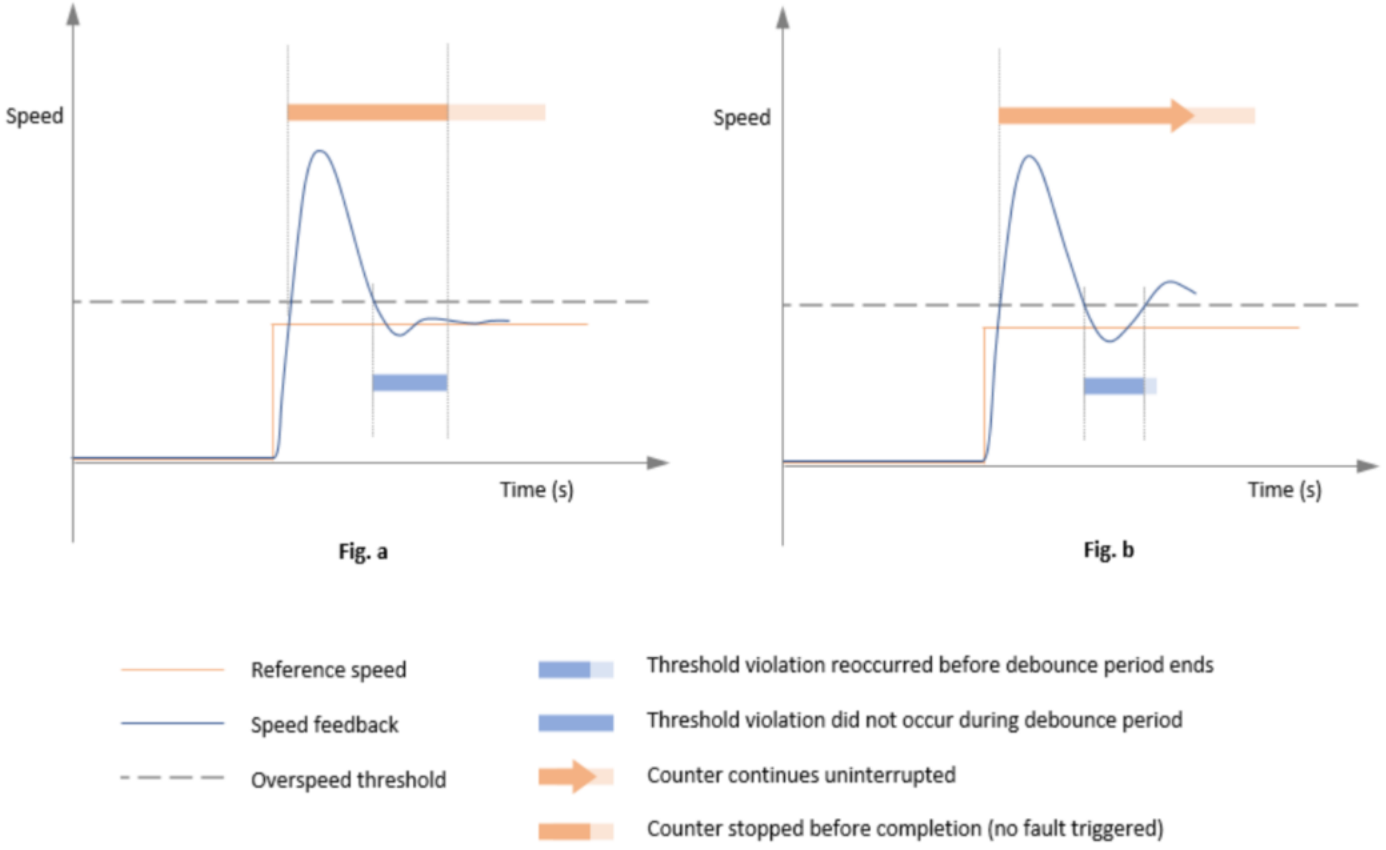
Implement PMSM Speed Control Using Active Disturbance Rejection...

Implement active disturbance rejection control (ADRC) of the speed of a permanent magnet synchronous motor (PMSM)

自抗扰控制

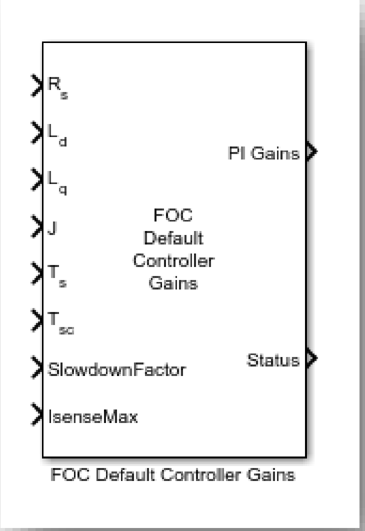
电机保护策略 - 继电器模块

- 过流保护
- 过压保护
- 欠压保护
- 超速保护

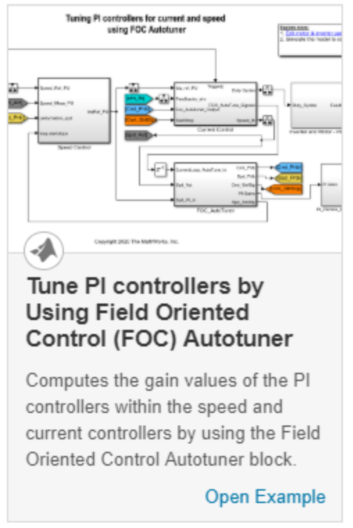


调整控制环增益

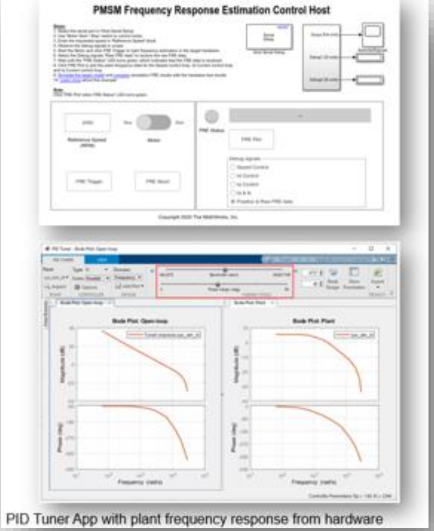
- 控制算法设计
- 控制环增益调节
- 电机仿真&验证
- 调整电机大小



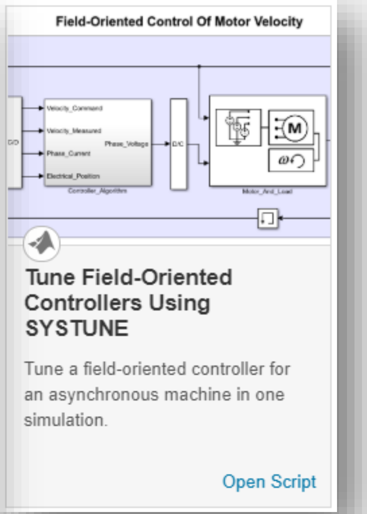
经验值计算



FOC Autotuner



在线频谱估计 +
PID tuner app



经典控制理论

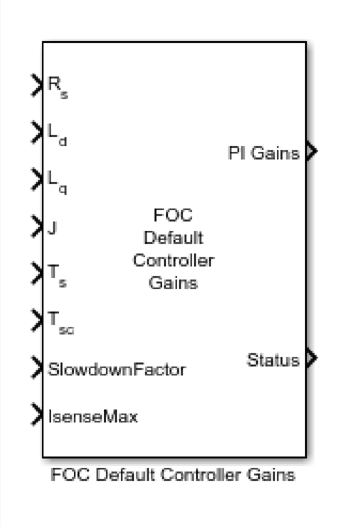
Motor Control Blockset

Motor Control Blockset and
Simulink Control Design

Simulink
Control Design

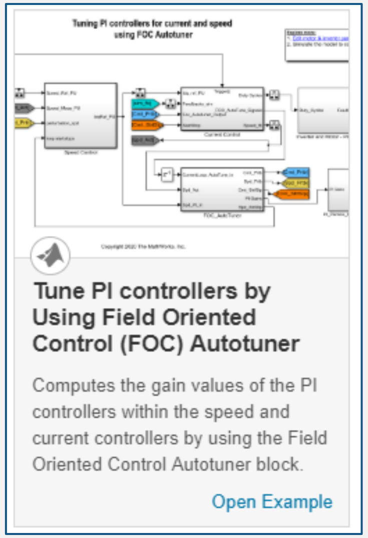
调整控制环增益

- 控制算法设计
- 控制环增益调节
- 电机仿真&验证
- 调整电机大小

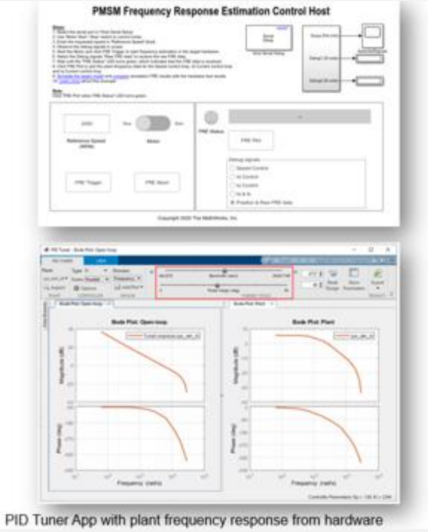


Empirical Computation

...ntrol Blockset

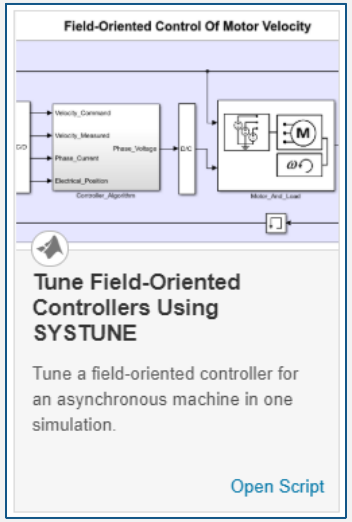


FOC Autotuner



Online frequency estimation and PID tuner app

Motor Control Blockset and Simulink Control Design



Classical Control Theory

Simulink Control Design

控制工程师

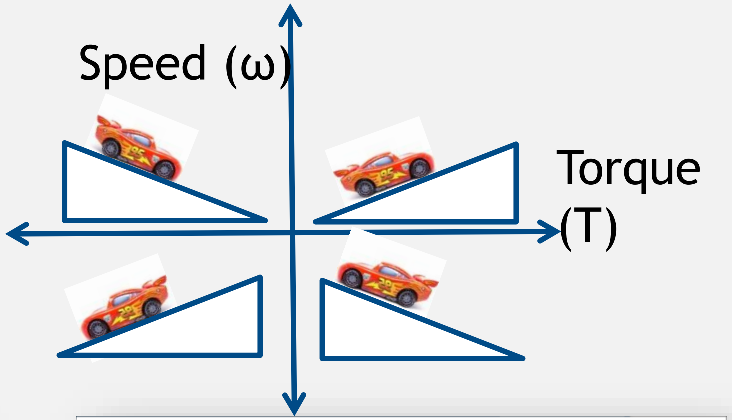
如何调整控制环路增益以实现性能?

