EV Component Development Using Virtualization and Scaling to Cloud

Abhisek Roy
Senior Application Engineer

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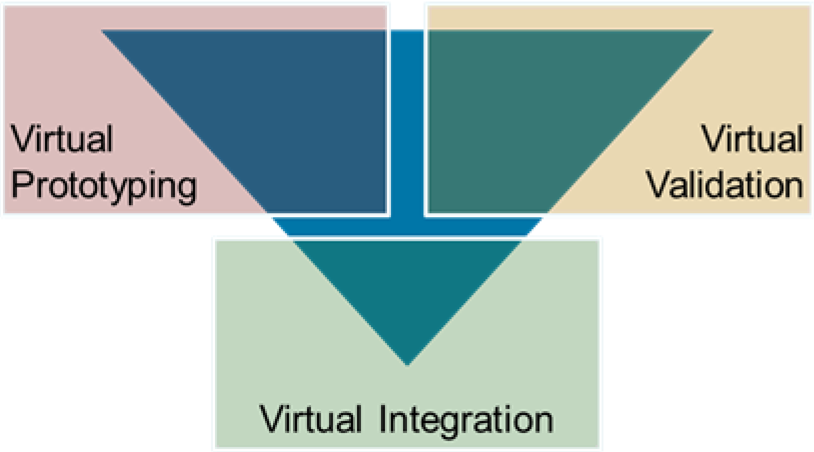
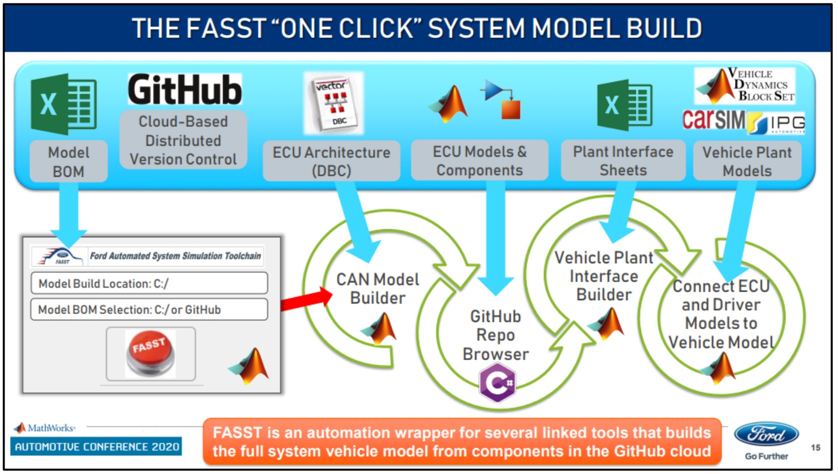
Application Engineer

MathWorks

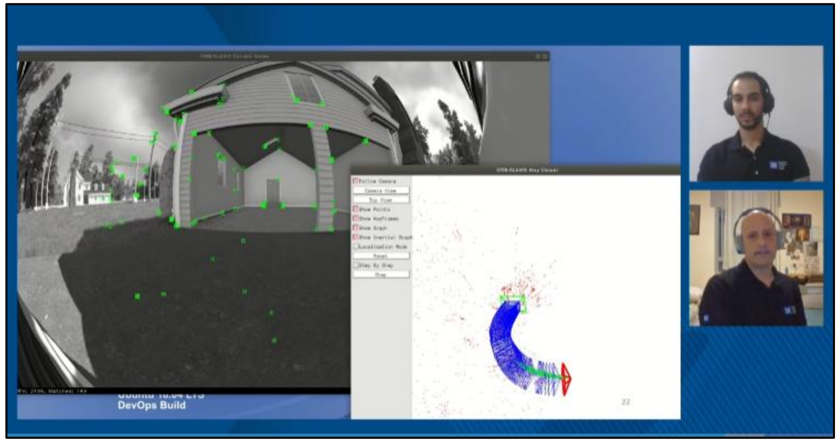
Virtual Vehicle Development is Growing in Complexity

- Companies are deepening virtual development
  - Increasing reliance on system-level simulation for development
  - Reducing scope of physical prototypes towards confirmation and final validation
  - Focus on powertrain, vehicle dynamics and ADAS / AD

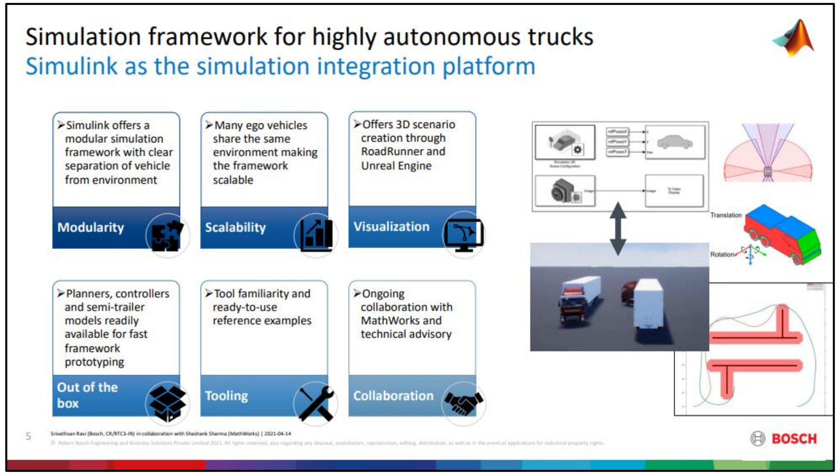




[Ford: Build Virtual Vehicle in minutes]



