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North America

Rapid System-Level Analysis and Control Design for EV Thermal Management Systems

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Overview

- Motivation
- Model Overview
- System Level, High Speed
  - Defining requirements
  - DC-DC Converter cooling case study
- High Fidelity, High Accuracy
  - Geometric parametrization
  - Validation and correlation
- Conclusion

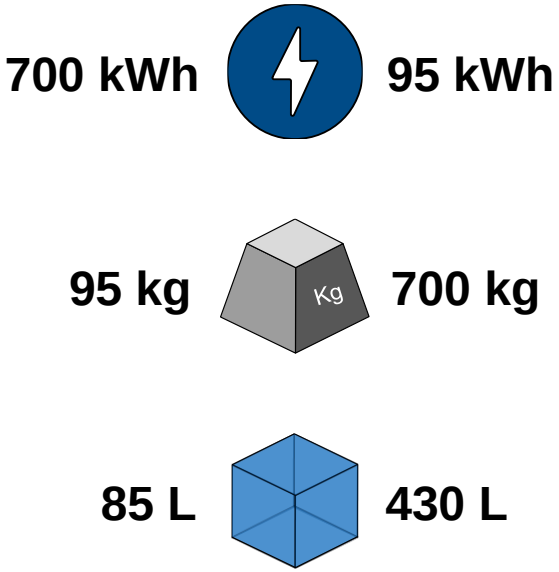
Consumer Demands

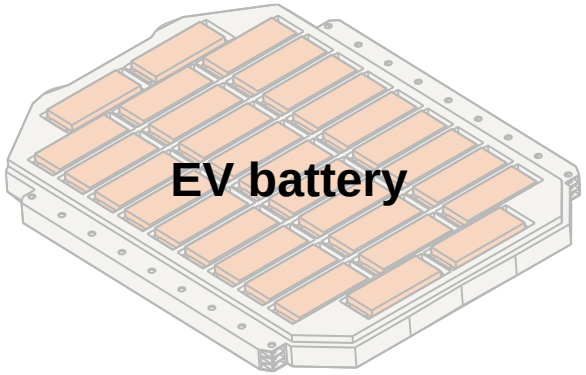
- Wide variety of options
- Range anxiety
- Comfort
- Reliability

Engineering Challenges

- Time-to-market
- Model refreshes
- Energy efficiency
- Weight reduction
- Calibration effort
- Costs
- Thermal management