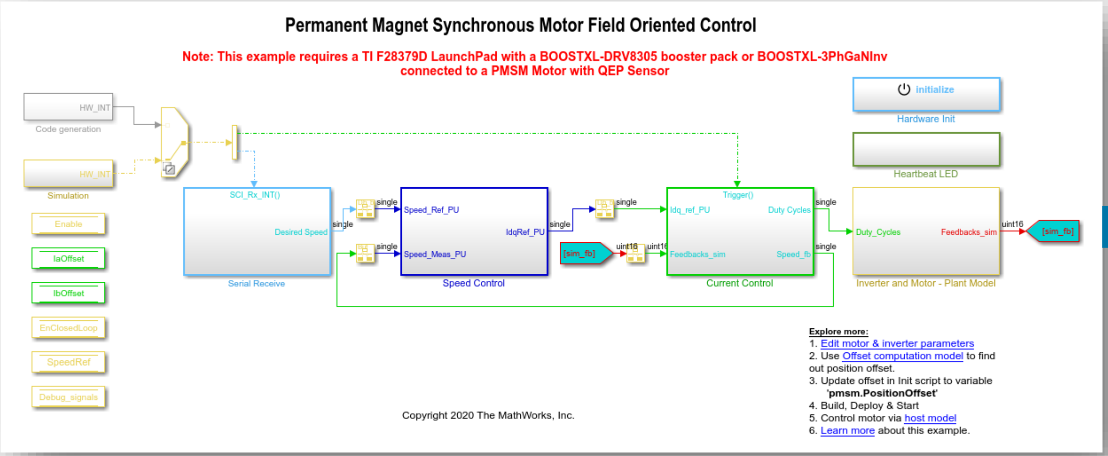
使用本页列出的任何一种方法来调整控制增益

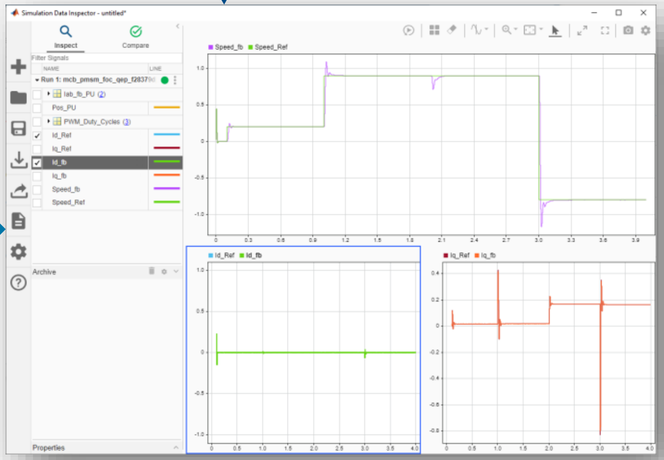
仿真验证

- 控制算法设计
- 控制环增益调节
- 电机仿真&验证
- 调整电机大小

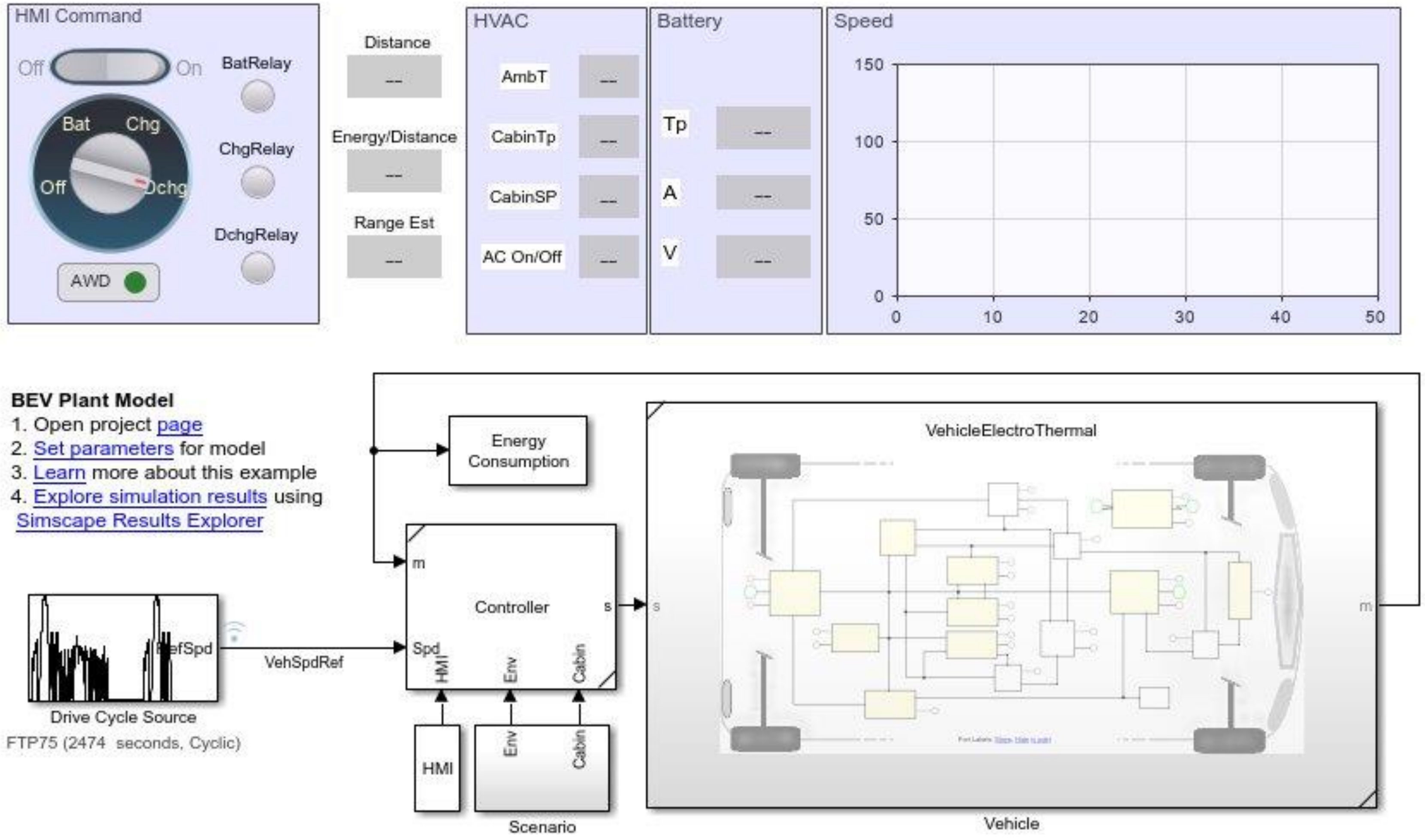
仿真四象限运行并验证电机和控制特性

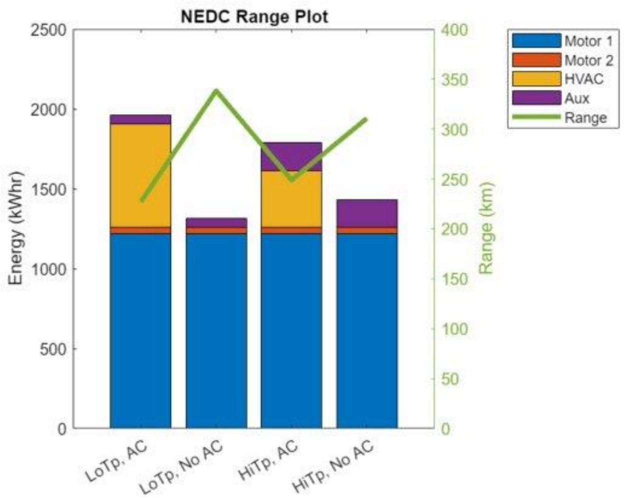






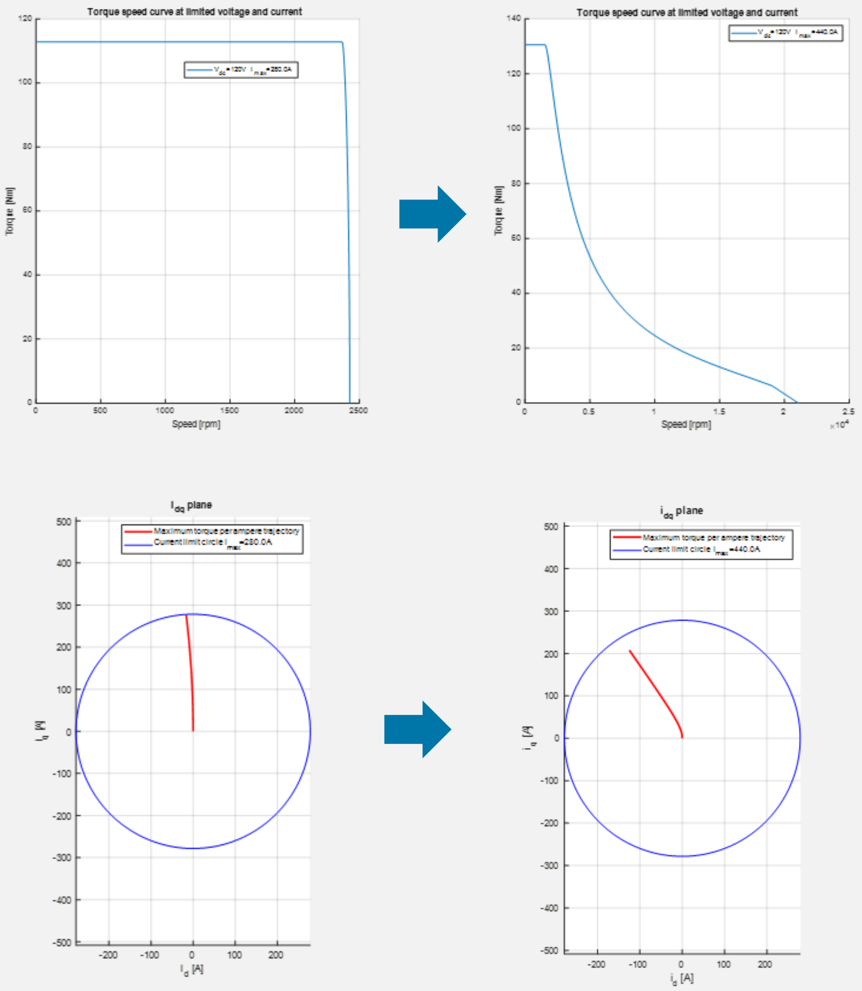
整车系统仿真


HMI Command
Off
On
BatRelay
Bat
Chg
ChgRelay
Off
Dchg
DchgRelay
AWD
Distance
Energy/Distance
Range Est
HVAC
AmbT
CabinTp
CabinSP
AC On/Off
Battery
Tp
A
V
Speed
150
100
50
0
0
10
20
30
40
50
BEV Plant Model
1. Open project page
2. Set parameters for model
3. Learn more about this example
4. Explore simulation results using
Simscape Results Explorer
Energy Consumption
VehicleElectroThermal
Controller
m
s
Spd
HMI
Env
Cabin
VehSpdRef
Drive Cycle Source
FTP75 (2474 seconds, Cyclic)
HMI
Scenario
Vehicle


NEDC Range Plot
Energy (kWhr)
Range (km)
Motor 1
Motor 2
HVAC
Aux
Range
0
500
1000
1500
2000
2500
0
50
100
150
200
250
300
350
400
LoTp, AC
LoTp, No AC
HiTp, AC
HiTp, No AC