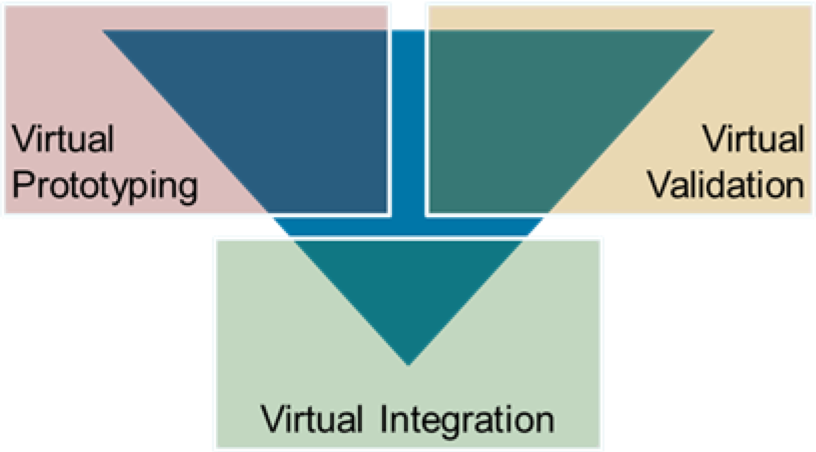
[GM: Autonomous parking development]



[Bosch: Autonomous truck development]

Virtual Vehicle Development is Growing in Complexity

- Companies are deepening virtual development
  - Increasing reliance on system-level simulation for development
  - Reducing scope of physical prototypes towards confirmation and final validation
  - Focus on powertrain, vehicle dynamics and ADAS / AD
- Common challenges



Access to “right level” **fidelity** models across organization

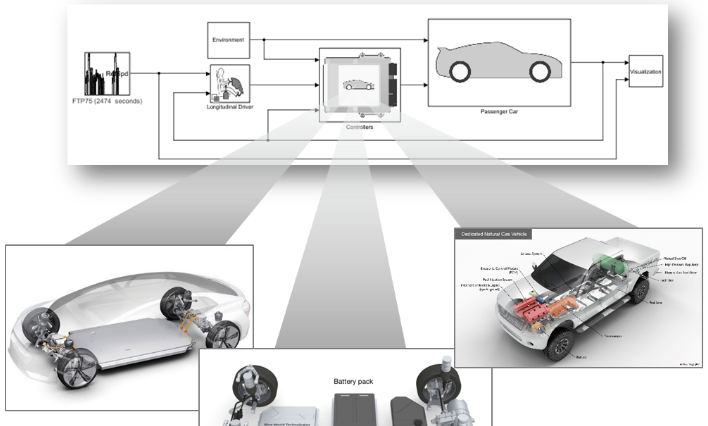
Integration of both **physics** and **software** models

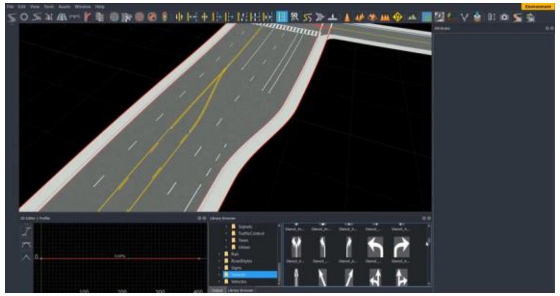
Deploying models to users who **aren’t tool experts**

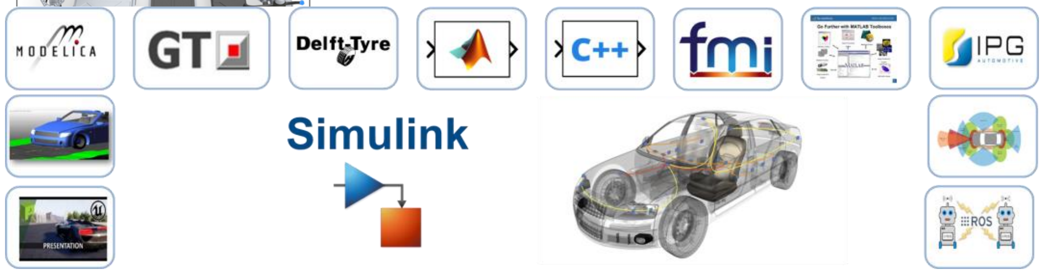
MathWorks Offering for Virtual Vehicle Simulation

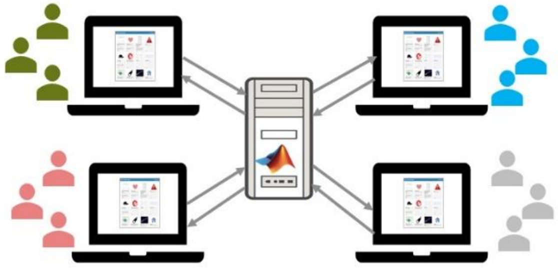
Engineering Tools + Application Expertise

Create Vehicle	Integrate Software	Author Scenarios	Simulate & Analyze	Deploy Simulation
Vehicle Templates Subsystem Libraries Modeling Guidelines	C/C++ Interface Reduced Order Models FMU Integration	Scene & Scenarios Open Standards Drive Cycles	Visualization Data Analysis Report Generation	Cloud Integration Datalake Integration HIL Deployment









Value proposition:

- Proven tools for modeling of physics and software
- Reference applications for reduced time-to-simulation
- Common platform for model reuse
- Solutions for large-scale modeling and simulation
- Flexible platform for growth / new use cases

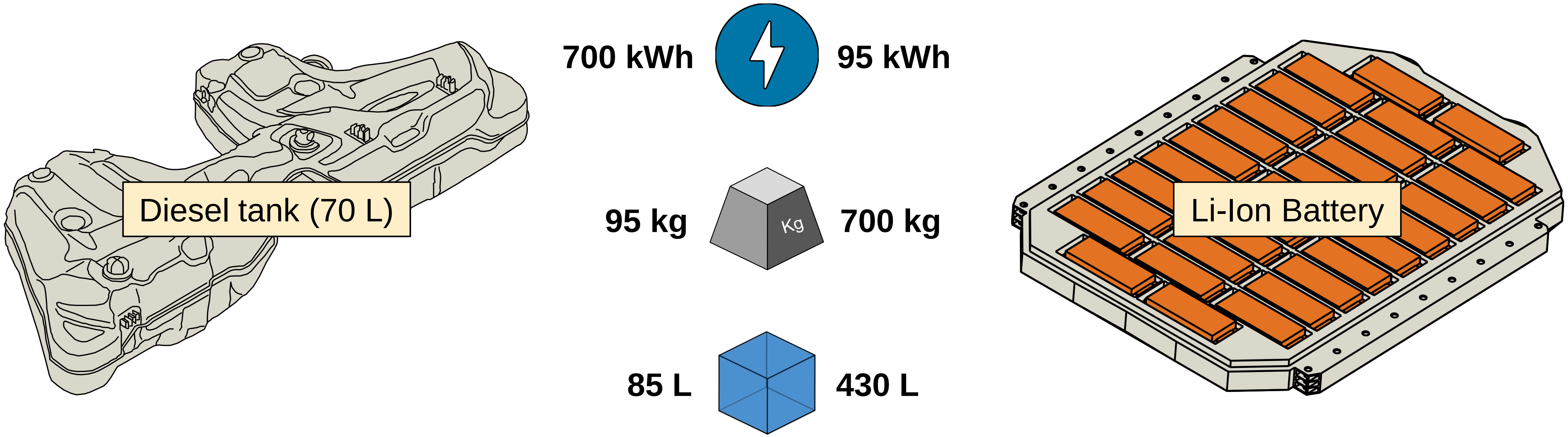
Problem statement: the electrification of the powertrain