Fuel tank

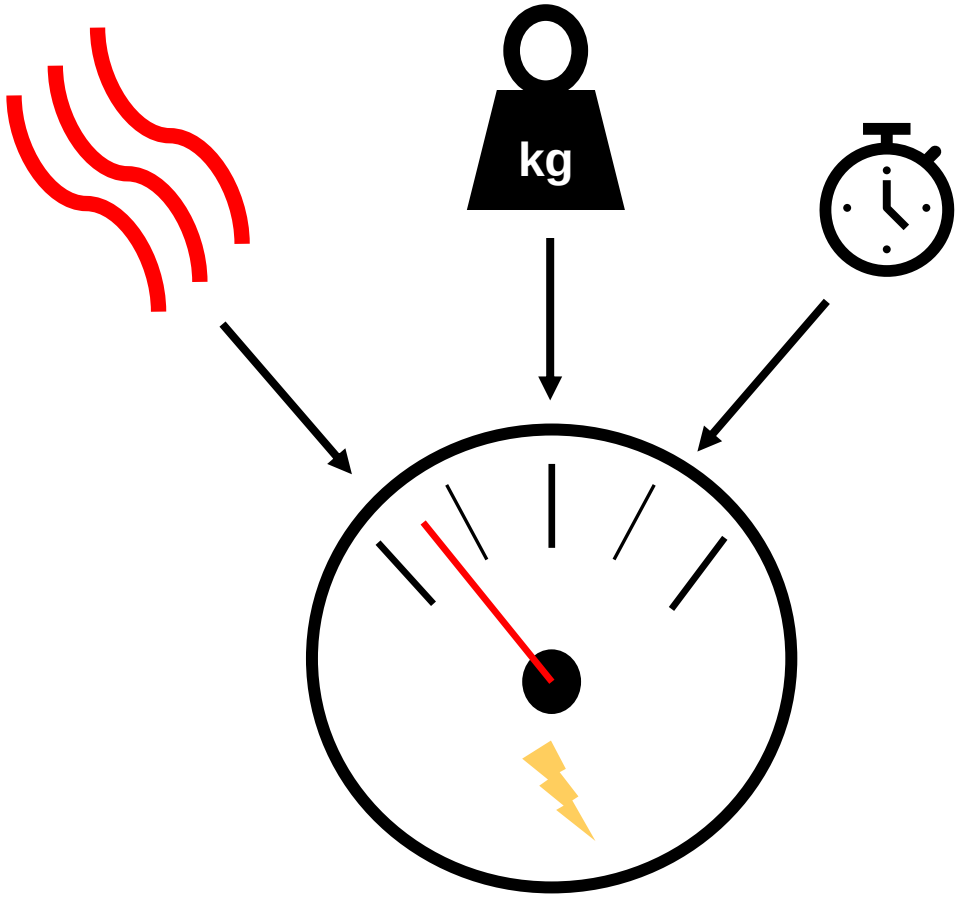




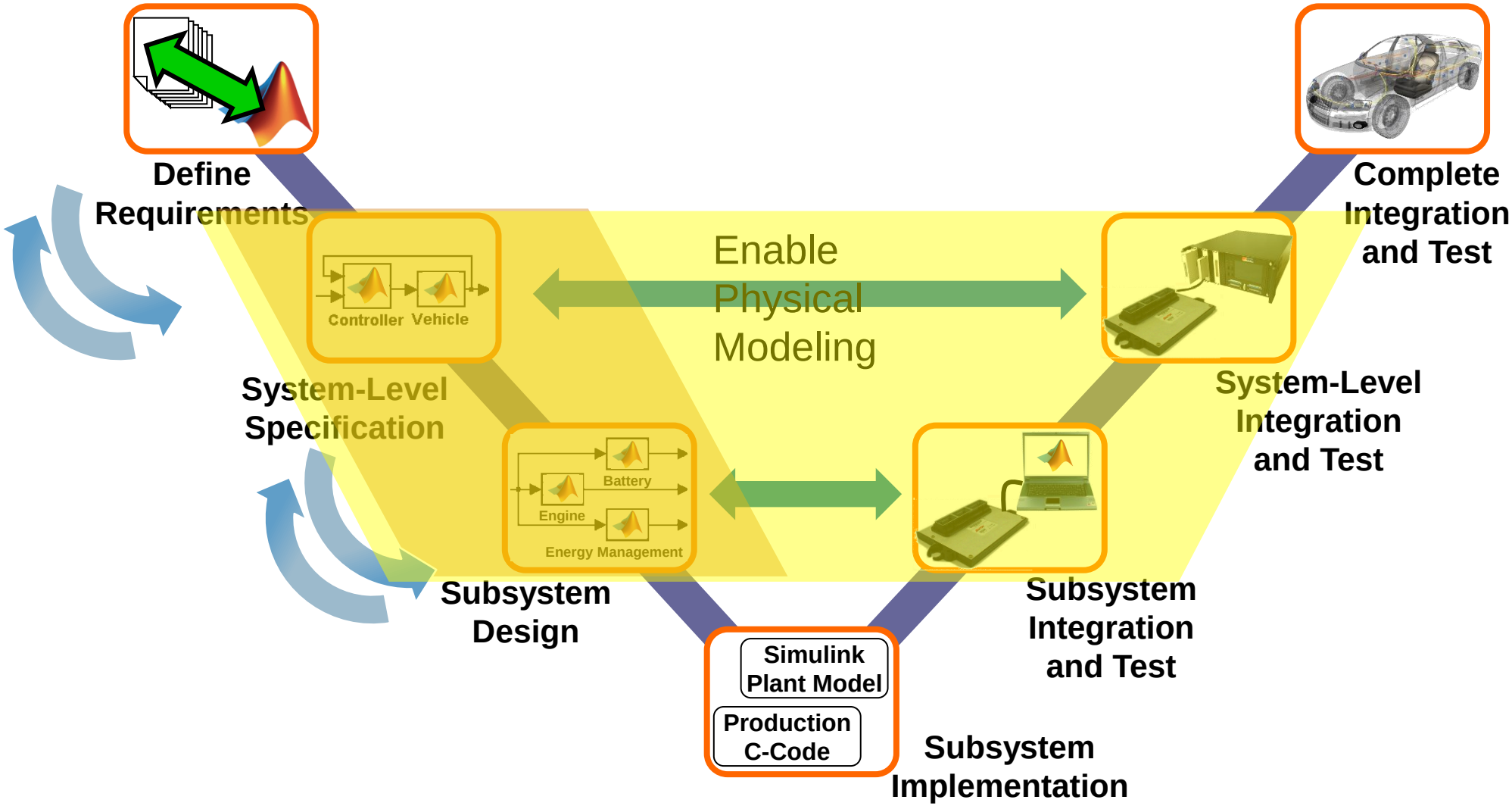
EV battery

Big Problems

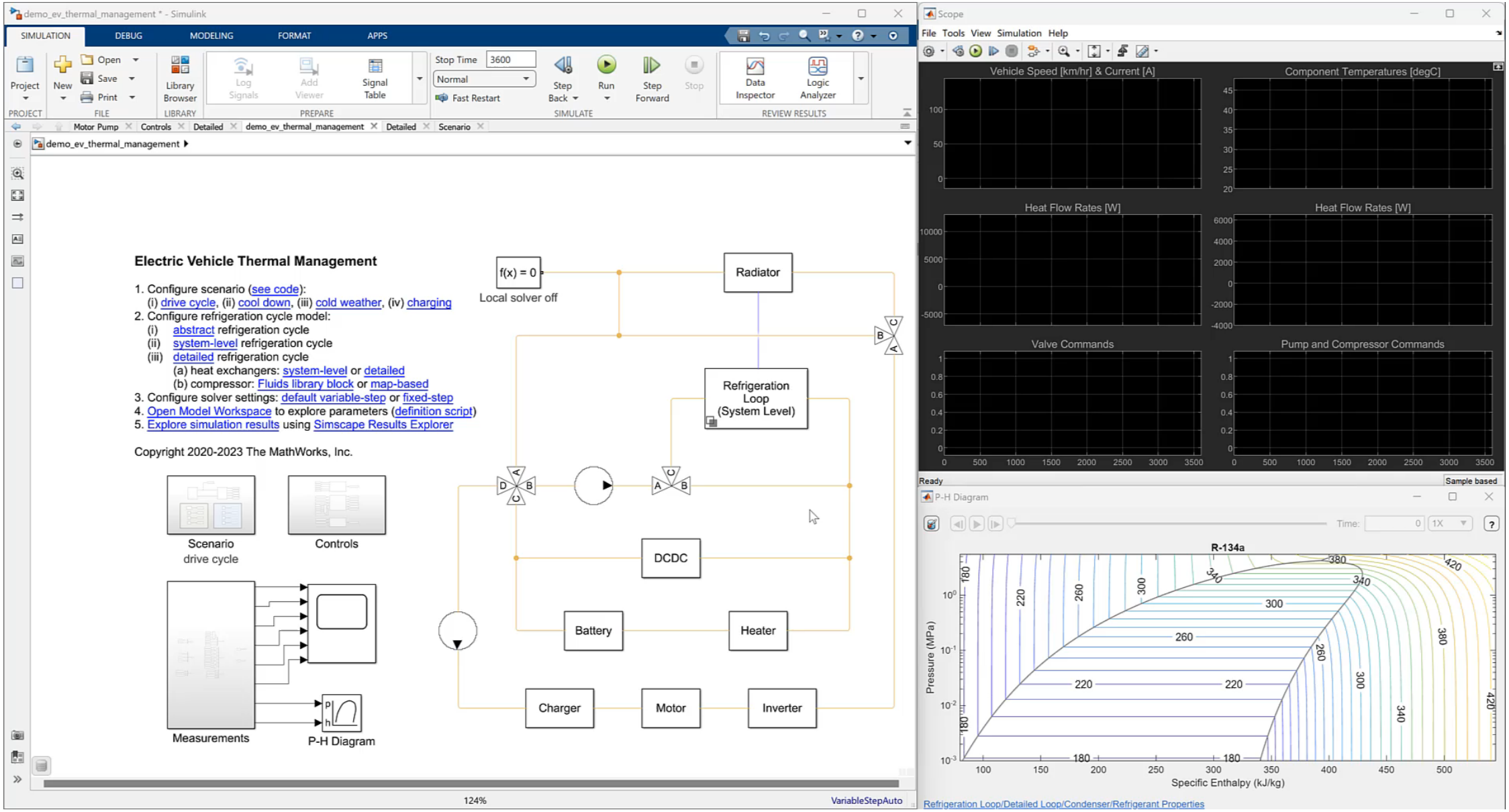
- Every bit of energy wasted reduces range
- Improperly sized components can add weight or waste energy
- Overly complex solutions maybe actually reduce efficiency if program timing is unable to support calibration
- Analysis becomes extremely important to predict issues



Model-Based Design Workflow



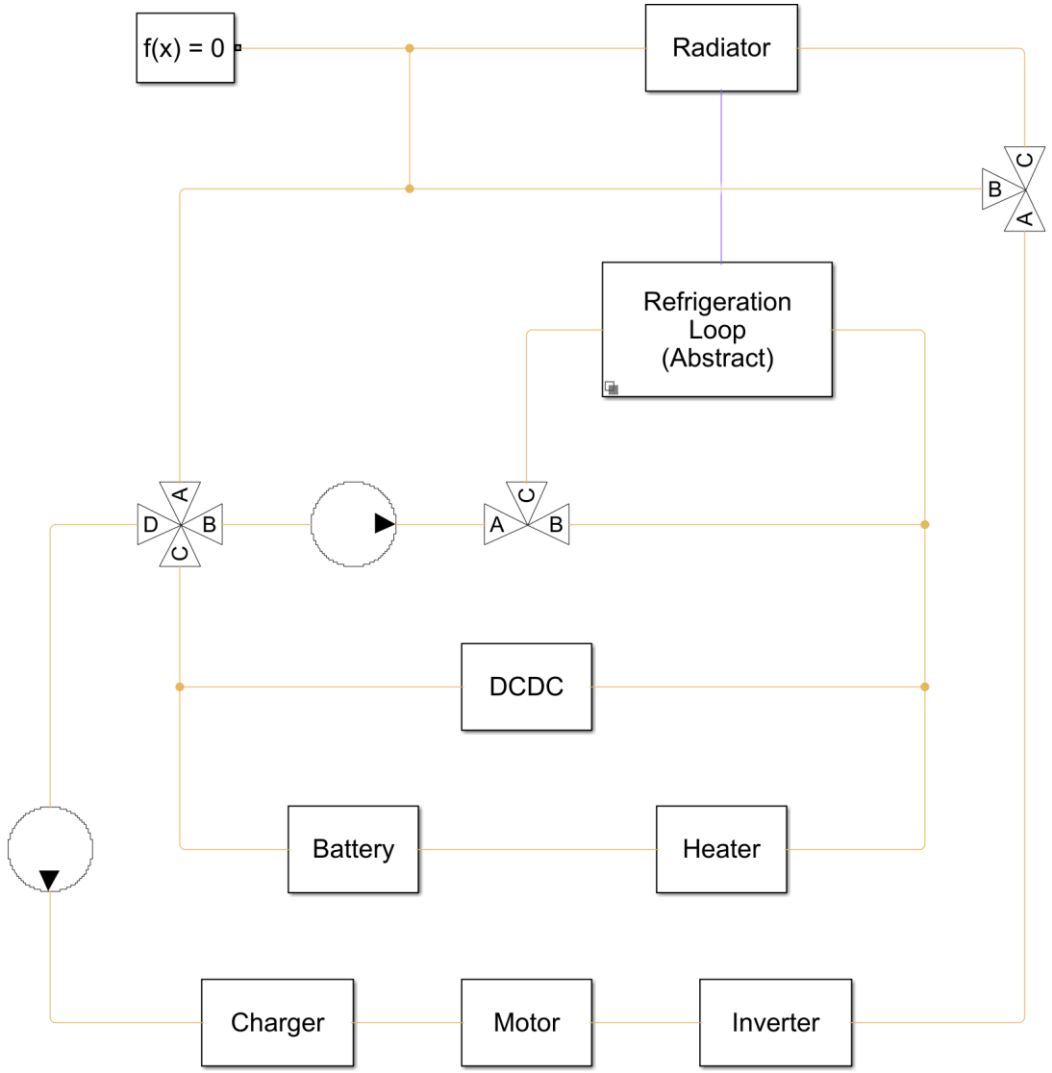
Thermal Management System Simulation in Simscape



Model Overview

Top View of Model

- Model represents a standard electric vehicle
- Each component is masked under its own block
- Provides quick glance of flow paths



Model Overview

Programmatic configuration of model

- Hyperlinks allow for selection of model settings
- Able to set various drive modes
- Selectable refrigeration methods varying from simple to complex