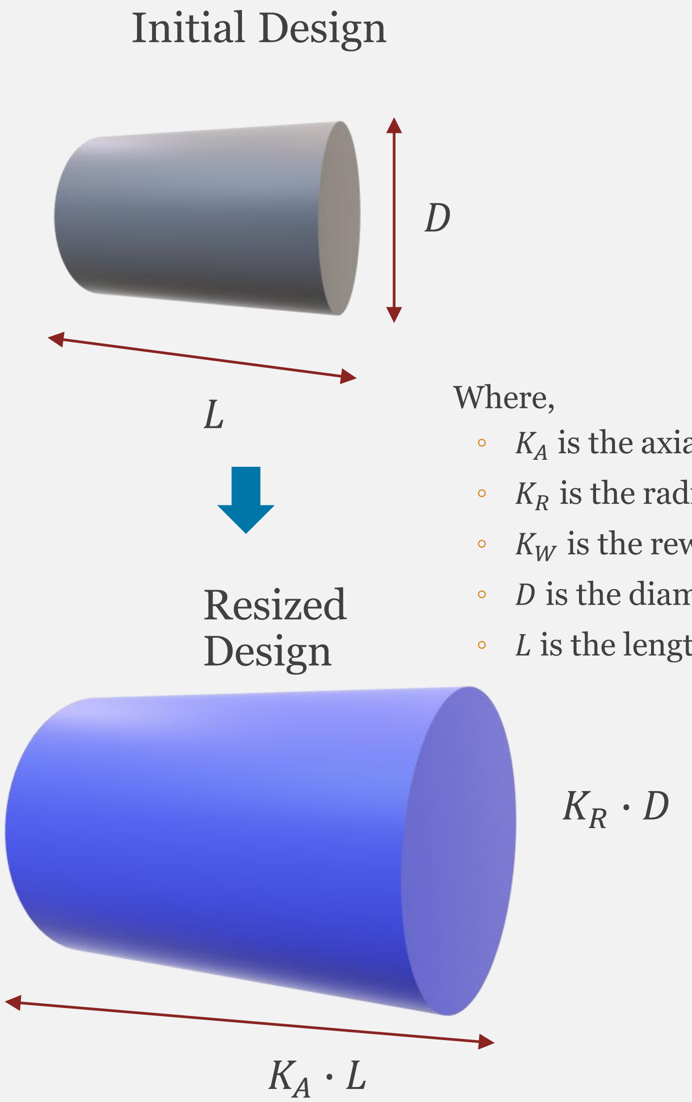
根据系统要求重新设计电机

- 控制算法设计
- 控制环增益调节
- 电机仿真&验证
- 调整电机大小



Existing characteristics

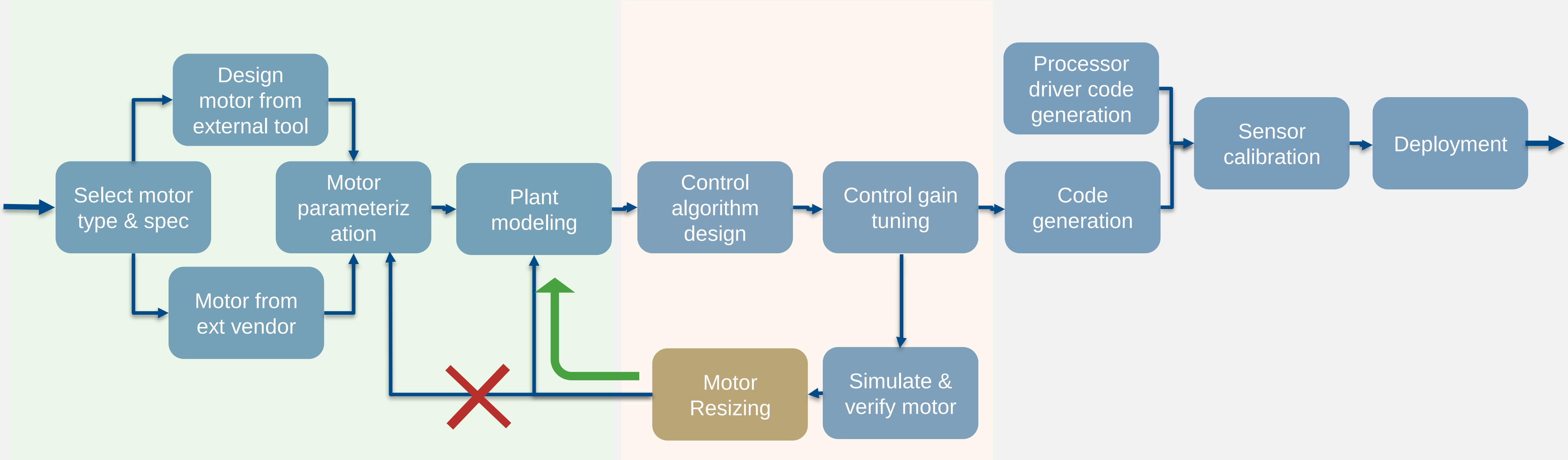
Proposed characteristics



Where,

- K_A is the axial resize factor
- K_R is the radial resize factor
- K_W is the rewinding factor
- D is the diameter of motor
- L is the length of motor

无需重新参数化

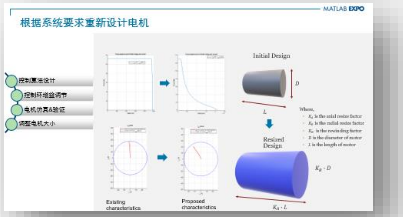


电机参数化和被控对象建模

控制算法实现

代码生成和部署

- 对于重新设计的电机无需再次运行测功机测试
- 重用已有的电机参数（乘以系数）
- 节省台架测试时间和费用



Motor Resizing

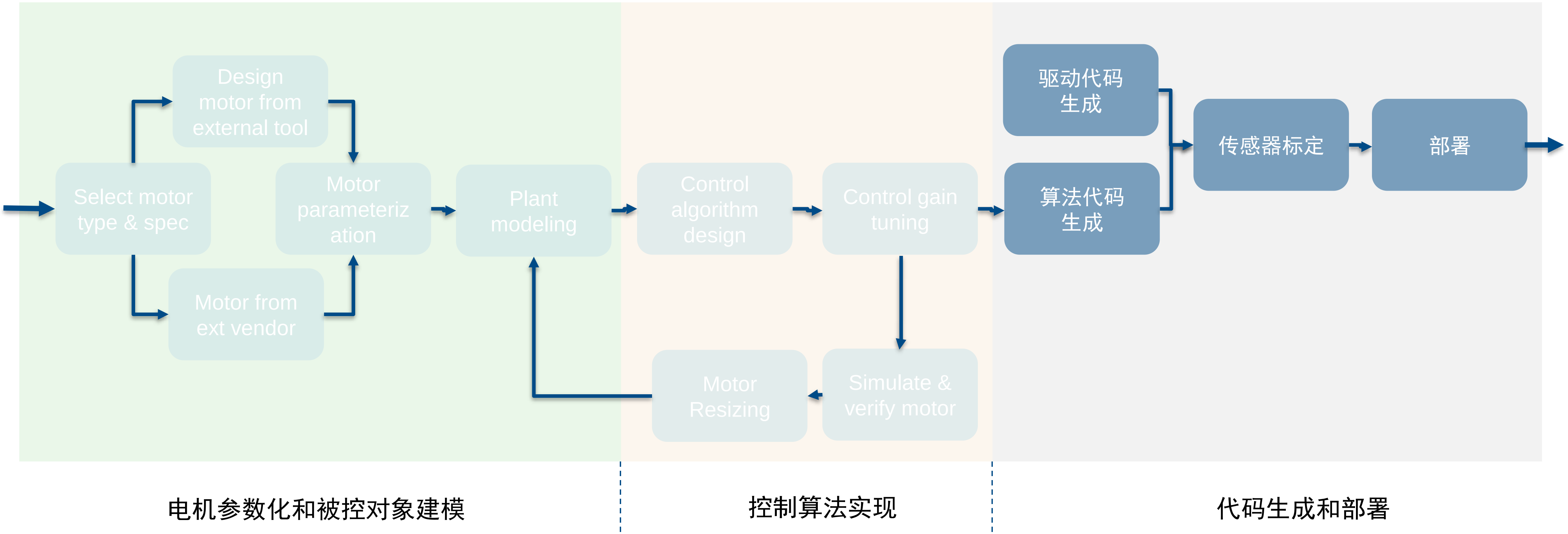
实现控制算法并在仿真中进行验证

- 控制算法设计
- 控制环增益调节
- 电机仿真&验证
- 调整电机大小

小结

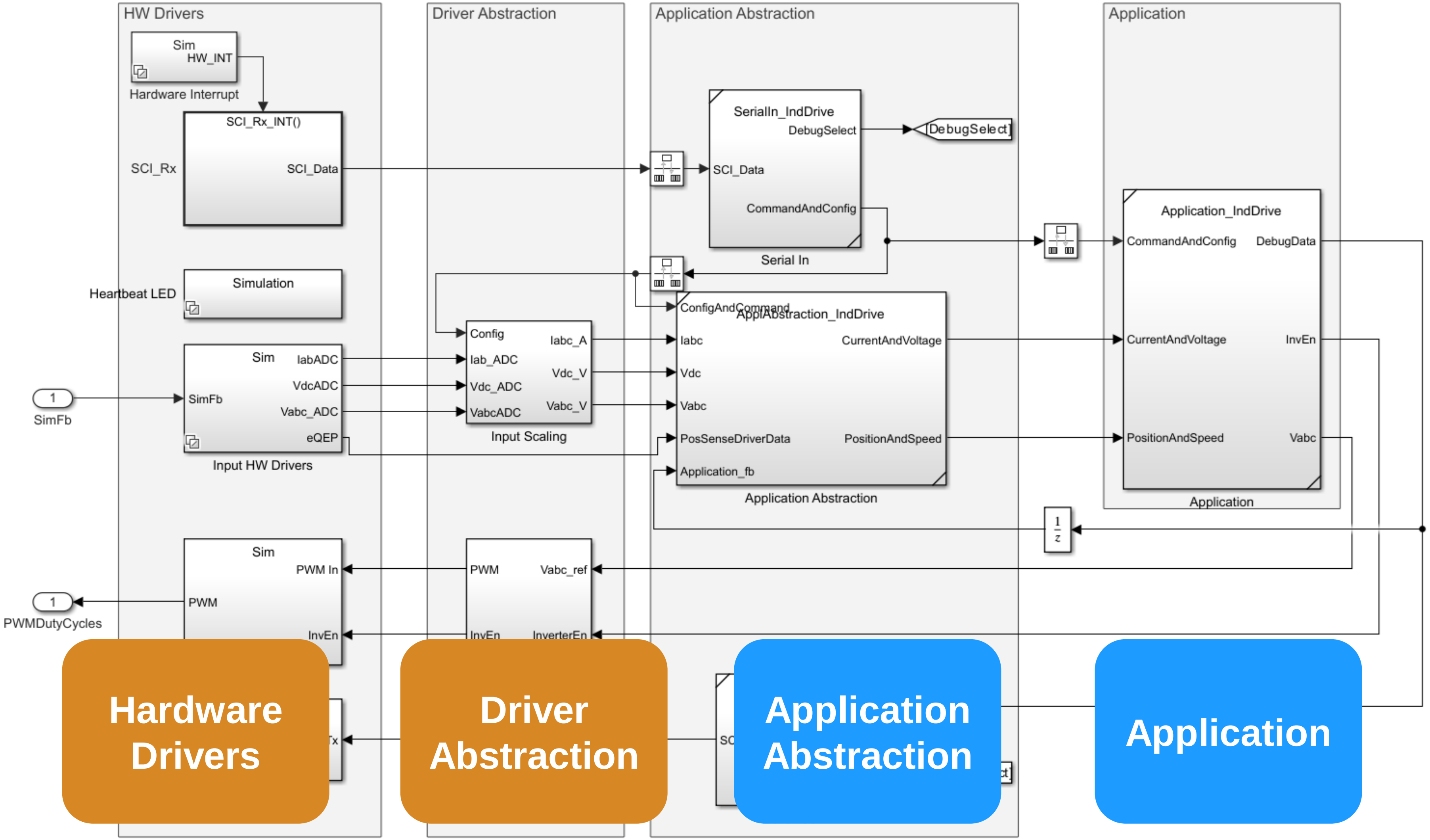
- 了解常见的控制策略和新的控制策略
- 讨论弱磁控制(MTPA, MTPV)
- 讨论控制环增益调整的方法
- 讨论电机重新设计