Current challenges

The automotive sector is focusing on reducing CO_2 emissions. For this scope, Battery Electric Vehicles (BEVs) are a promising solution:

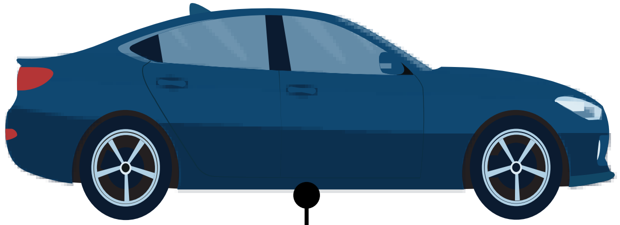
- Localize emissions to energy production source
- Can be charged with renewable energy

However, **engineering challenges remain** …



Introduction to the Customer

Abhisek Roy
System Engineering



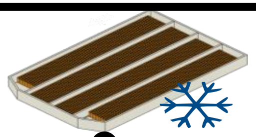
System Architecture

System-level models to quantify vehicle range, battery performance, and costs.

Objectives

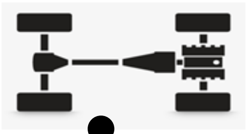
Target:
- Range estimation and component sizing

Test Case:
- Effect of Environmental and cabin conditions on Range,
- Different Drive cycles- MIDC/WOT



Battery Team

Perform detailed battery design studies



E-Powertrain

Perform detailed Motor design studies

Thermal Management

Perform HVAC studies

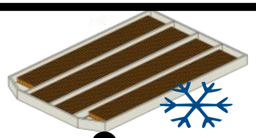
Objectives

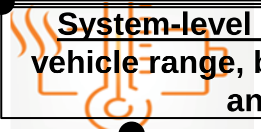
Component-Level Test Cases:
- Battery Thermal Behaviour
- Motor-Inverter Thermal Behaviour
- HVAC for refrigeration performance