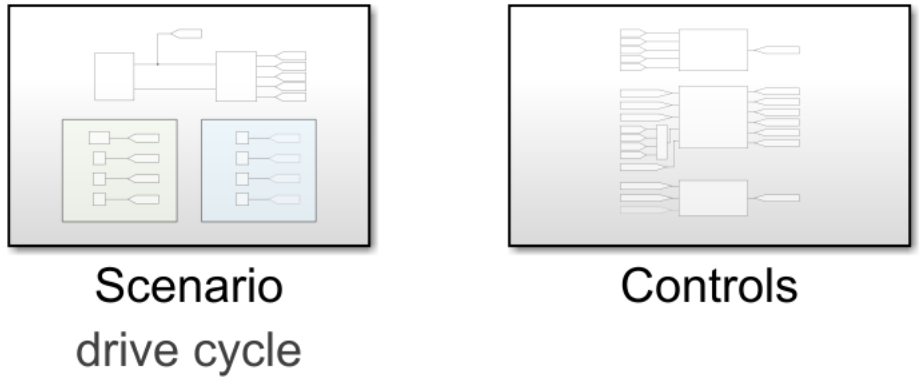
Electric Vehicle Thermal Management

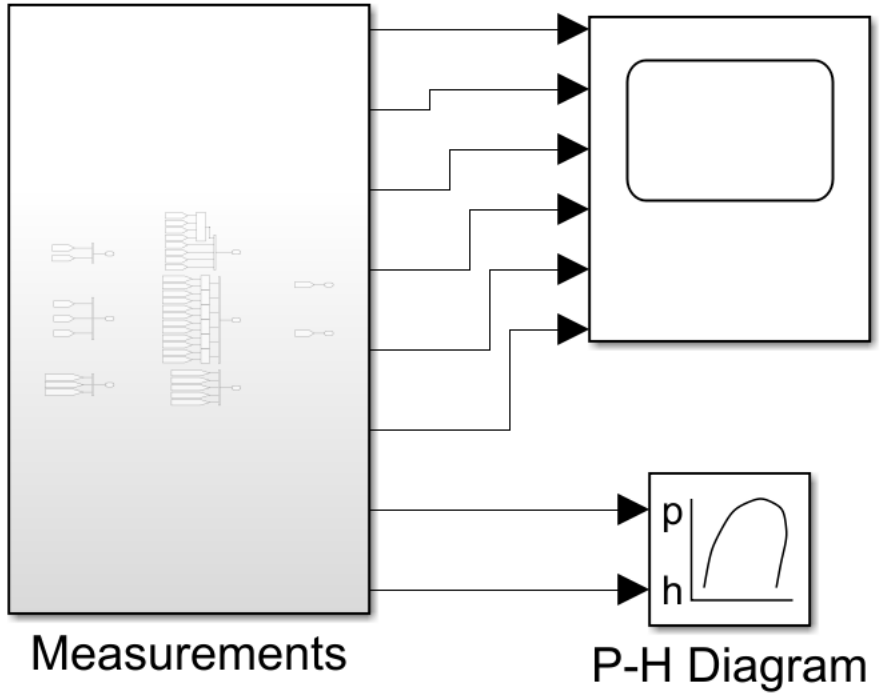
1. Configure scenario (see code):
   (i) drive cycle, (ii) cool down, (iii) cold weather, (iv) charging
2. Configure refrigeration cycle model:
   (i) abstract refrigeration cycle
   (ii) system-level refrigeration cycle
   (iii) detailed refrigeration cycle
      (a) heat exchangers: system-level or detailed
      (b) compressor: Fluids library block or map-based
4. Open Model Workspace to explore parameters (definition script)
5. Explore simulation results using Simscape Results Explorer

Model Overview

Inputs/Outputs

- Scenario defines the drive cycle and environmental conditions
- Controls provides a simple strategy all in one location
- Measurements and P-H Diagram show results





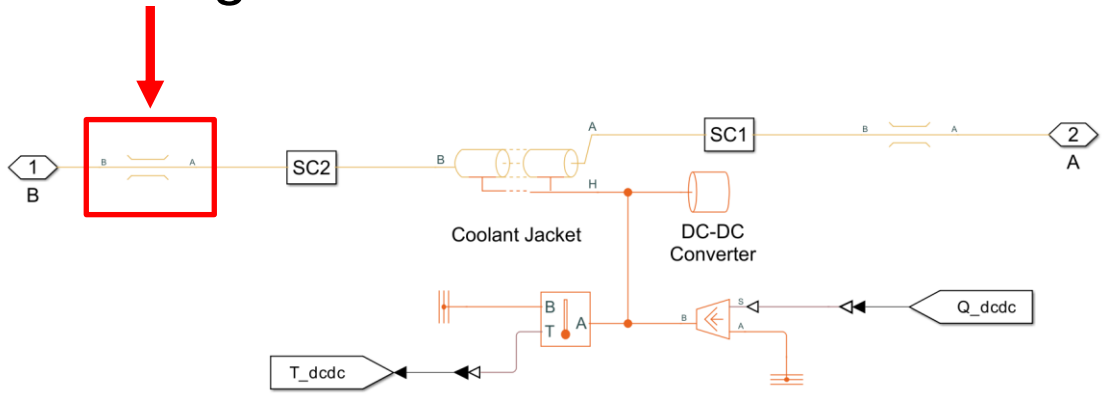
System Level Components: Component Requirements

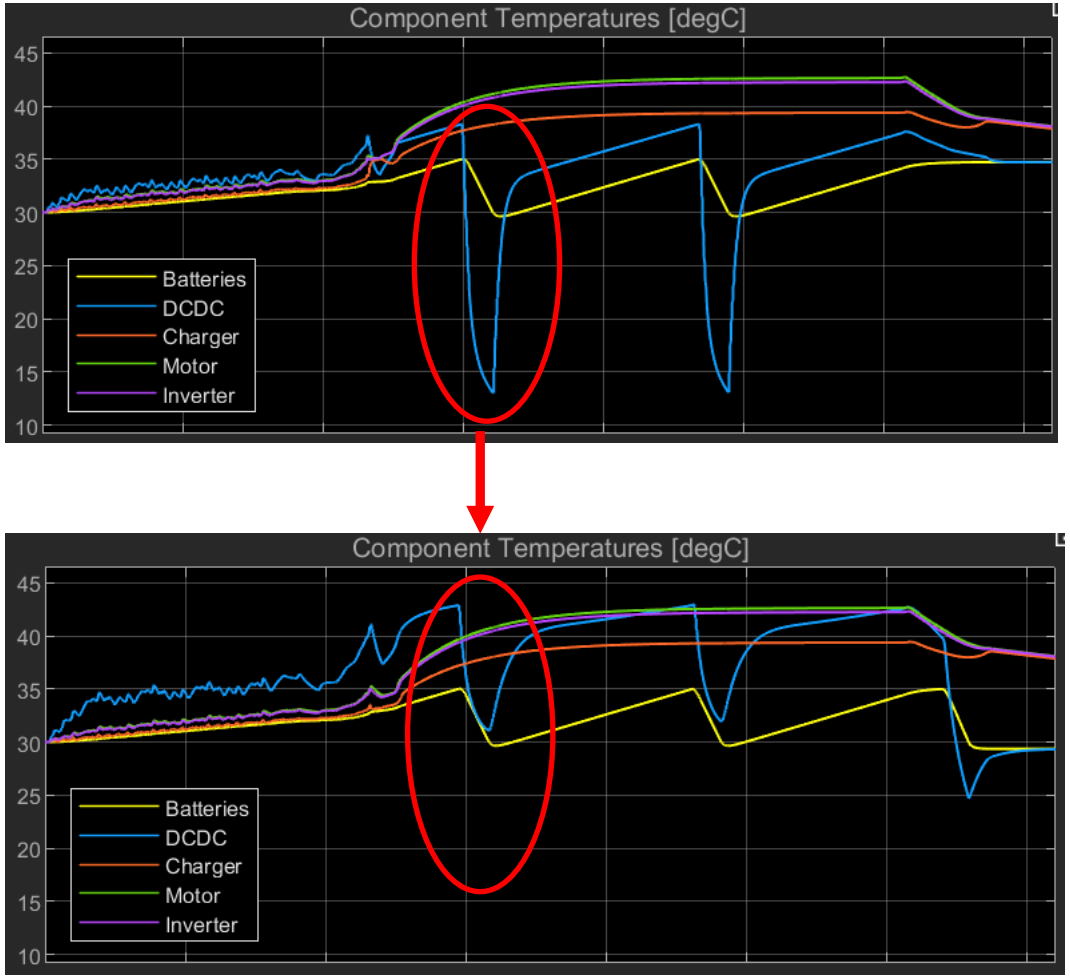
- Test various architectures without knowing specific components
- Determine if heat redistribution is beneficial
- Optimize number of components to reduce calibration time later in product development

Component Requirements: DC-DC Cooling Case study

Restrictor sizing

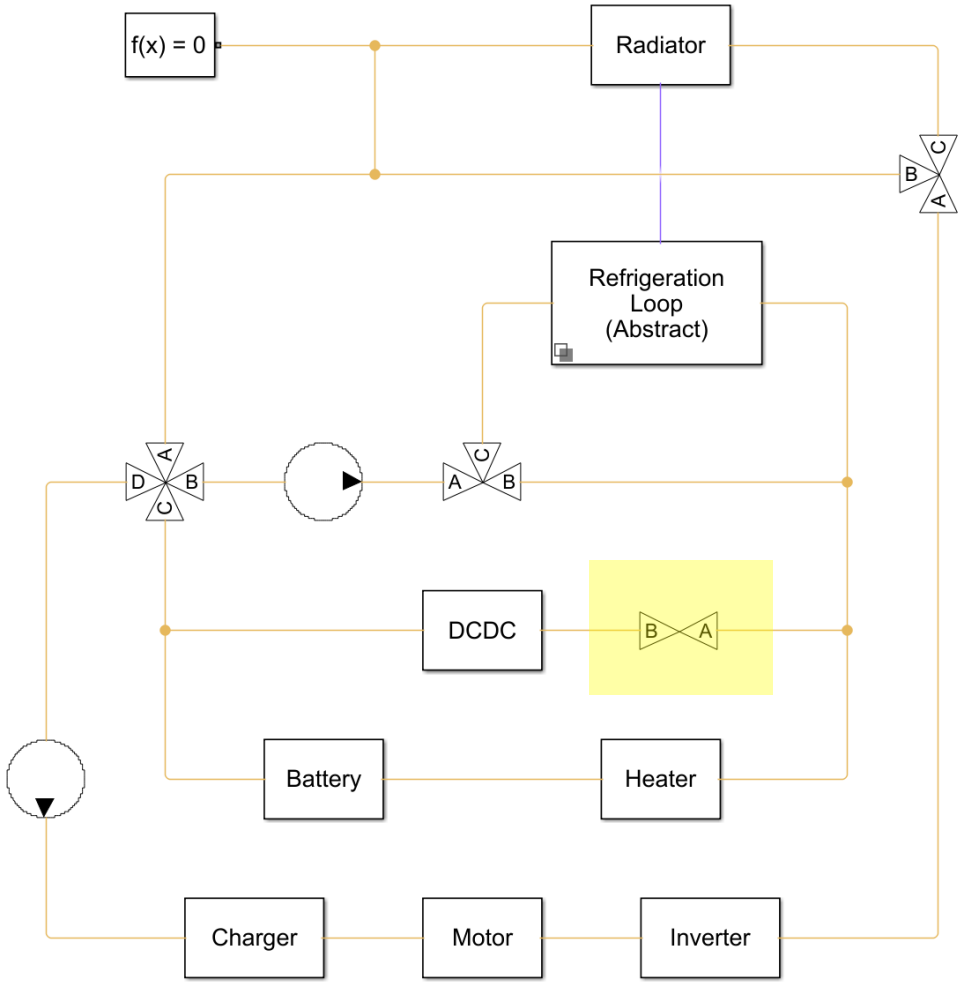
- Define temperature requirements
- Quickly iterate through flow restrictions on drive cycles with Simulink Test
- Convert flow restriction to restrictor sizing