建议的电动车驱动电机控制软件开发流程



模型架构及层次——便于算法在不同硬件之间的移植（从原型到产品）

- 模型架构
- 外设驱动代码
- 代码部署
- 静态代码分析
- 传感器标定
- 处理器在环(PIL)
- AUTOSAR集成



模型架构及层次——便于算法在不同硬件之间的移植（从原型到产品）

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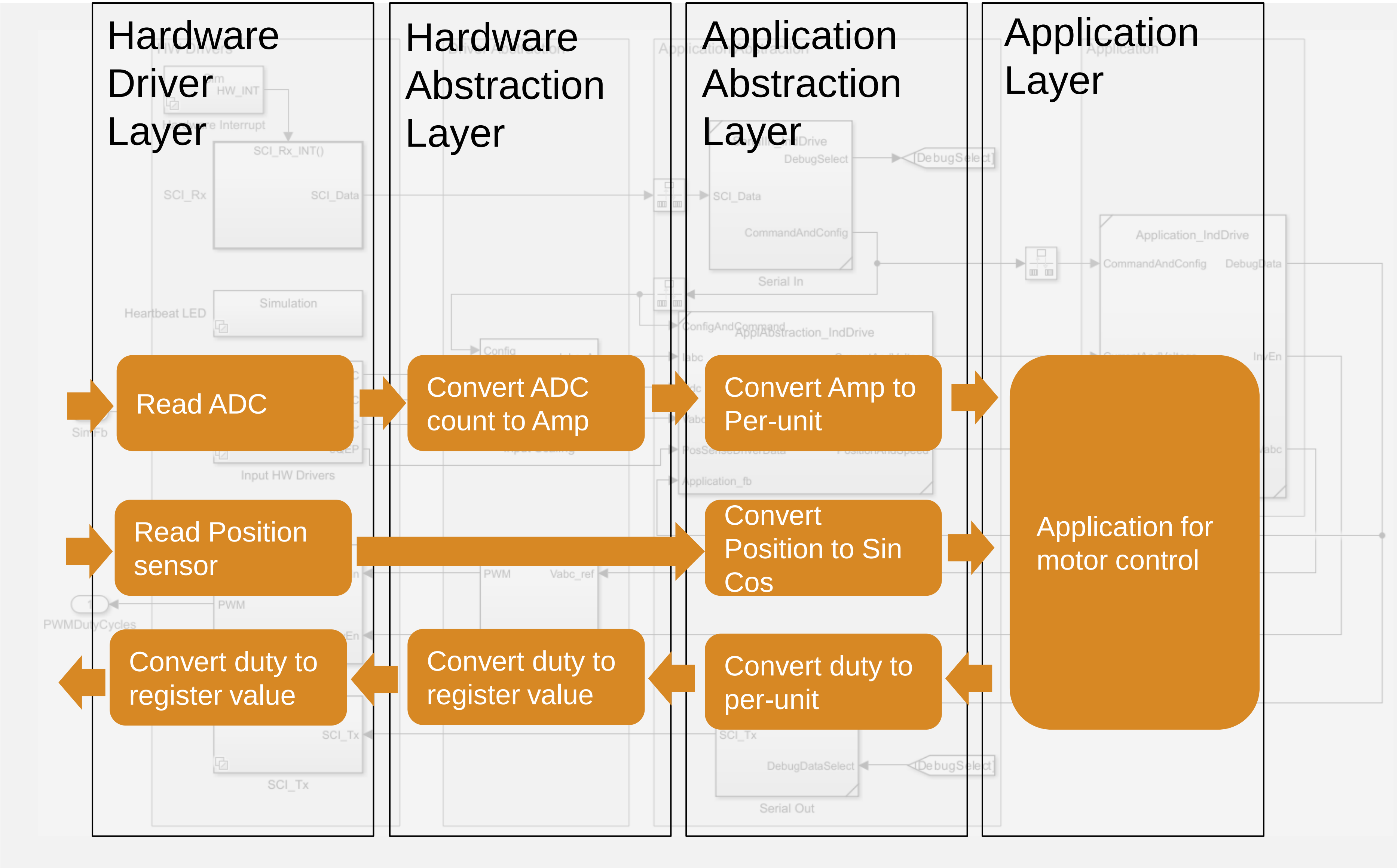
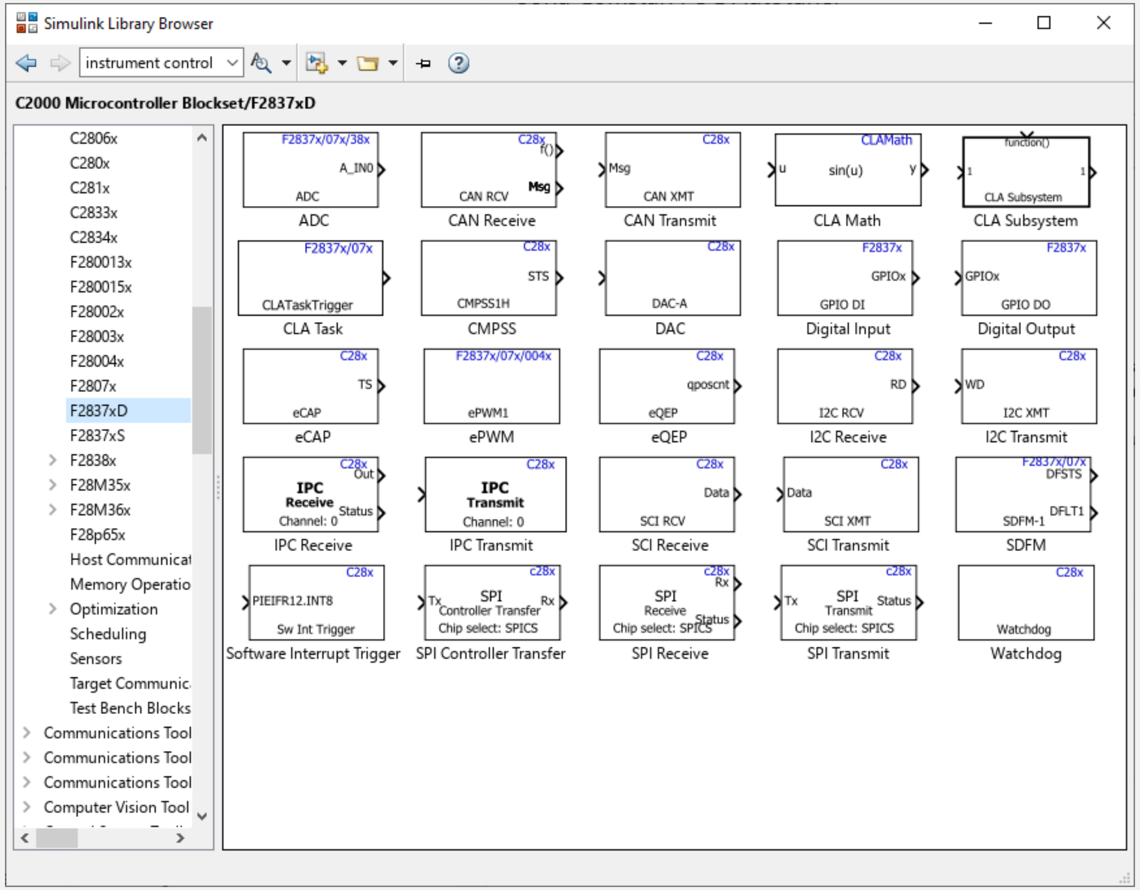
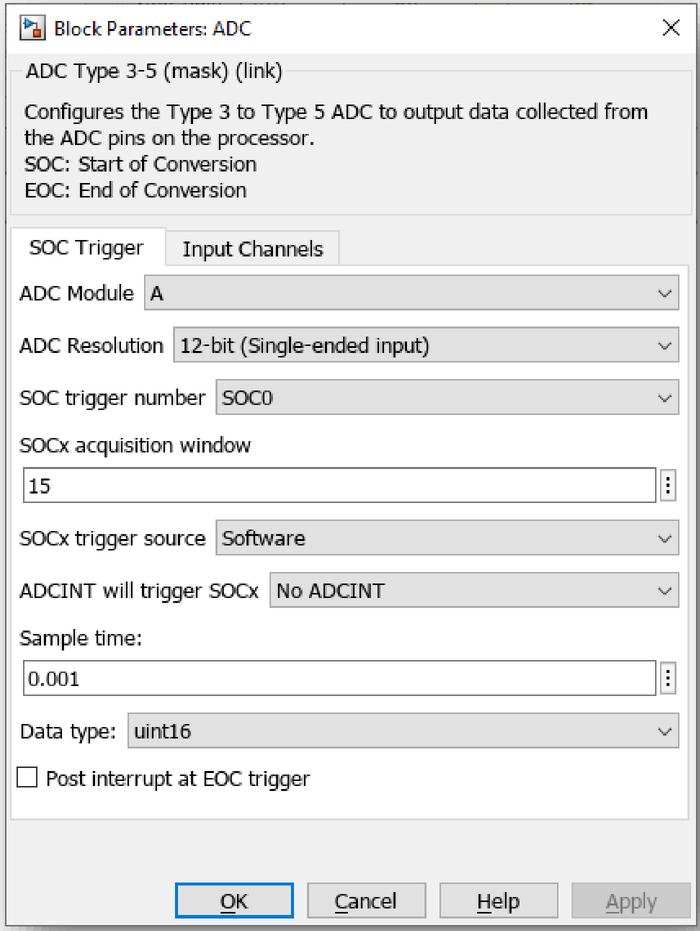


硬件驱动代码——来自硬件支持包或驱动模块

- 模型架构
- 外设驱动代码
- 代码部署
- 静态代码分析
- 传感器标定
- 处理器在环(PIL)
- AUTOSAR集成

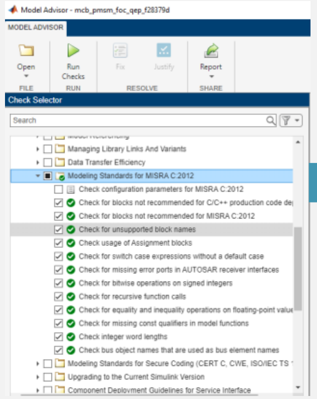
ADC, PWM, Interrupt trigger, Serial communication blocks



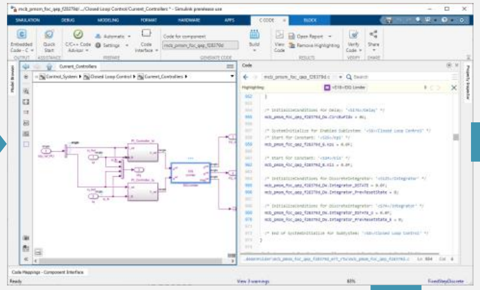


生成C代码或HDL代码，并与外设驱动代码集成

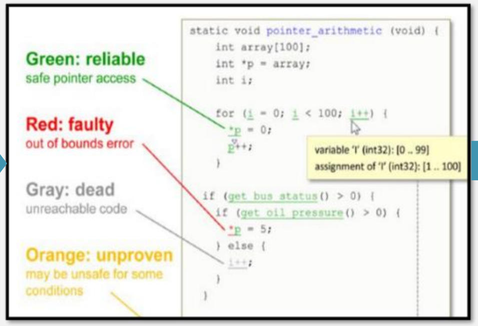
- 模型架构
- 外设驱动代码
- 代码部署
- 静态代码分析
- 传感器标定
- 处理器在环(PIL)
- AUTOSAR集成