System-Level Test Cases:
- EV Thermal Management

Sree Varshini

Head of COE's





System Architecture

System-level models to quantify vehicle range, battery performance, and costs

Battery Team

Perform detailed battery design studies

E-Powertrain

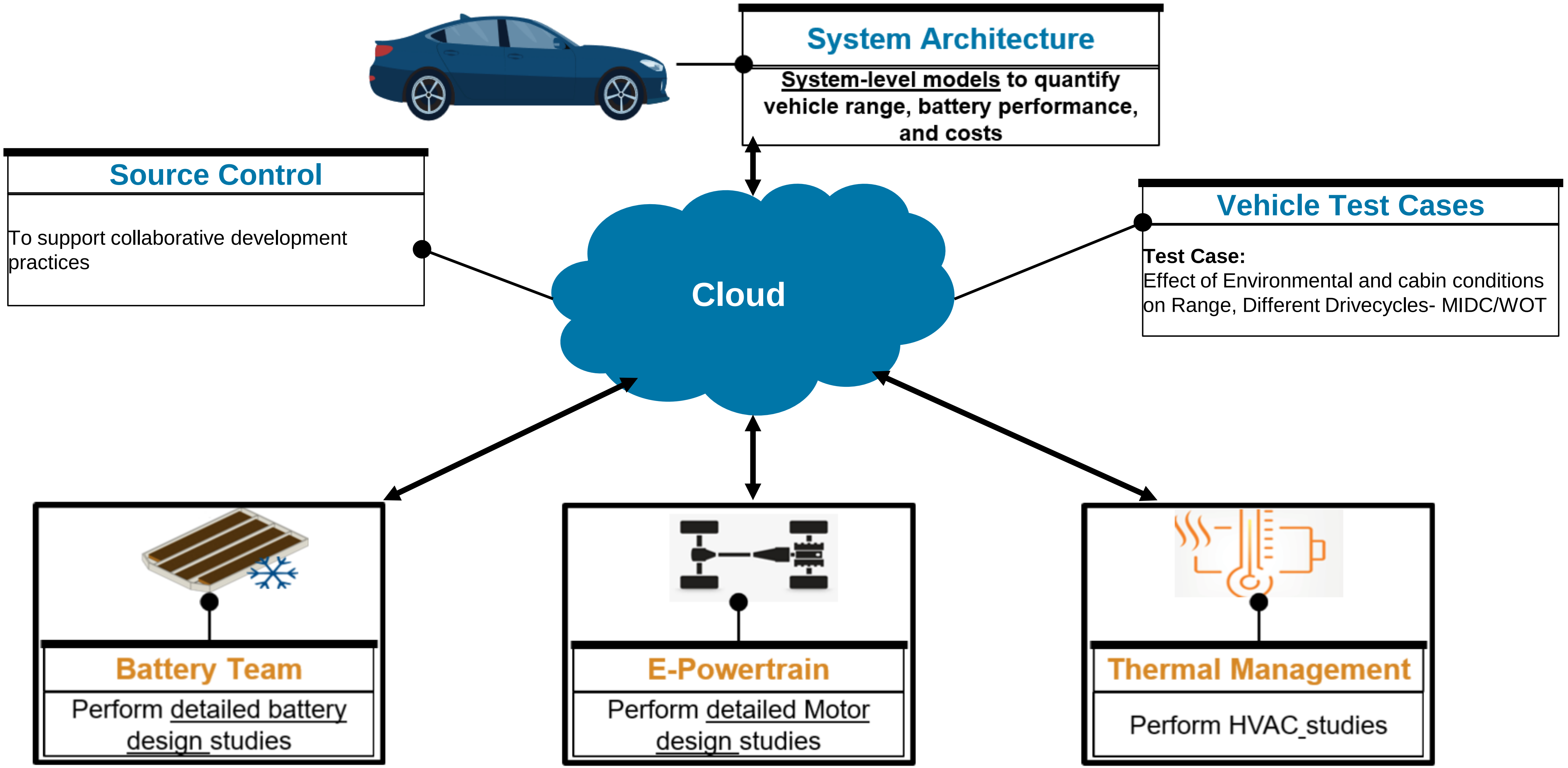
Perform detailed Motor design studies

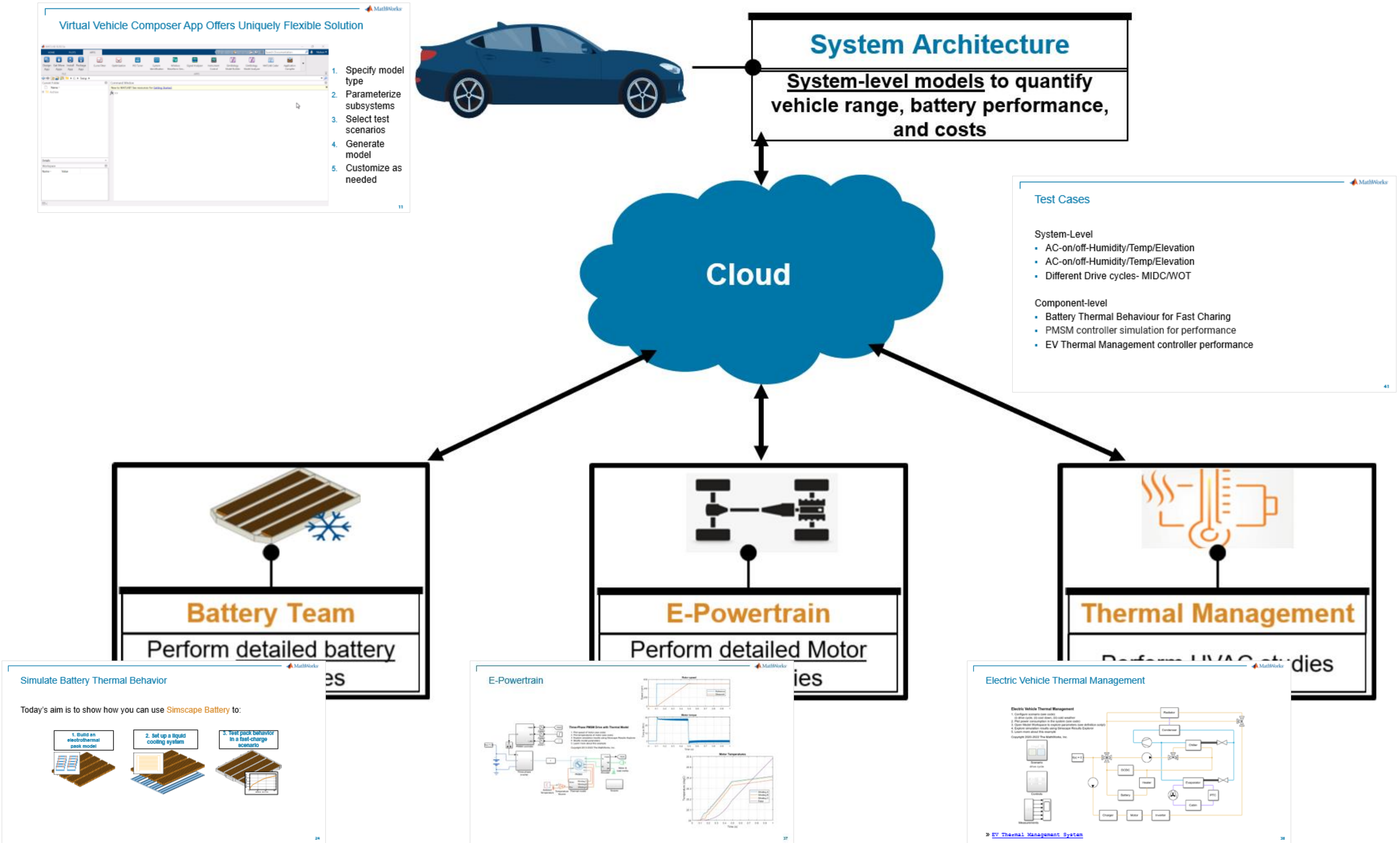
Thermal Management

Perform HVAC studies

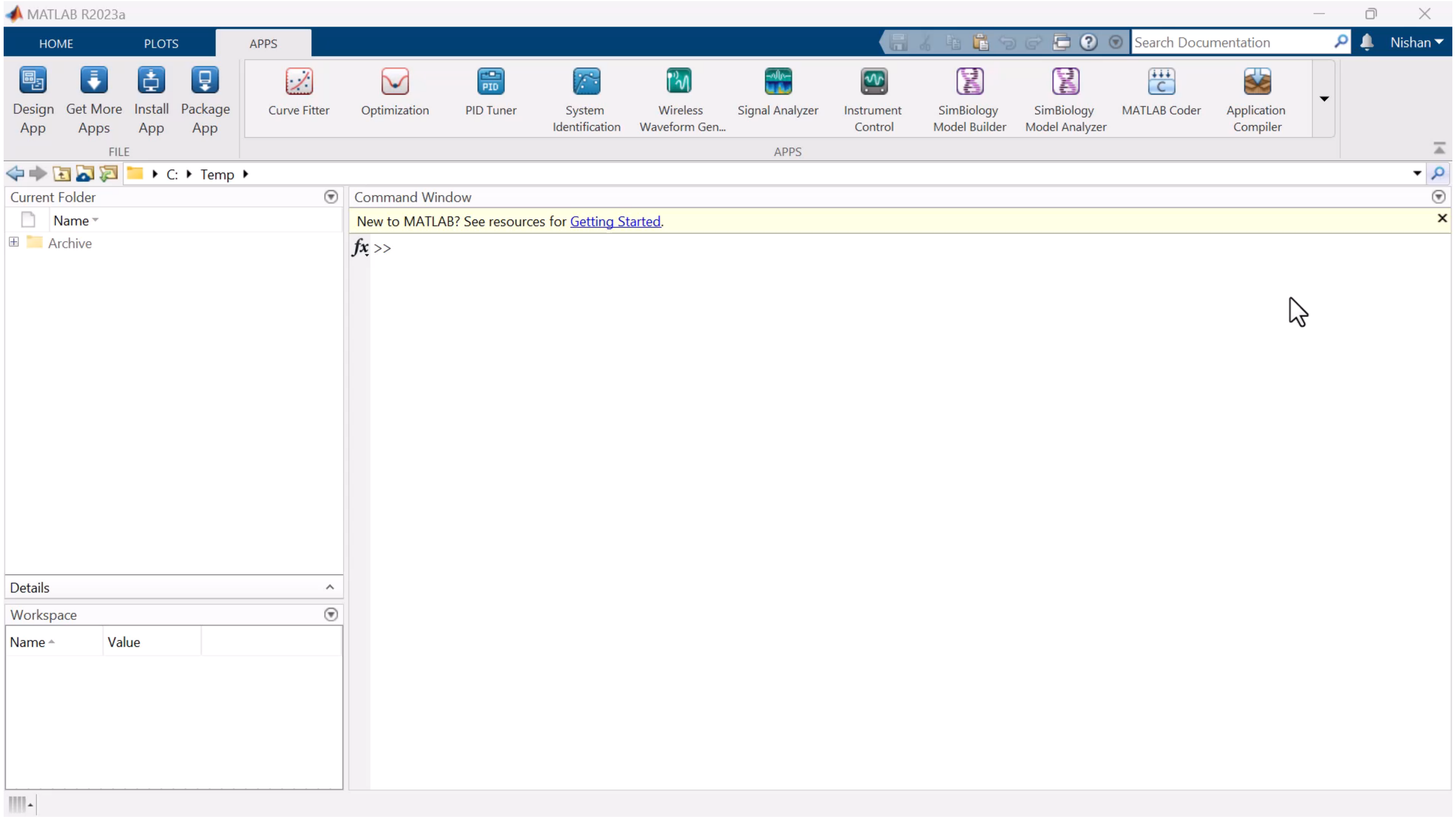
Sree Varshini

Head of COE’s


System Architecture
System-level models to quantify vehicle range, battery performance, and costs
Source Control
To support collaborative development practices
Cloud
Vehicle Test Cases
Test Case:
Effect of Environmental and cabin conditions on Range, Different Drivecycles- MIDC/WOT
Battery Team
Perform detailed battery design studies
E-Powertrain
Perform detailed Motor design studies
Thermal Management
Perform HVAC studies