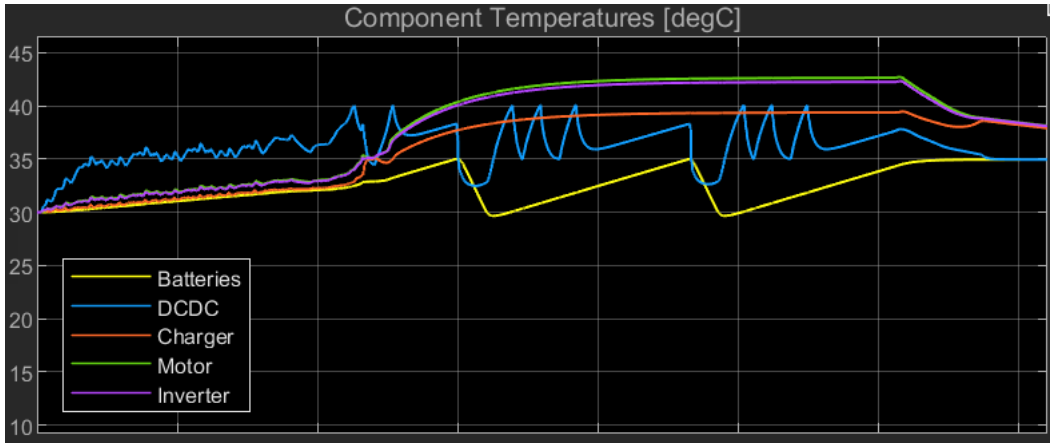
Component Requirements: DC-DC Cooling Case study

- Investigate adding additional valves
- Determine valve type
- Define requirements for controller

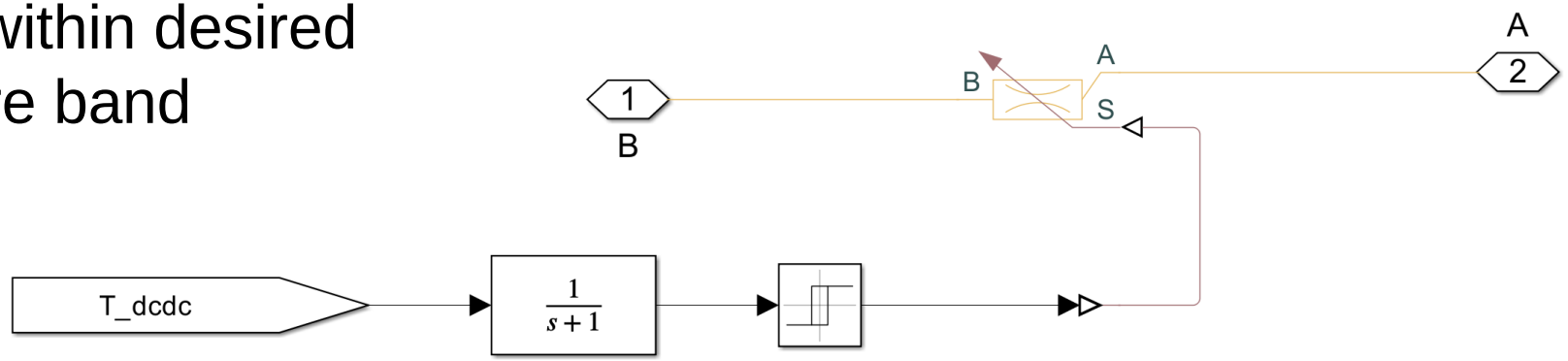


Component Requirements: DC-DC Cooling Case study

Solenoid valve



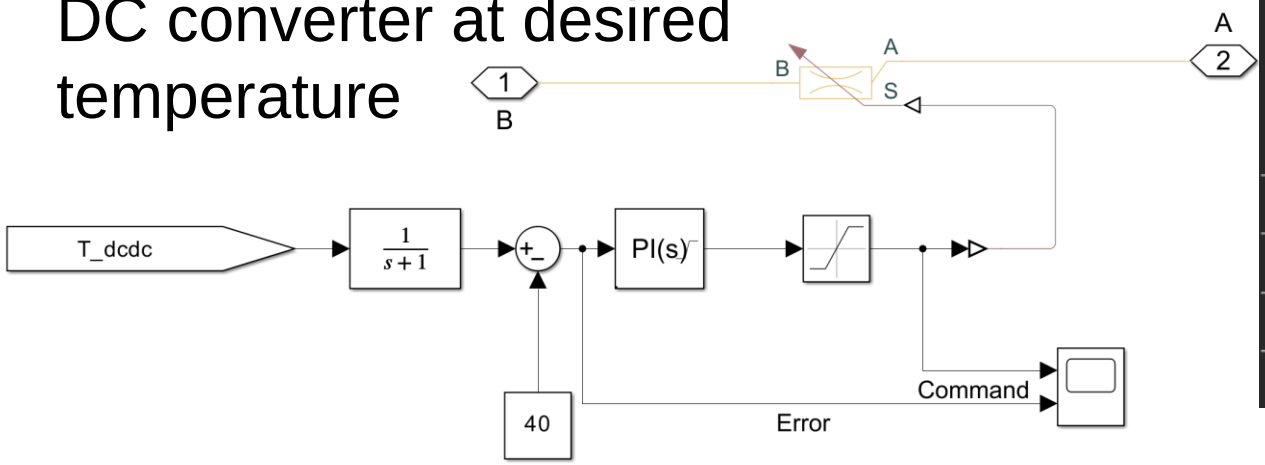
- Simple valve only requires single pin for controller
- Thermostatic control used in this model
- Able to easily keep DC-DC converter within desired temperature band