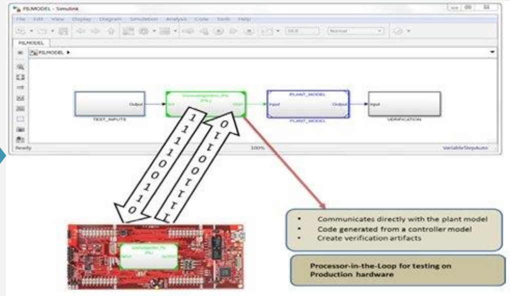
运行建模规范检查并符合Misra-C 和ISO26262



使用Embedded Coder生成代码

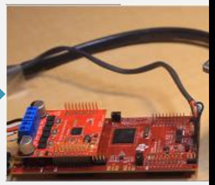


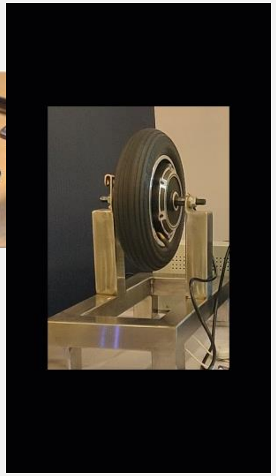
使用Polyspace运行静态代码分析



处理器在环测试（验证代码执行时间）

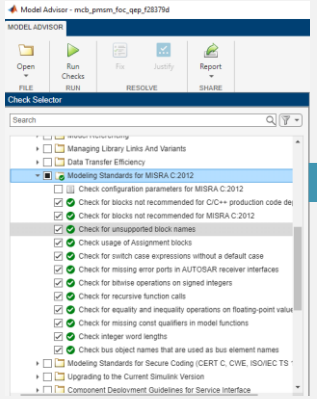
外设驱动代码 (手写代码或者通过硬件支持包自动生成)



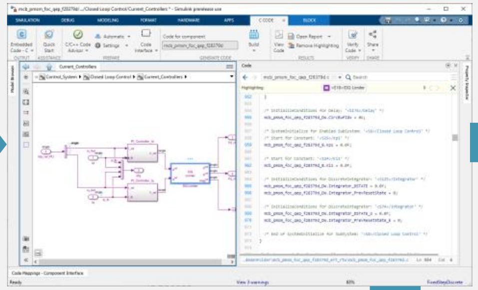


生成C代码或HDL代码，并与外设驱动代码集成

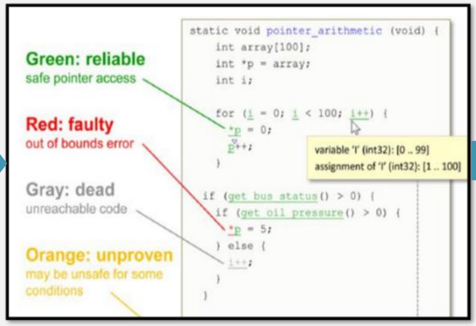
- 模型架构
- 外设驱动代码
- 代码部署
- 静态代码分析
- 传感器标定



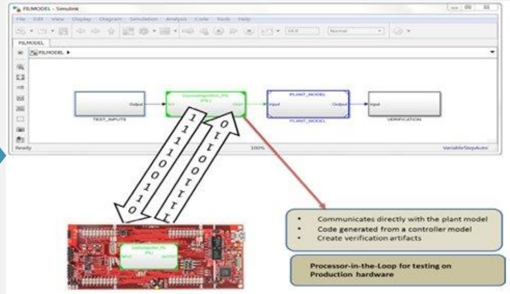
运行建模规范检查并符合Misra-C 和 ISO26262



使用Embedded Coder生成代码

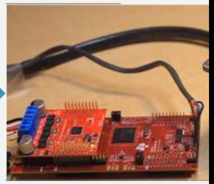


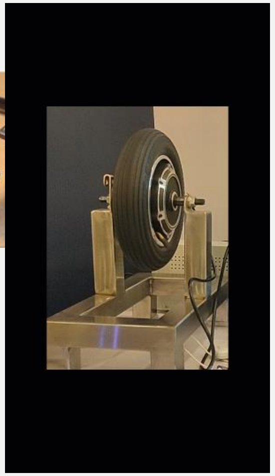
使用Polyspace运行静态代码分析



处理器在环测试（验证代码执行时间）

外设驱动代码 (手写代码或者通
支持包自动生成)





嵌入式
工程师

如何生成高效的代码并移植到不同的硬件?

使用分层模型架构，通过Embedded生成可移植且高效的代码。

硬件驱动代码——来自硬件支持包或驱动模块

- 模型架构
- 外设驱动代码
- 代码部署
- 静态代码分析
- 传感器标定
- 处理器在环(PIL)
- AUTOSAR集成

Processor peripheral driver code generation (ADC, PWM, Interrupt trigger, Serial communication)

Embedded Coder Support Package for Texas Instruments C2000 Processors by MathWorks Embedded Coder Team STAFF

Generate code optimized for C2000 MCU.

Embedded Coder® Support Package for Texas Instruments C2000™ Processors enables you to run Simulink® models on TI C2000 MCUs. Embedded Coder automatically generates C code for your algorithms and

TI

Field-Oriented Control of PMSM Using NXP™ S32K144 Kit version 1.0 by Shivaprasad Narayan STAFF

The workflow demonstrates Field Oriented Control of a Permanent Magnet Synchronous using NXP™ MCSPTE1AK144: S32K144 Development Kit

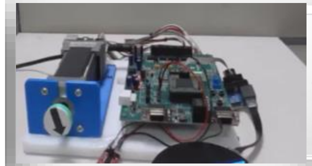
FOC-of-PMSMField-Oriented Control of Permanent Magnet Synchronous Motor Using NX S32K144 Development kitThis example implements a motor control system using the NX MCSPTE1AK144 hardware. The

NXP

Demo for Motor Control Deployment on Microchip Controllers version 1.0.0 by Brian McKay STAFF

Demo used in MathWorks-Microchip joint webinar: Deploying Motor Control Algorithms on Microchip dsPIC, PIC32, and SAM Controllers.

which includes a dsPIC33E Digital Signal Controller.The demo also require you to download and install the free add-on MPLAB Device Blocks for Simulink: dsPIC, PIC32, and SAM MCU's.View the webinar for a



Microchip

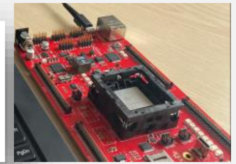
Embedded Coder Support Package for STMicroelectronics STM32 Processors by MathWorks Embedded Coder Team STAFF

Generate code optimized for STMicroelectronics STM32 Processor boards

STM

Embedded Coder Support Package for Infineon AURIX TC4x Microcontrollers by MathWorks Embedded Coder Team STAFF

Generate code optimized for Infineon AURIX TC4x Microcontrollers



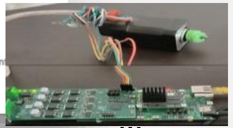
Infineon

HDL Coder Support Package for Xilinx Zynq Platform by MathWorks HDL Coder Team STAFF

Generate code for the FPGA portion of the Zynq-7000 SoC.

HDL Coder™ Support Package for Xilinx®Zynq®-7000 Platform supports the generation of IP cores that can be in FPGA designs using Xilinx Vivado® or Xilinx ISE. When used in combination

Hardware Support



Xilinx FPGA

Simulink Real-Time Target Support Package by MathWorks Simulink Real Time Target Team STAFF

Tools to compile a real-time application that runs on a Speedgoat target computer

Speedgoat

使用Polyspace 执行静态代码分析

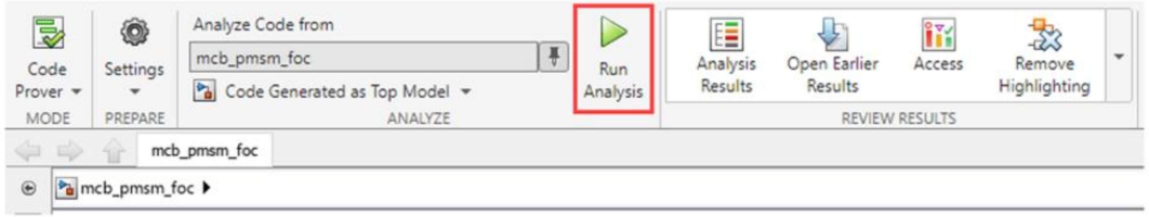
- 模型架构
- 外设驱动代码
- 代码部署
- 静态代码分析
- 传感器标定
- 处理器在环(PIL)
- AUTOSAR集成

Analyze and Verify Motor Control Algorithms Using Polyspace R2023b

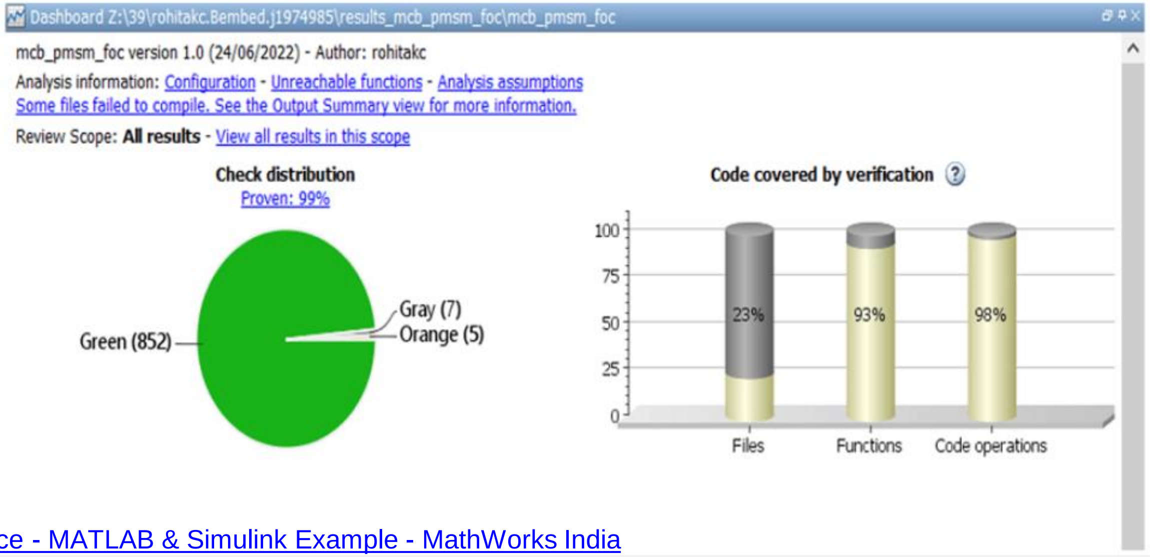
This example uses the Polyspace® static code analysis tools to analyze and verify Simulink® models containing motor control algorithms. Static code analysis is a software verification technique that analyzes source code for quality, reliability, and security without executing the code. This approach uses robust error detection routines (that include checks for critical run-time errors) to identify bugs and defect... ensures compliance with common coding standar...

This example uses:
Polyspace Bug Finder
Polyspace Code Prover
Motor Control Blockset

3. Click **Run Analysis** to start running the Code Prover tool.



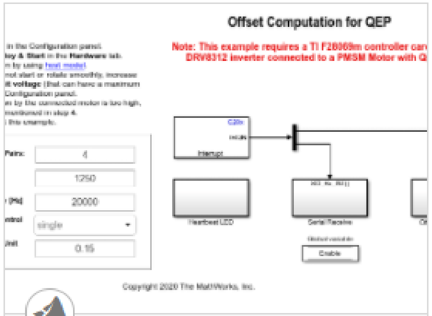
4. After the tool execution completes, click **Polyspace > Analysis Results** to open the code analysis results in the Polyspace app.



Analyze and Verify Motor Control Algorithms Using Polyspace - MATLAB & Simulink Example - MathWorks India

使用参考示例校准位置传感器

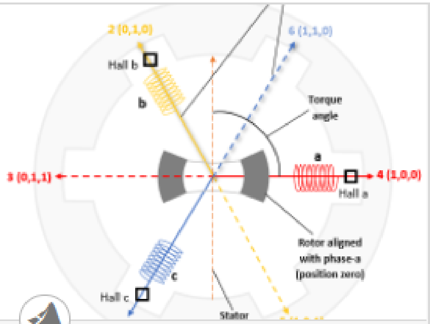
- 模型架构
- 外设驱动代码
- 代码部署
- 静态代码分析
- 传感器标定
- 处理器在环(PIL)
- AUTOSAR集成



Quadrature Encoder Offset Calibration for PMSM Motor

Calculates the offset between the d-axis of the rotor and encoder index pulse position as detected by the quadrature encoder sensor. The

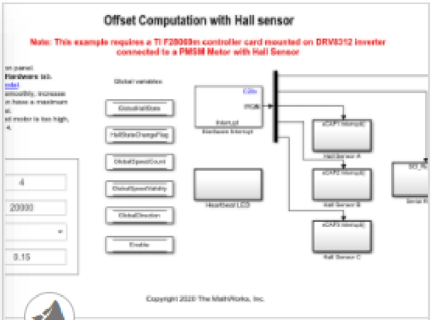
Quadrature encoder calibration



Hall Sensor Sequence Calibration of BLDC Motor

Calculates the Hall sensor sequence with respect to position zero of the rotor in open-loop control.