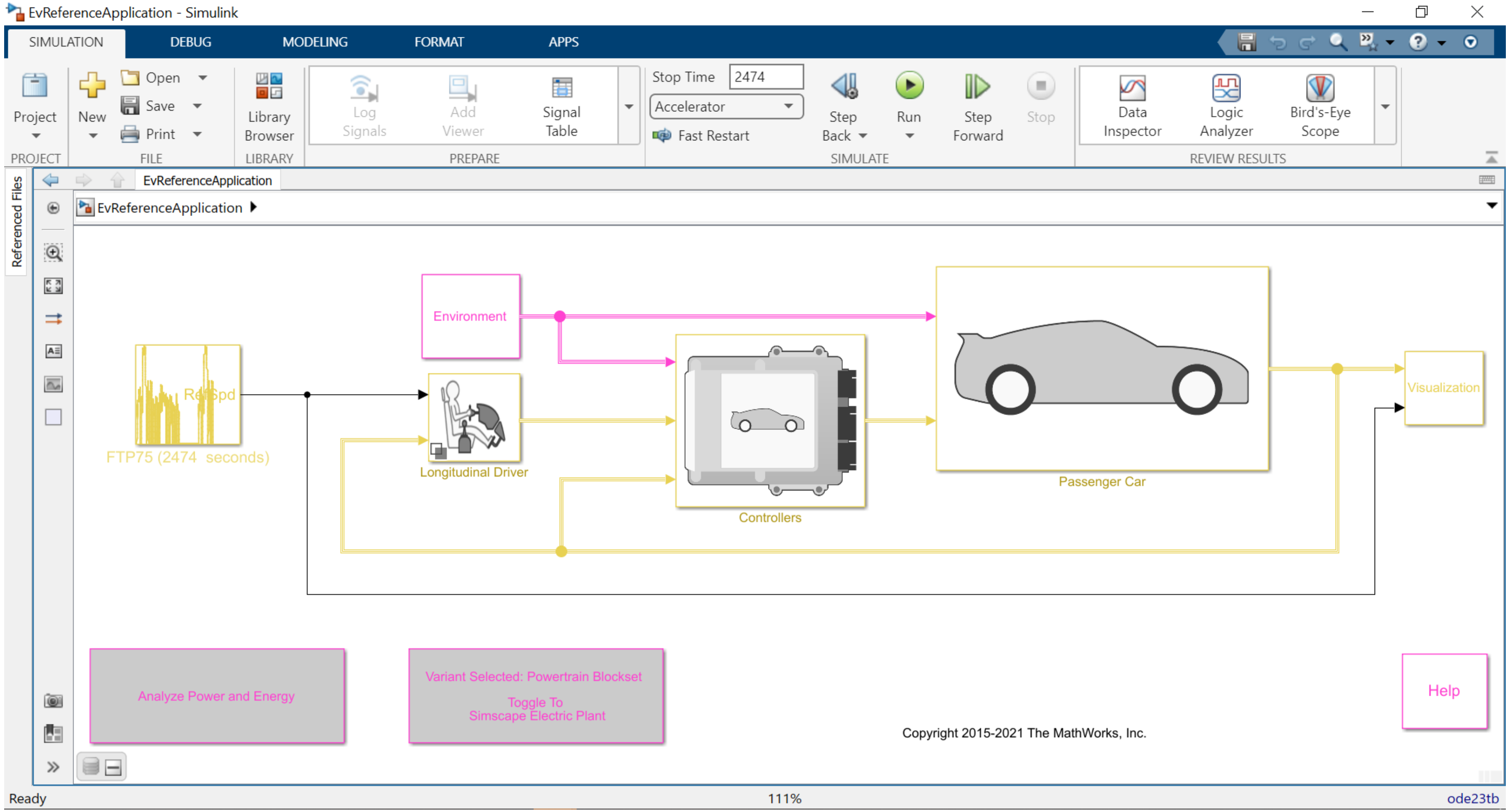

Virtual Vehicle Composer App Offers Uniquely Flexible Solution
1. Specify model type
2. Parameterize subsystems
3. Select test scenarios
4. Generate model
5. Customize as needed
System Architecture
System-level models to quantify vehicle range, battery performance, and costs
Cloud
Test Cases
System-Level
AC-on/off-Humidity/Temp/Elevation
AC-on/off-Humidity/Temp/Elevation
Different Drive cycles- MIDC/WOT
Component-level
Battery Thermal Behaviour for Fast Charing
PMSM controller simulation for performance
EV Thermal Management controller performance
Battery Team
Perform detailed battery
E-Powertrain
Perform detailed Motor
Thermal Management
Simulate Battery Thermal Behavior
Today's aim is to show how you can use Simscape Battery to:
1. Build an electrothermal pack model
2. Set up a liquid cooling system
3. Test pack behavior in a fast-charge scenario
E-Powertrain
Electric Vehicle Thermal Management
EV Thermal Management System

Virtual Vehicle Composer App Offers Uniquely Flexible Solution



1. Specify model type
2. Parameterize subsystems
3. Select test scenarios
4. Generate model
5. Customize as needed

Root Level



EvReferenceApplication - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Project
New
Open
Save
Print
Library Browser
Log Signals
Add Viewer
Signal Table
Stop Time
2474
Accelerator
Fast Restart
Step Back
Run
Step Forward
Stop
Data Inspector
Logic Analyzer
Bird's-Eye Scope
PROJECT
FILE
LIBRARY
PREPARE
SIMULATE
REVIEW RESULTS
Referenced Files
EvReferenceApplication
Environment
RefSpd
FTP75 (2474 seconds)
Longitudinal Driver
Controllers
Passenger Car
Visualization
Analyze Power and Energy
Variant Selected: Powertrain Blockset
Toggle To
Simscape Electric Plant
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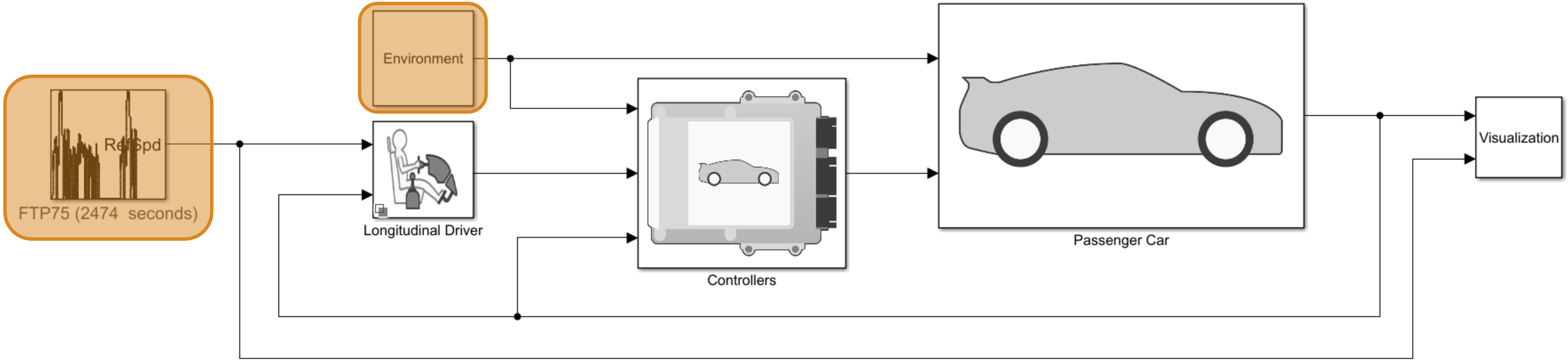
Help
Ready
111%
ode23tb