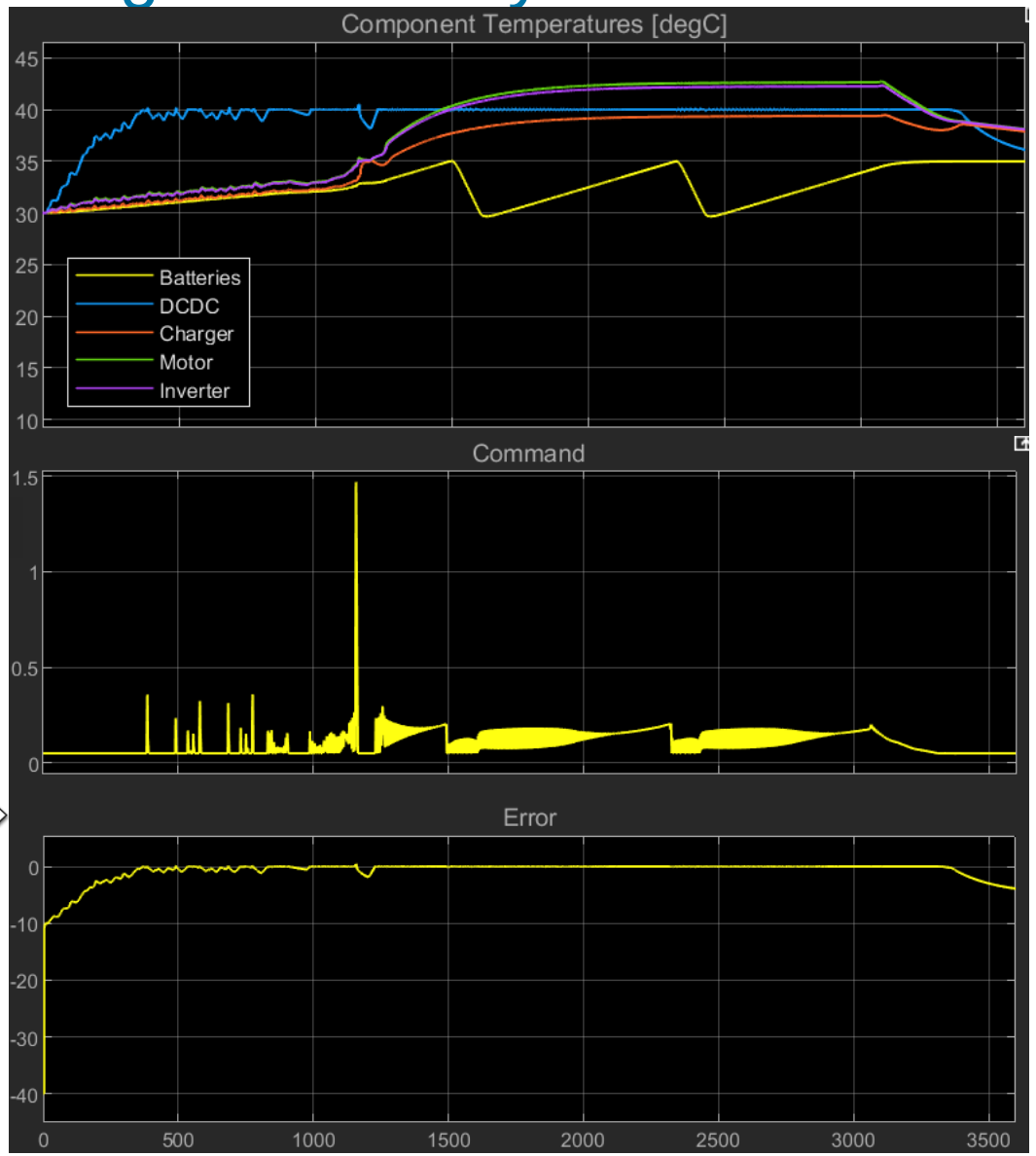


Component Requirements: DC-DC Cooling Case study

Proportional valve

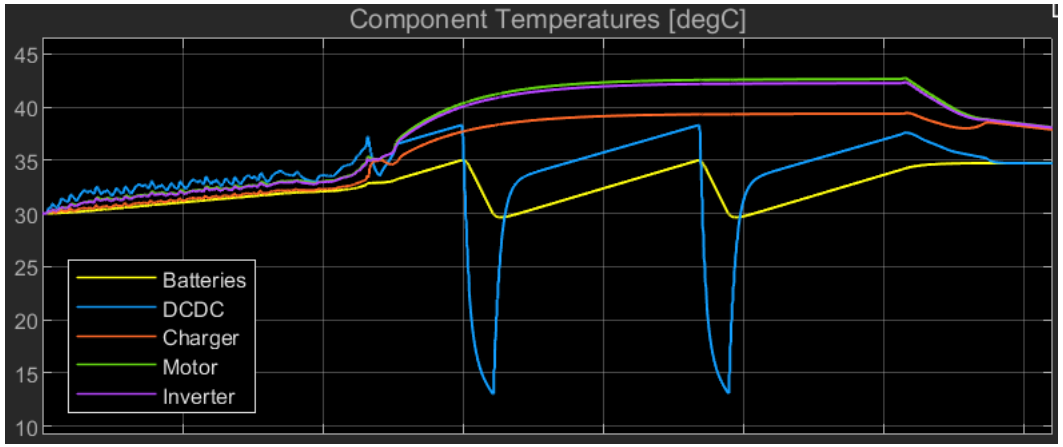
- More complex valve and controller requirements
- PI controller used as controller
- Able to very accurately keep DC-DC converter at desired temperature