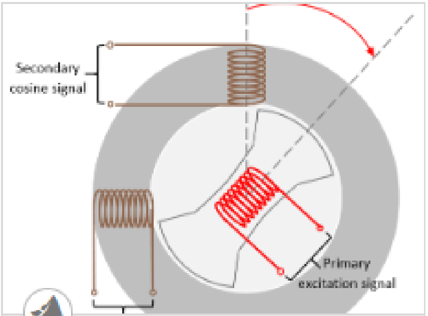
Identify Hall sensor sequence



Hall Offset Calibration for PMSM Motor

Calculates the offset between the rotor direct axis (d-axis) and position detected by the Hall sensor. The field-oriented control (FOC)

Calibrate Hall sensor



Monitor Resolver Using Serial Communication

Operates the resolver sensor to measure the rotor position. The resolver consists of two orthogonally placed stator windings

Resolver with Square-pulse carrier frequency

https://in.mathworks.com/help/mcb/gs/quadrature-encoder-offset-calibration-pmsm-motor.html

https://in.mathworks.com/help/mcb/gs/hall-sensor-sequence-calibration-bldc-motor.html

执行PIL测试

- 模型架构
- 外设驱动代码
- 代码部署
- 静态代码分析
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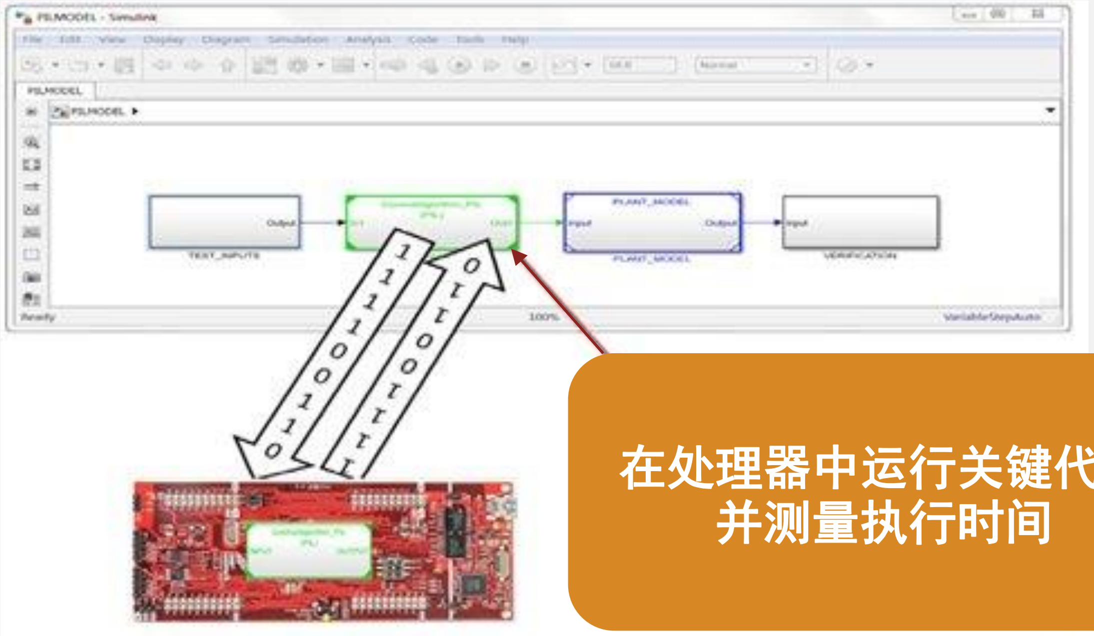
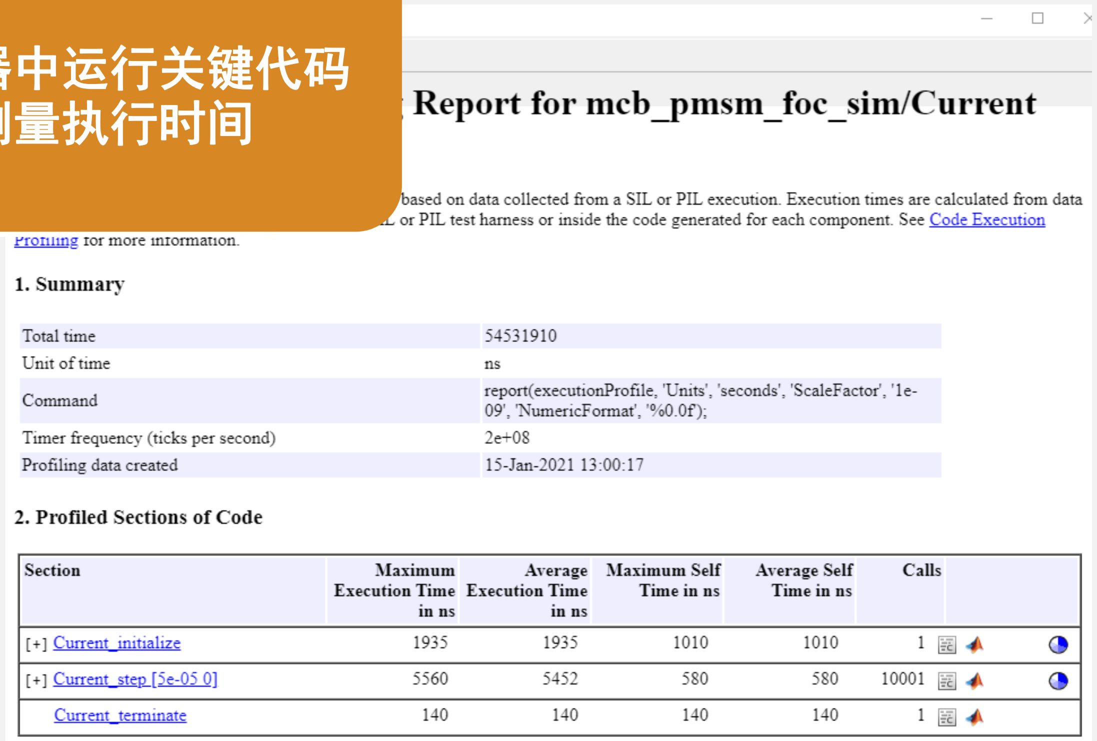


在处理器中运行关键代码
并测量执行时间



Report for mcb_pmsm_foc_sim/Current

…based on data collected from a SIL or PIL execution. Execution times are calculated from data …L or PIL test harness or inside the code generated for each component. See Code Execution Profiling for more information.

1. Summary

Total time	54531910
Unit of time	ns
Command	report(executionProfile, 'Units', 'seconds', 'ScaleFactor', '1e-09', 'NumericFormat', '%0.0f');
Timer frequency (ticks per second)	2e+08
Profiling data created	15-Jan-2021 13:00:17

2. Profiled Sections of Code

Section	Maximum Execution Time in ns	Average Execution Time in ns	Maximum Self Time in ns	Average Self Time in ns	Calls
[+] Current_initialize	1935	1935	1010	1010	1
[+] Current_step [5e-05 0]	5560	5452	580	580	10001
Current_terminate	140	140	140	140	1

Code Verification and Profiling Using PIL Testing - MATLAB & Simulink Example - MathWorks India

在AUTOSAR架构中集成电机控制算法

- 模型架构
- 外设驱动代码
- 代码部署
- 静态代码分析
- 传感器标定
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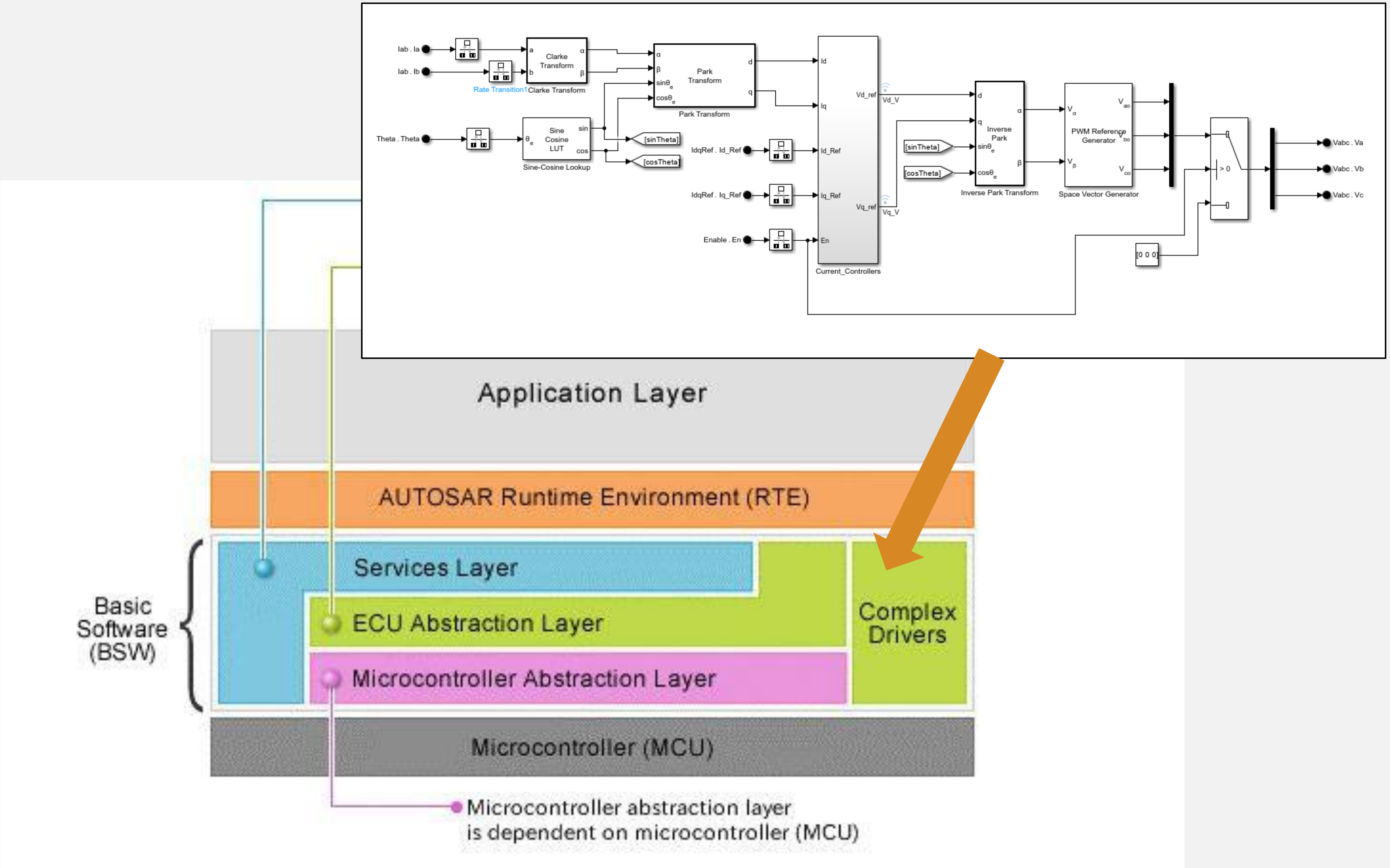