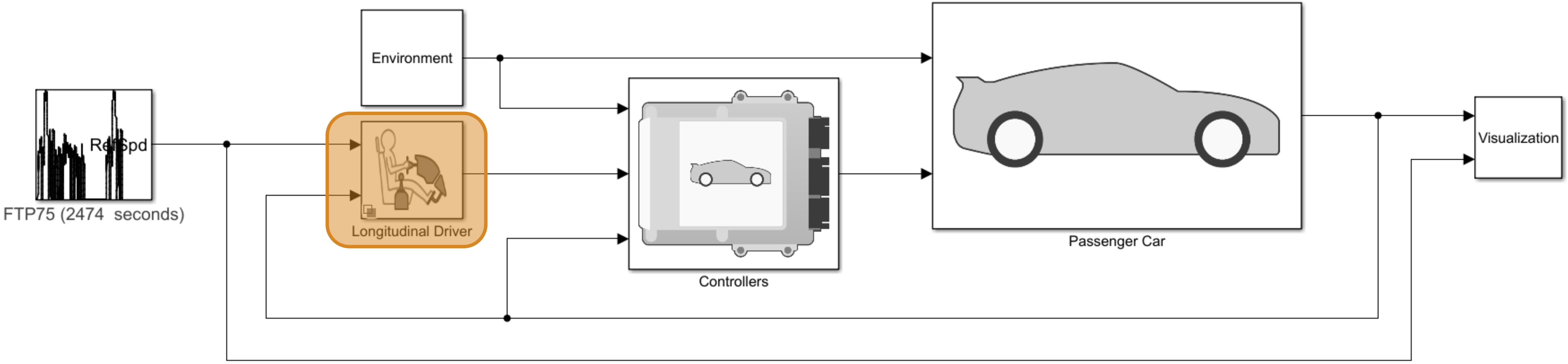
Root Level Model

1. Set target speed and ambient conditions



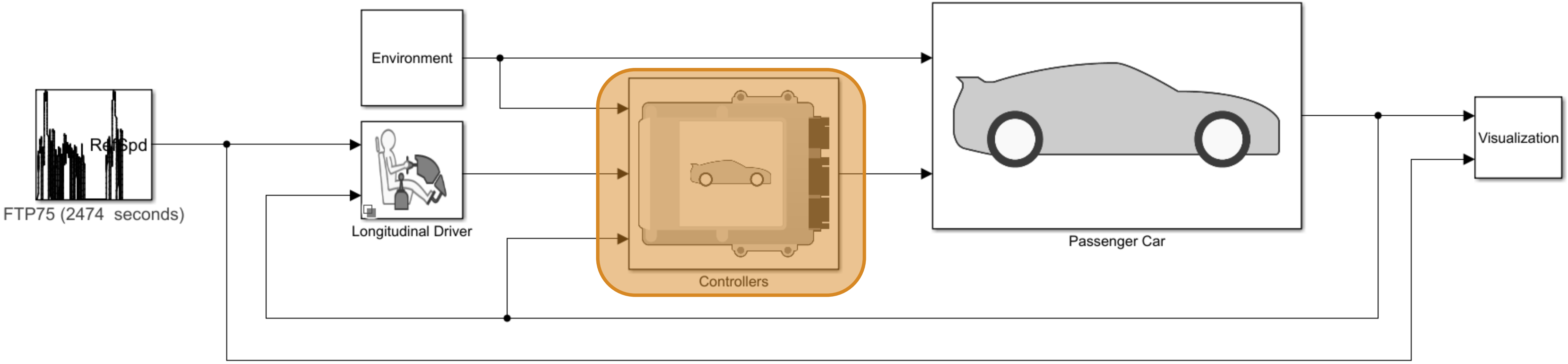
Root Level Model

1. Set target speed and ambient conditions
2. Set brake / accel / shift commands to achieve target speed



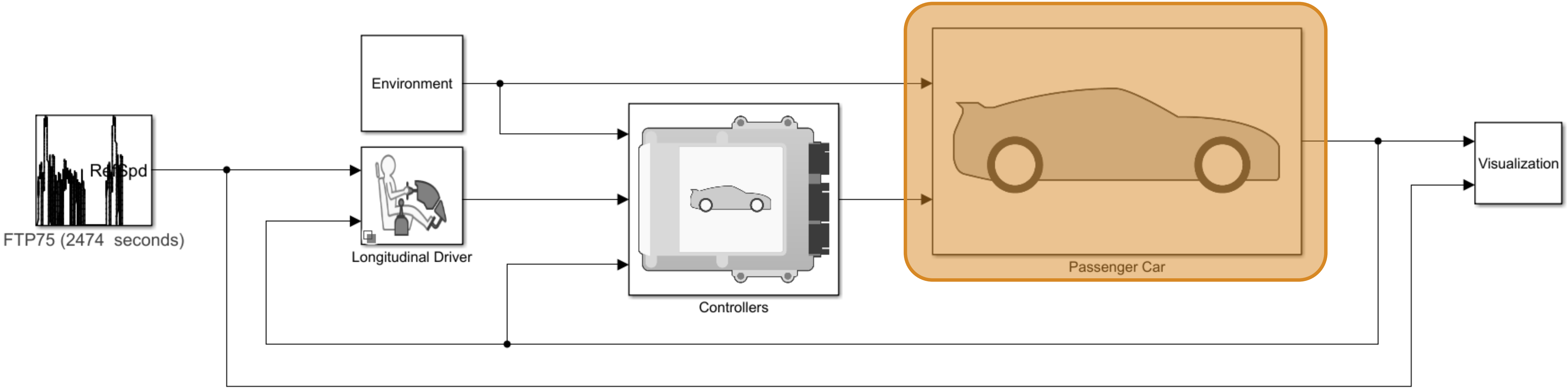
Root Level Model

1. Set target speed and ambient conditions
2. Set brake / accel / shift commands to achieve target speed
3. Set lower-level control commands (e.g., engine / motor torque)



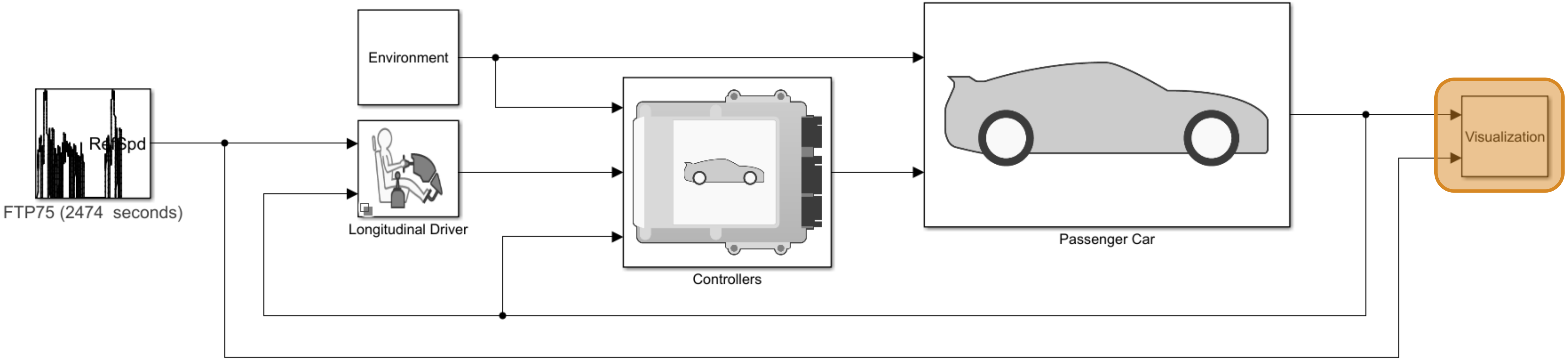
Root Level Model

1. Set target speed and ambient conditions
2. Set brake / accel / shift commands to achieve target speed
3. Set lower-level control commands (e.g., engine / motor torque)
4. Calculate vehicle response