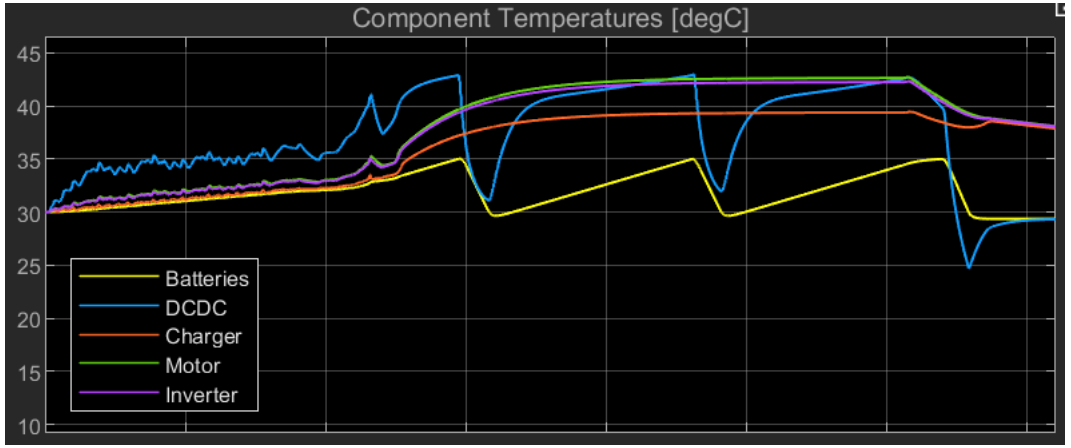


Component Requirements: DC-DC Cooling Case Study Results

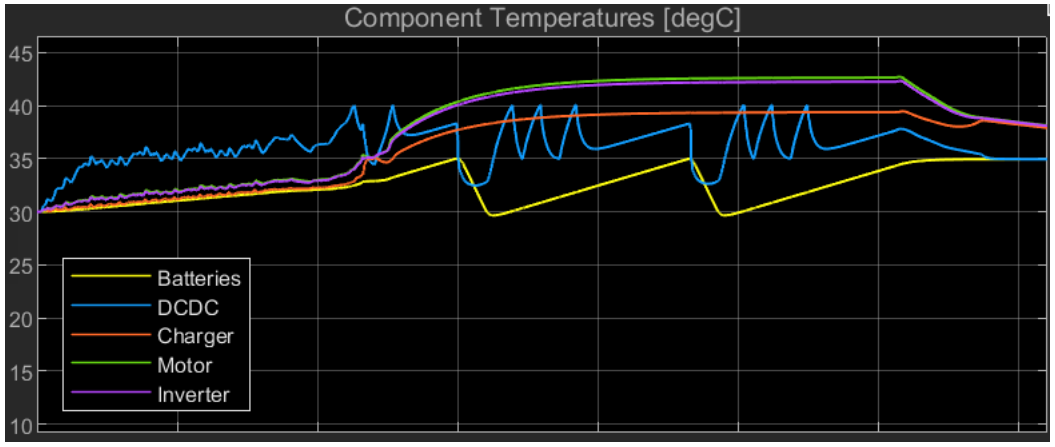
Baseline



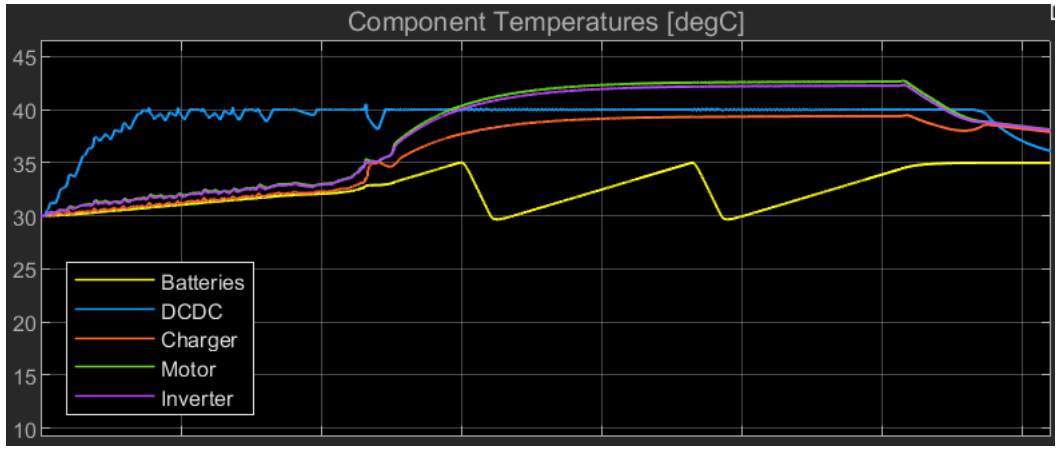
Optimized Restrictor



Solenoid Valve

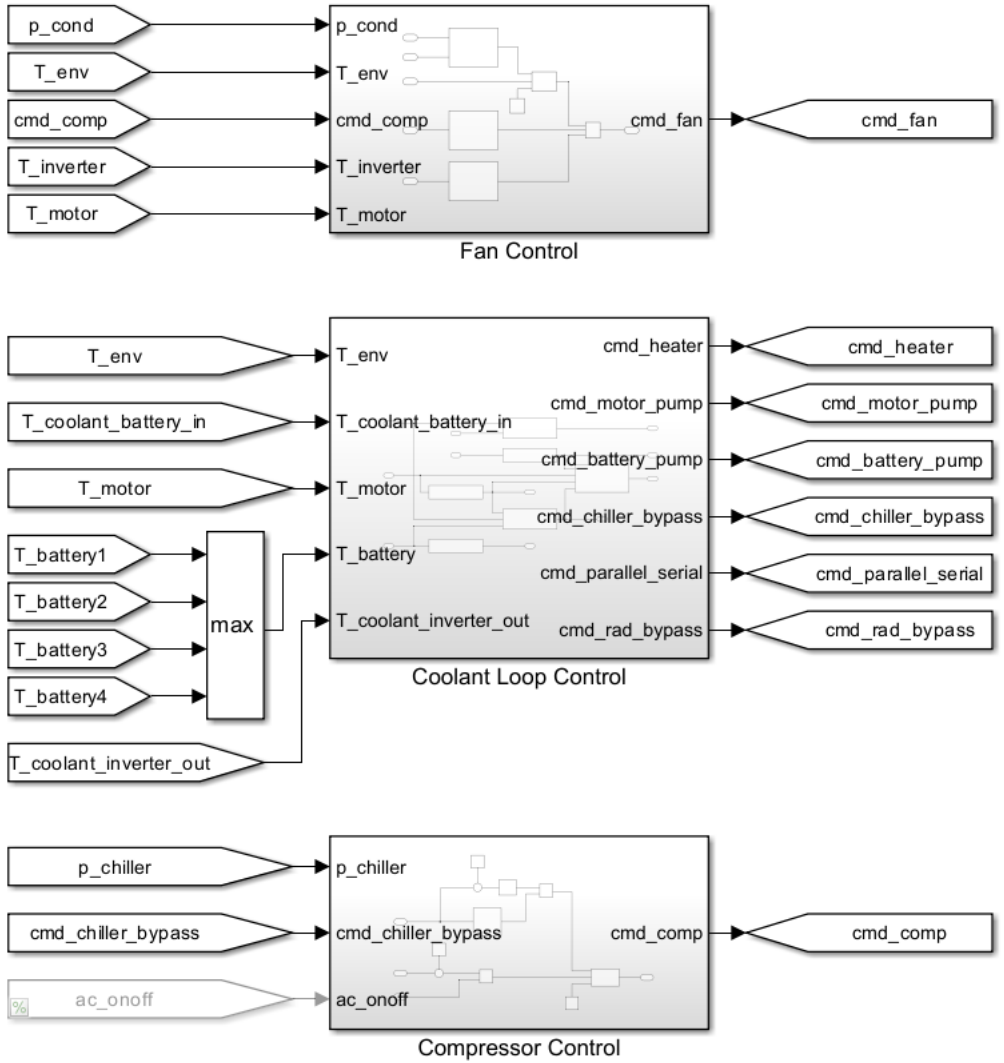


Proportional Valve



System Level Components: Control System Design

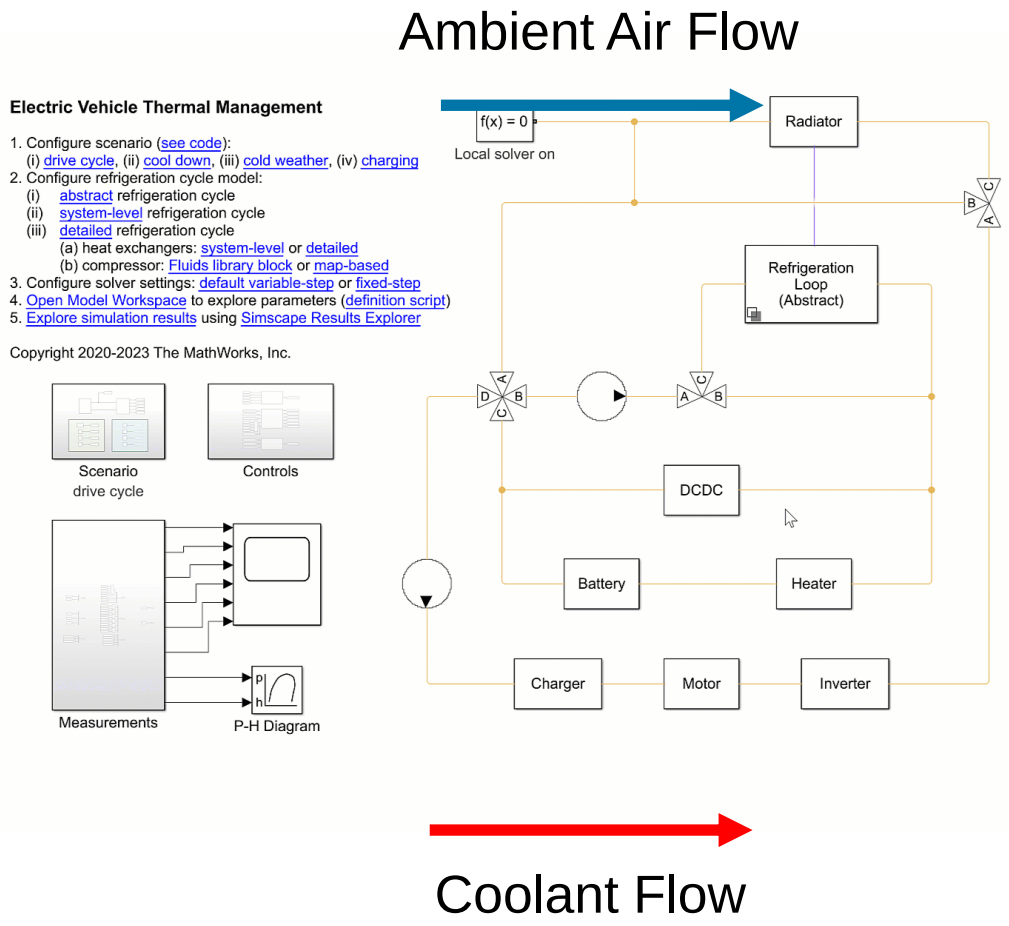
- Advanced controls can test various architectures around system level model
- Production can begin to define requirements and develop code before hardware is available
- Feeds into HiL testing years earlier



System Level Components: Capacity Requirements

Abstract refrigeration cycle

- Simple model that avoids need for two-phase modeling
- Coefficient-of-Performance (COP) table can be estimated o built using empirical data
- Offers opportunity to use data driven approach to avoid complicated modeling and parametrization effort

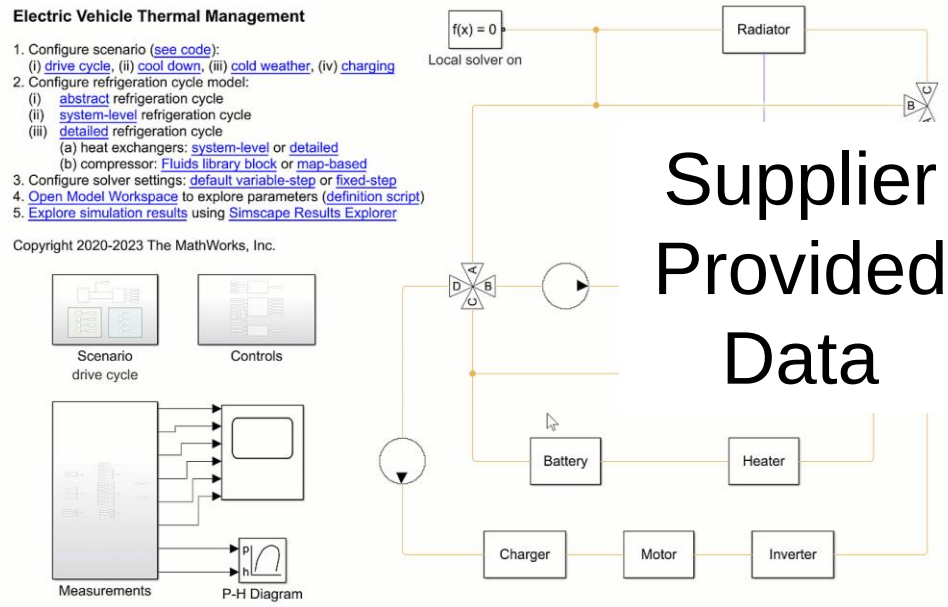


System Level Components: Capacity Requirements

System-level refrigeration cycle

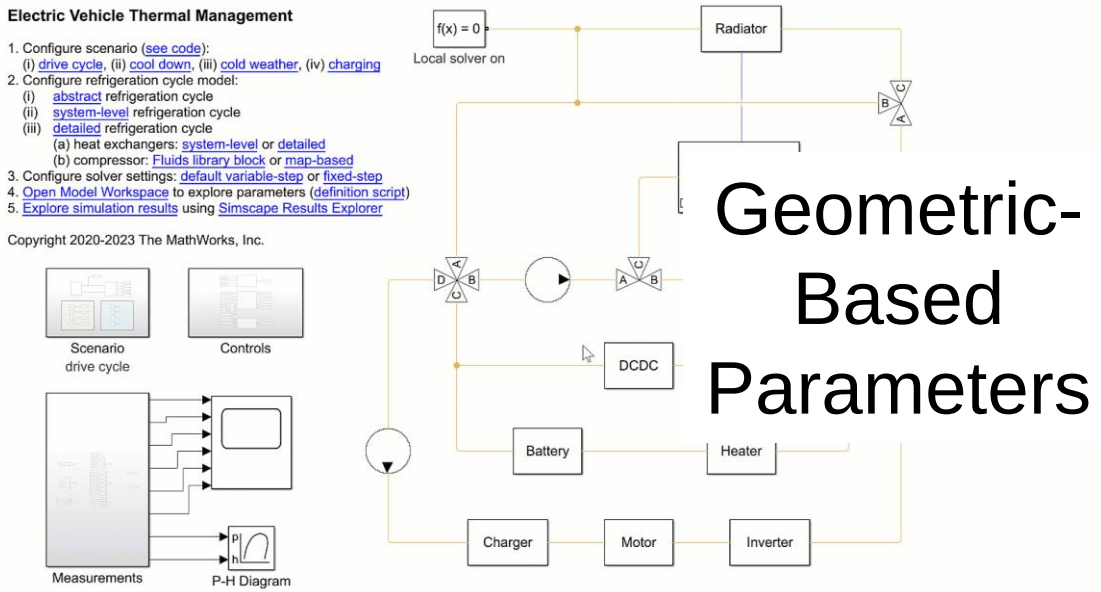
New R2023a block

- Able to simulate various drive cycles to determine heat rejection requirements
- Determine type of cooling system to meet requirements
- Define high-level vehicle specifications



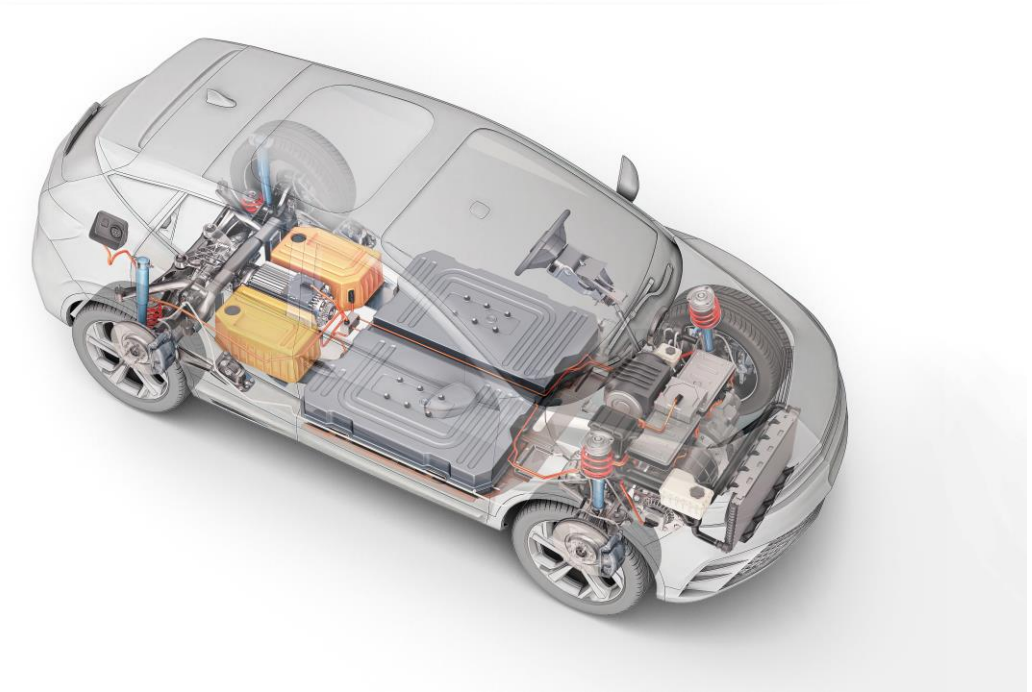
High Fidelity: Geometric Parametrization