在AUTOSAR架构中集成电机控制算法

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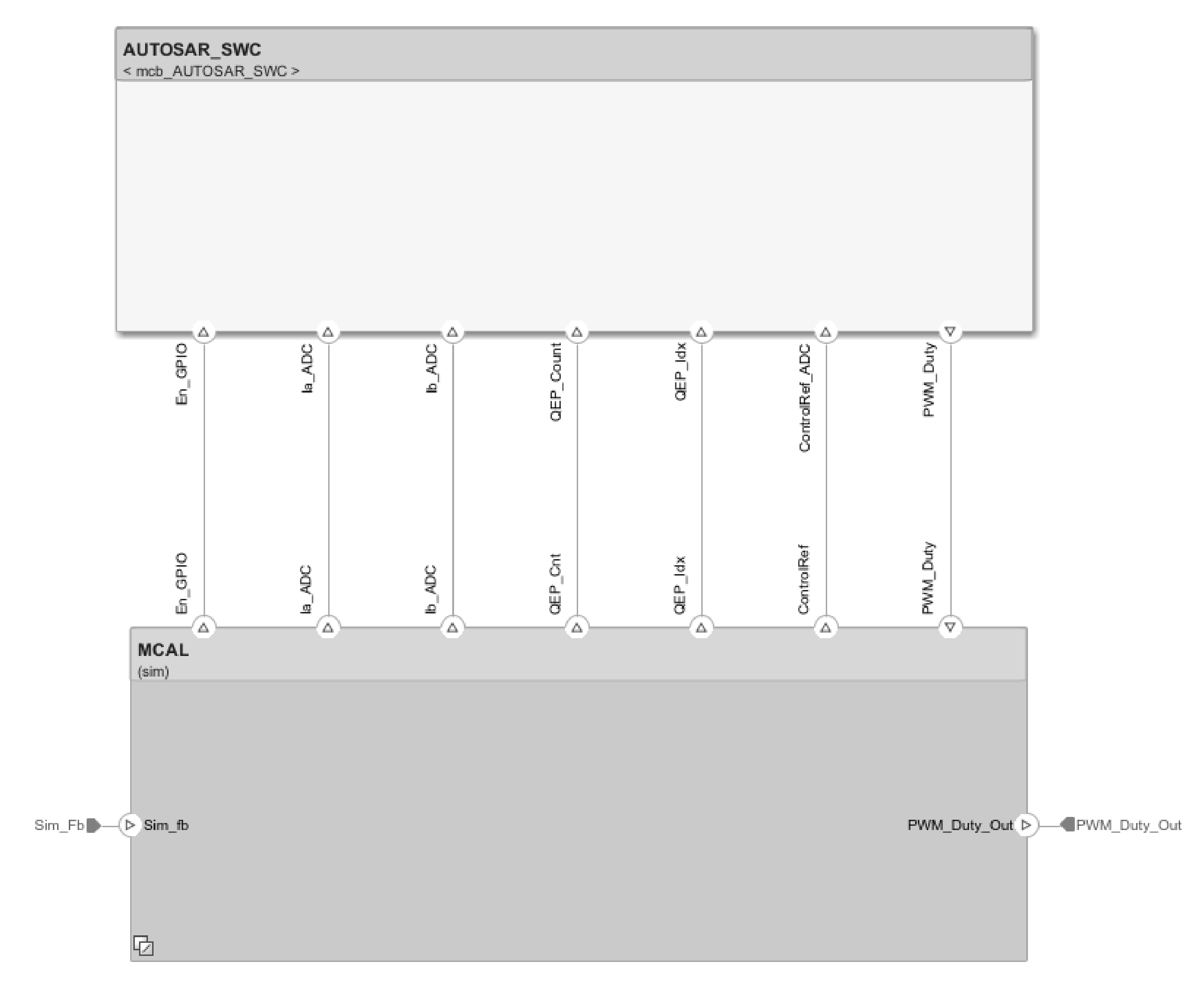

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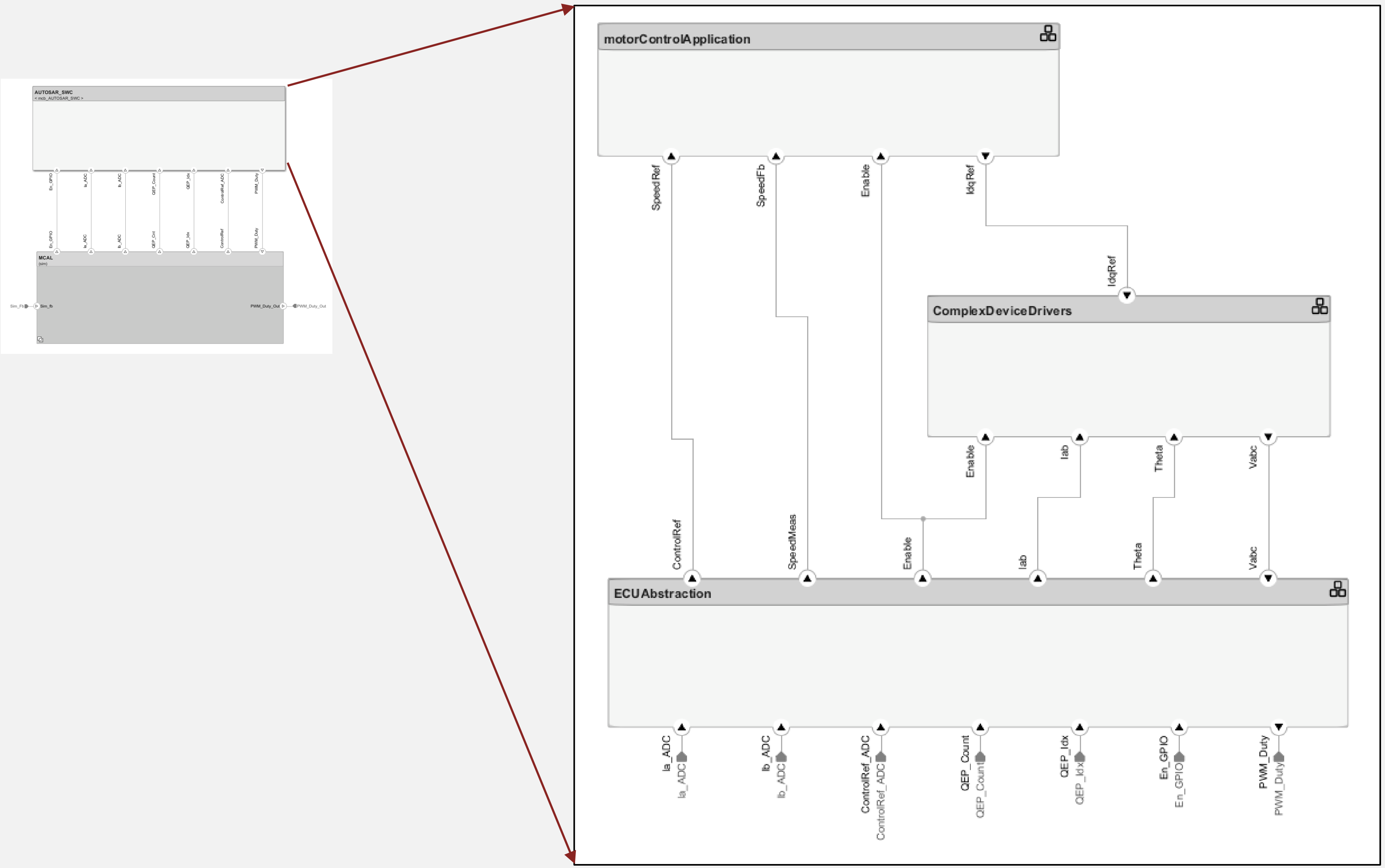

在AUTOSAR架构中集成电机控制算法

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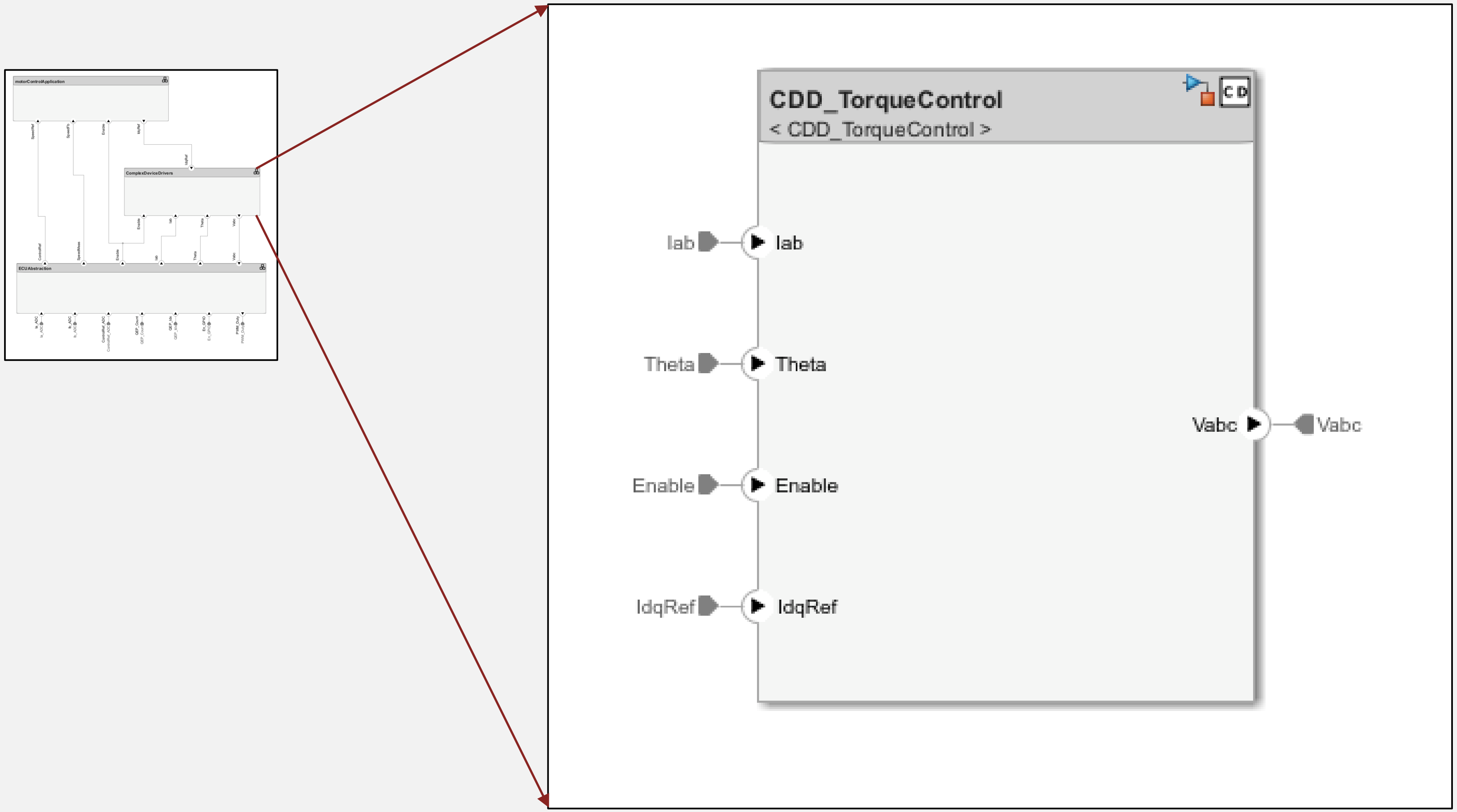