- Model can be handed off to various teams responsible for each component
- High fidelity model can be run on each component individually or as a system
- Define exact geometry to see real-world results and deliver requirements to suppliers



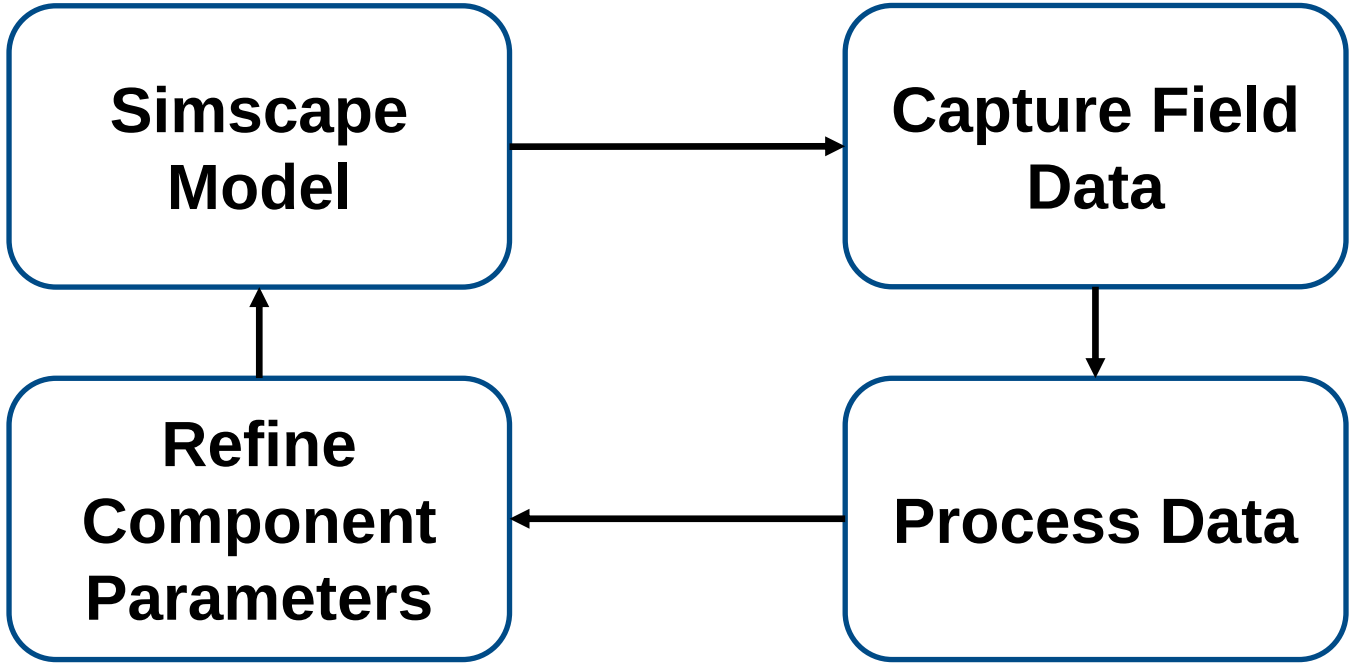
High Fidelity: Packaging Study

- Since geometry can be defined, packaging can be optimized earlier in vehicle design
- Maximum capacity can be easily calculated for existing packaging limitations



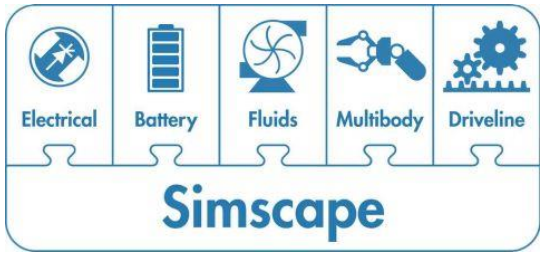
High Fidelity: Lifecycle Cost Savings

- As model years increment, can use real world data to correlate model with Parameter Estimator
- Model can then be used to optimize components to reduce costs and complexities

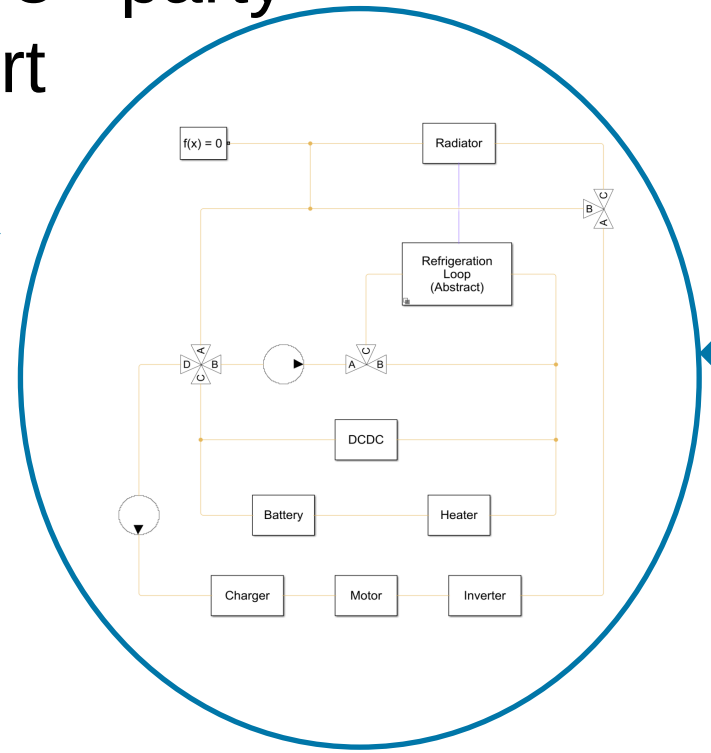


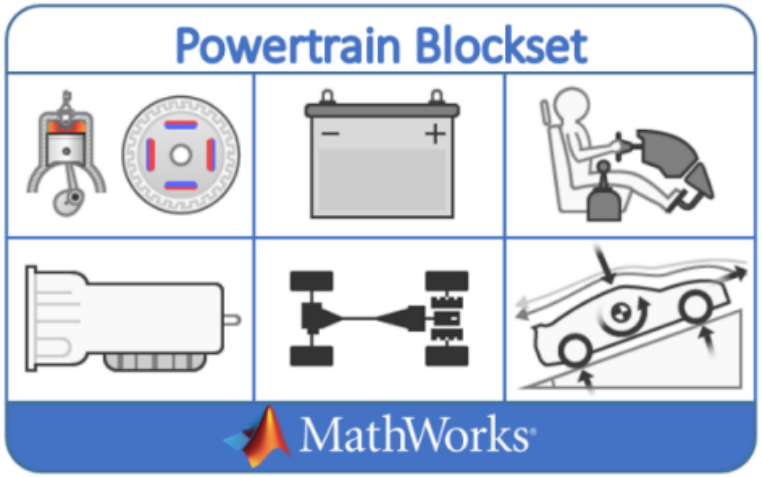
System Level Components: Co-Simulation

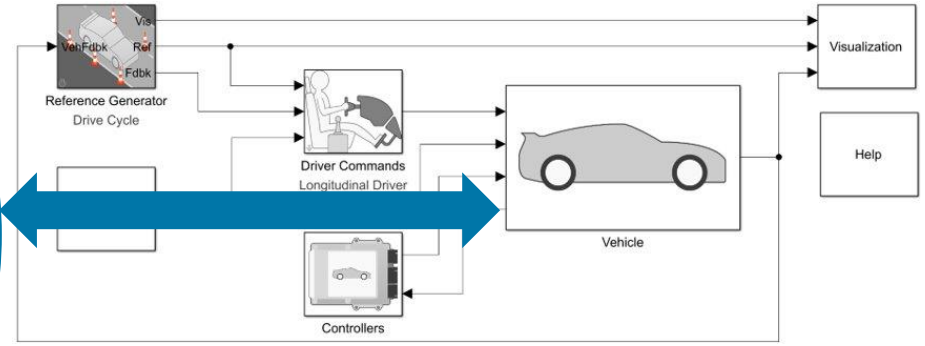
- Use existing Simscape or PTBS model to feed into cooling system
- Able to integrate with 3rd party models, if they support



3rd Party
S-functions
FMU/FMI





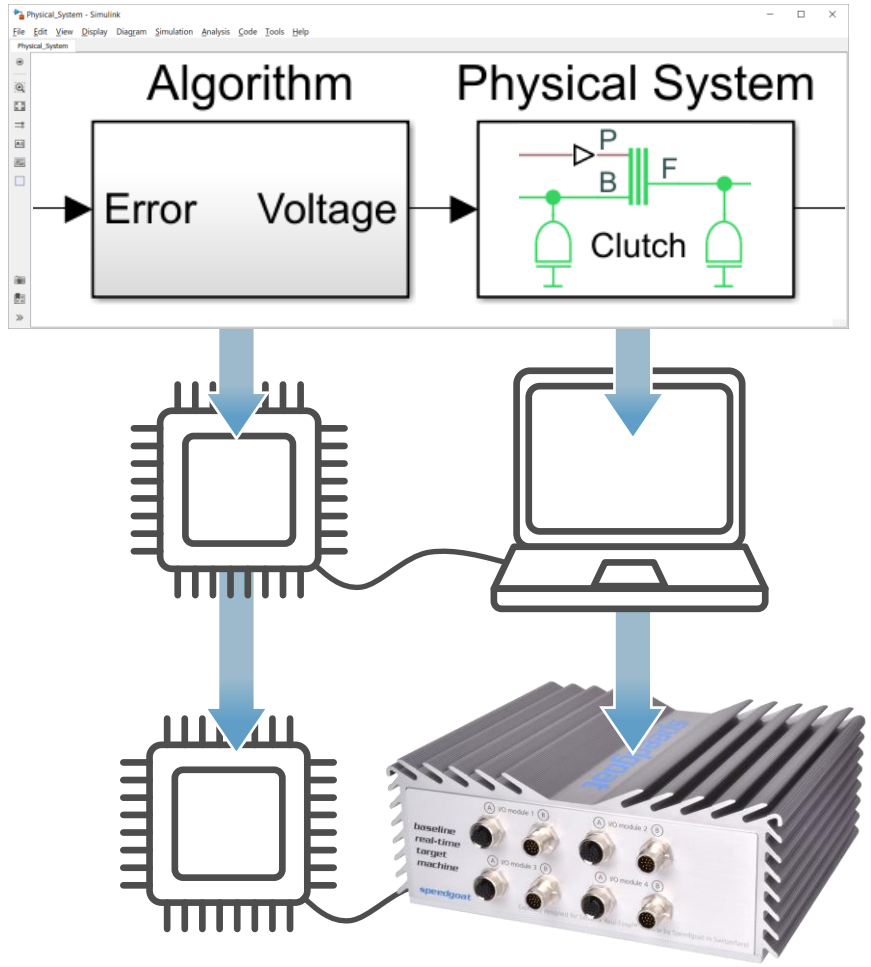


HiL: Simscape Model Directly Deployed

- Model is real-time capable
- Solver modifications are required (fixed-step, fixed-cost)
- Able to run model on real-time hardware

Processor-in-the-Loop (PIL)

Hardware-in-the-Loop (HIL)



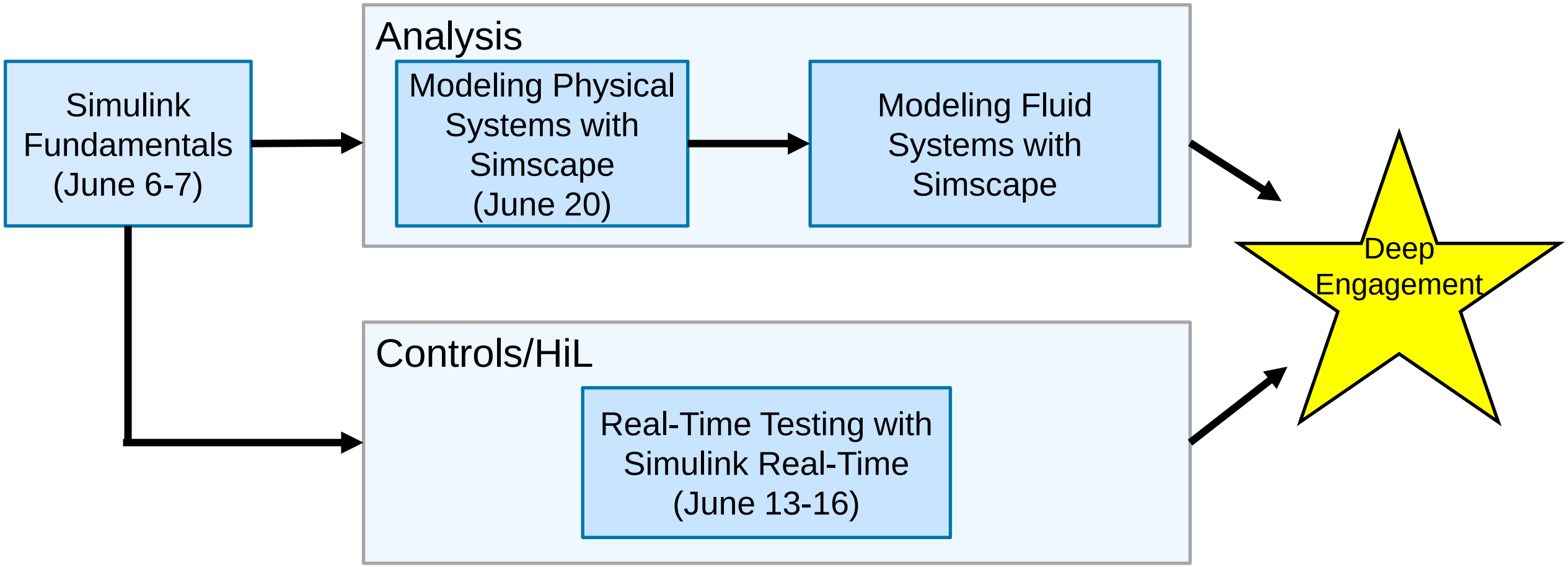
Conclusions

- Simscape provides a flexible model workflow
- Enables designing a top-down architecture
- Facilitates early design trade-off and analysis
- Allows for various fidelity levels for individual components
- Enables earlier and rapid design and testing for controls teams

Next Steps

- Contact us for model
- Try various scenarios
- Modify components to fit your needs
- Reach out to MathWorks sales representative or application engineer to set up a discussion or deep engagement

Training


Simulink Fundamentals (June 6-7)
Analysis
Modeling Physical Systems with Simscape (June 20)
Modeling Fluid Systems with Simscape
Controls/HiL
Real-Time Testing with Simulink Real-Time (June 13-16)
Deep Engagement

MathWorks Consulting Services Can Support You

Model Architecture

Model assessment
Simulation performance
Interface standardization
…

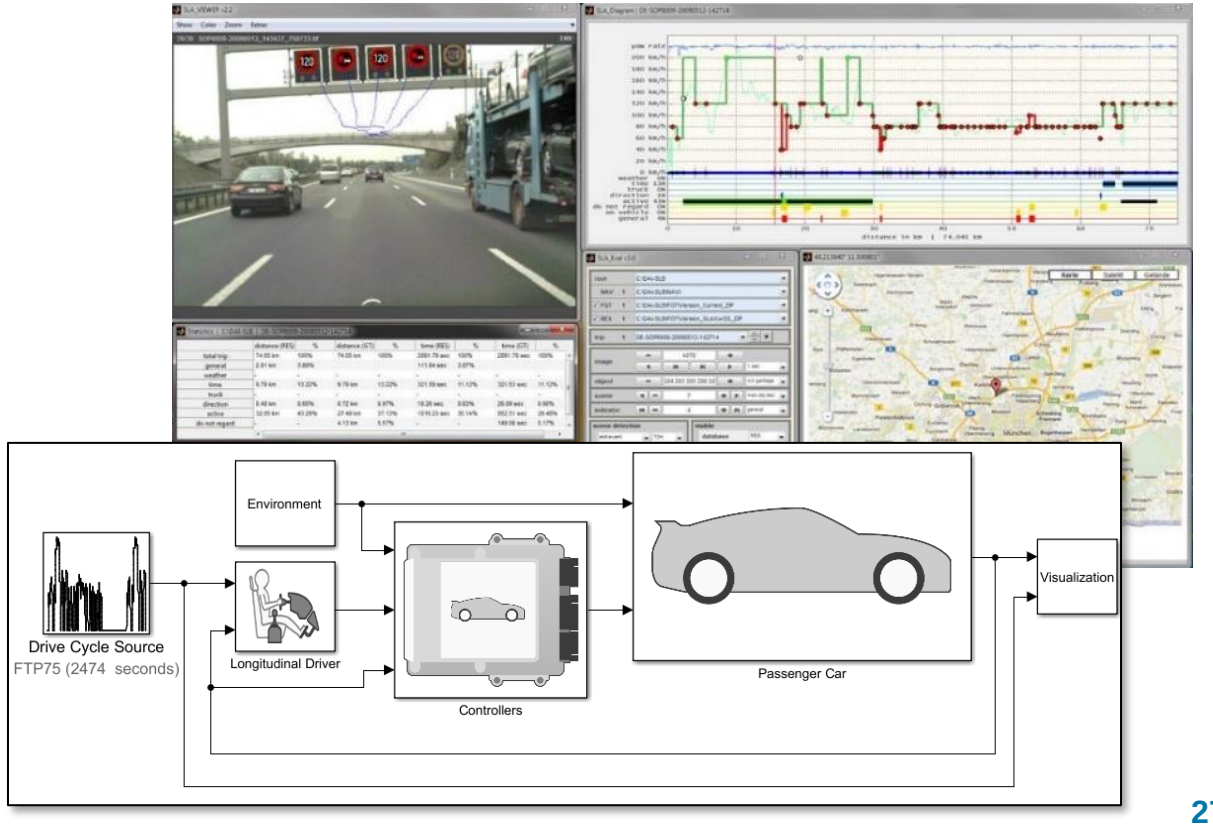
Construction

Build process automation
Database/Repo interface
Model-Building know-how
…

User Experience

GUI driven workflow
Tool compatibility support
Artifact creation
…

- Provide expert-level guidance
- Automate workflows
- Develop custom UI's



Learn more:
[MathWorks Consulting Services]

Additional Resources

- Overview of MathWorks' automotive solutions:
  - MATLAB and Simulink for Electric Vehicle Development
  - Building Your Virtual Vehicle with Simulink
  - Upskill for the Electric Vehicle Transition

- Products highlighted in this study:
  - Simscape Fluids
  - Simscape Battery
  - Simulink Design Optimization

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Thank you