在AUTOSAR架构中集成电机控制算法

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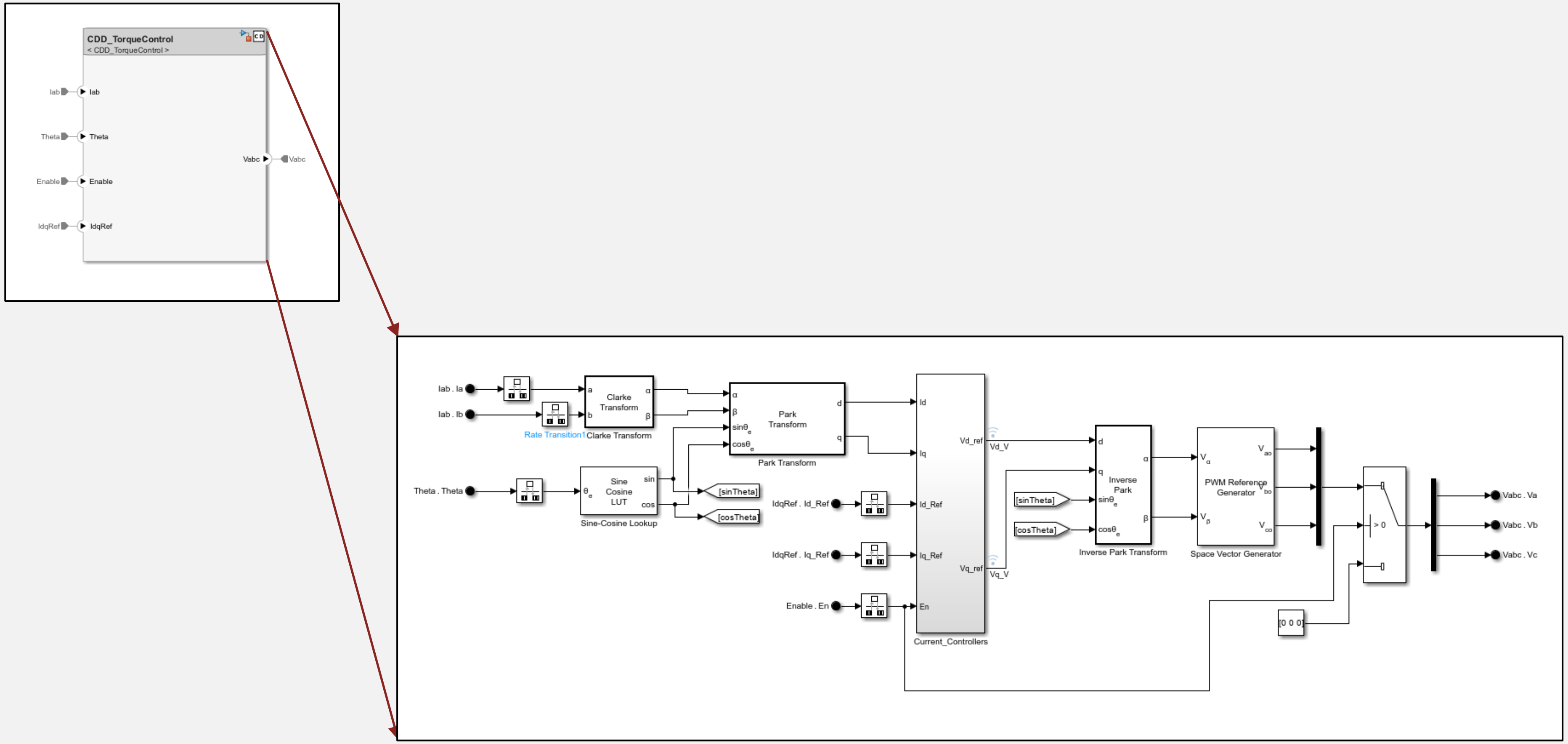

为电机控制组件生成符合AUTOSAR标准的代码和ARXML文件

- 模型架构
- 外设驱动代码
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- 静态代码分析
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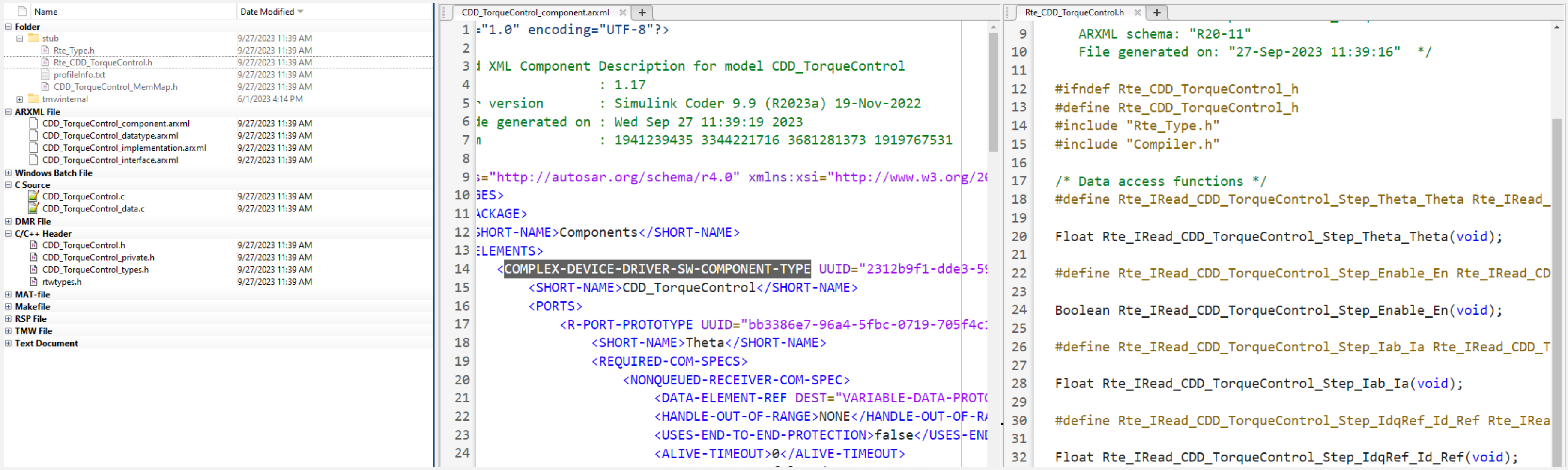
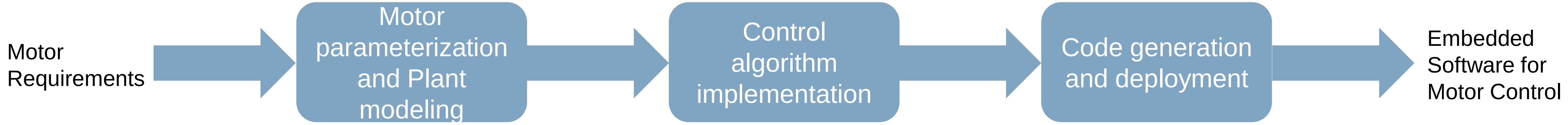


总结



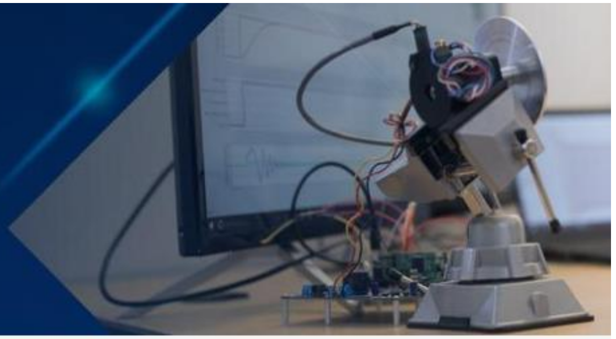
- ✓ 讨论了电机控制工作流程和每个步骤的参考示例
- ✓ 电机参数化的方法及不同的建模保真度
- ✓ 不同的控制策略及其控制环增益调整
- 部署到硬件并进行验证

了解更多

MATLAB and Simulink for Motor Drives and Traction Motors

Develop algorithms and embedded software for motor-inverter control systems

Free trial



How It Works

- Design motor control algorithms
- Test motor control algorithms
- Implement motor control algorithms on hardware

Simulate Motor Control Algorithms

Use MATLAB® and Simulink® to build motor models from libraries of motors, inverters, sources, and loads. Choose the level of fidelity in motor and inverter modeling based on your requirements and simulate motor control algorithms.

- Implement linear lumped-parameter motor models and use average value inverters with Motor Control Blockset™ for fast simulations
- Model and simulate nonlinear motor dynamics and ideal or detailed switching in the inverter using Power Systems Simulation Onramp
- Parametrize motor models to capture motor dynamics with the help of instrumented tests or import parameters from a database or finite element analysis

Motor Control Design with MATLAB and Simulink

MathWorks Videos

Suggest a video

Understanding Field-Oriented Control | Motor Control, Part 4

Reinforcement Learning for Developing Field-Oriented Control

Motor Control, Part 3: BLDC Speed Control Using PWM

» View all MathWorks videos

MATLAB 和 Simulink 咨询服务

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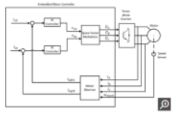
总览 | 已验证的解决方案 | 联系咨询服务

电机控制开发

电机仿真和控制是能源生产、汽车、航空航天、工业自动化等行业的一项重要技术。电机系统建模常用于优化逆变器和电机尺寸，开发复杂的控制算法（如磁场定向控制），以及分析系统配置和性能。复杂的电机控制技术可以使电机一直在所需的工作包线内运行，从而实现平稳的扭矩应用、精确的加速控制和更高的电机效率。为了实现电机控制器，必须基于电机和逆变器系统的详细且精确的被控对象模型开发控制算法。



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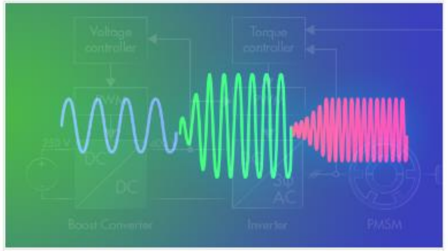
有问题吗？

» 联系咨询服务

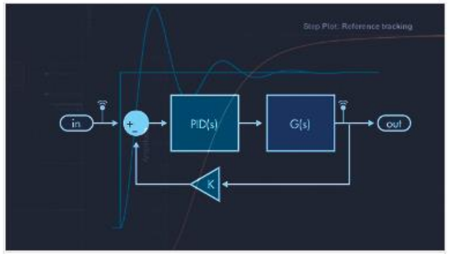
https://www.mathworks.com/solutions/electrification/motor-drives-traction-motors.html

让您的团队能够开发电机控制



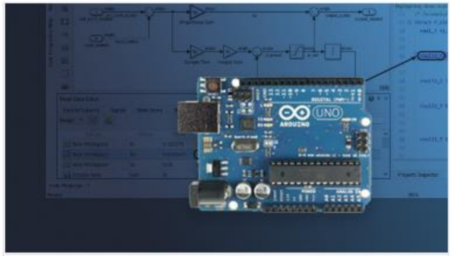
Power Electronics Control Design with Simulink and Simscape

Learn to model power electronic systems in the Simulink environment using Simscape Electrical™ and to design control with Simulink Control Design.



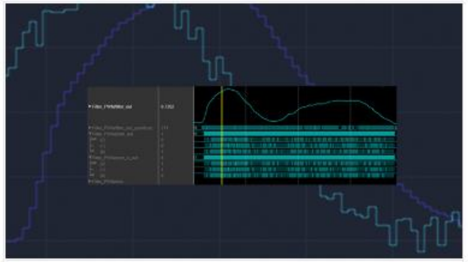
Control System Design with MATLAB and Simulink

Learn to design and model control systems with Simulink. Topics include system identification, parameter estimation, control system analysis, and response optimization.



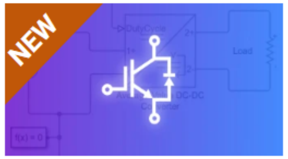
Embedded Coder for Production Code Generation

Develop Simulink models for deployment in embedded systems. Topics include code structure and execution, code generation options and optimizations, and deploying code to target hardware.



Generating HDL Code from Simulink

Learn to prepare Simulink models for HDL code generation, generate HDL code and testbench for a compatible Simulink model, and perform speed and area optimizations.



Power Electronics Simulation Onramp

5 modules | 1 hour | Languages

Learn the basics of simulating power electronics converters in Simscape.

Circuit Simulation Onramp

7 modules | 2 hours | Languages

Learn the basics of simulating electrical circuits in Simscape.

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MATLAB EXPO

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