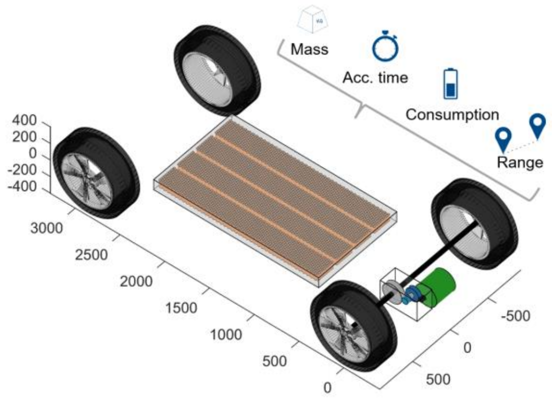
Root Level Model

1. Set target speed and ambient conditions
2. Set brake / accel / shift commands to achieve target speed
3. Set lower-level control commands (e.g., engine / motor torque)
4. Calculate vehicle response
5. Report results



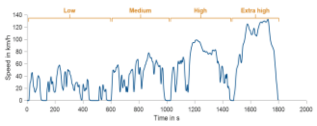
Battery Sizing and Performance Analysis

- How should I resize my battery?



Input different Scenarios

- Drive Cycles
- Initial Battery Charge
- Ambient Temp



Change Design Parameters

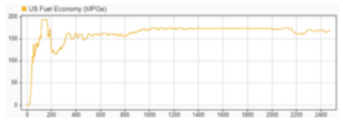
- #Cells
- Motor Size
- SoC est. technique

Measure Dynamic Response

- Vehicle Speed
- Battery Temp
- Motor Current

Calculate Metrics

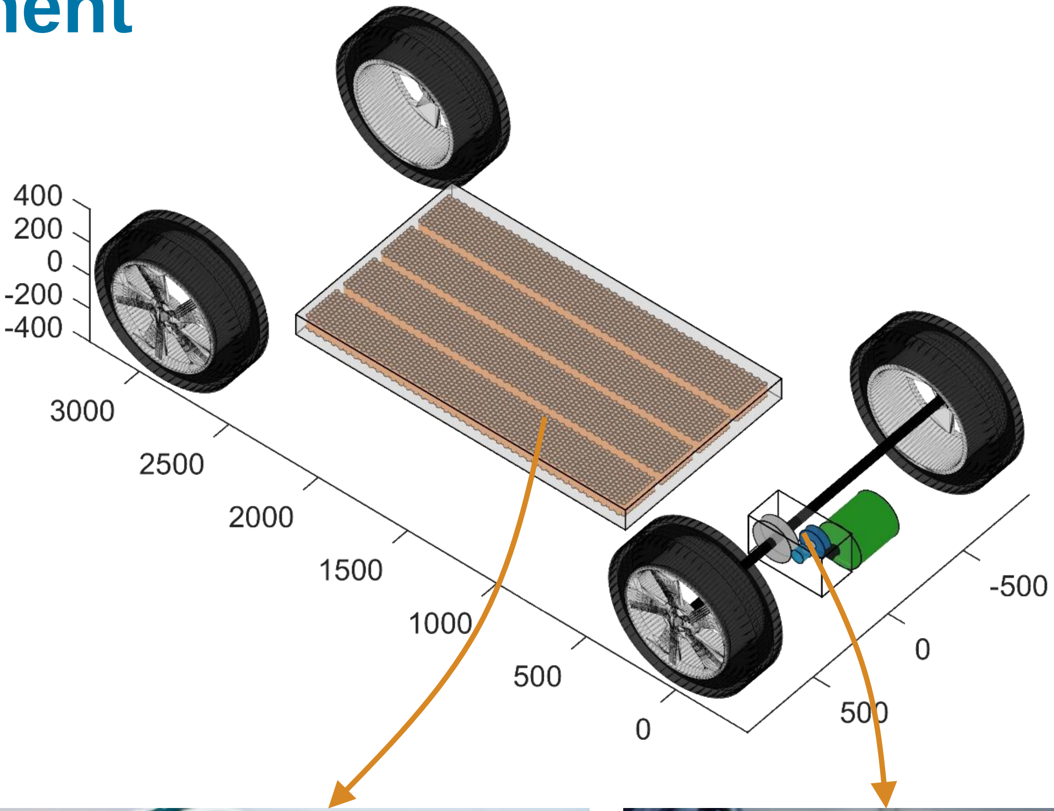
- Est. Range
- Fuel Consumption

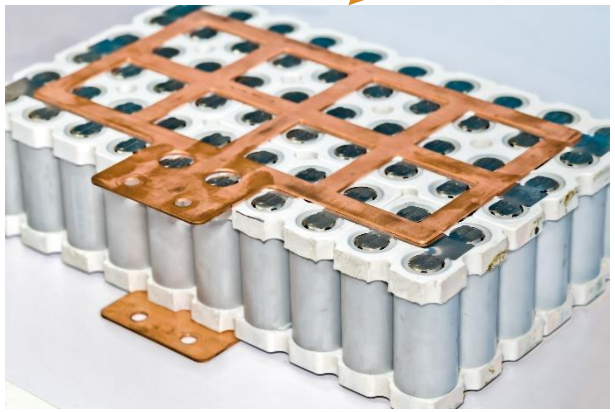


Iterate

Component sizing problem statement

- Goals:
  - Find battery size & gearing that provides good efficiency at a reasonable price
- Constraints:
  - Meets typical driving demands
  - Reasonable BEV range
  - Reasonable acceleration
- Design Variables:
  - Number of battery cells in parallel (Np)
  - Number of battery cells in series (Ns)
  - Gearbox ratio (Nd)





Component sizing problem statement

- Goals:

$\min f(\mathbf{x}) = w_1 * ECR + w_2 * Cost$

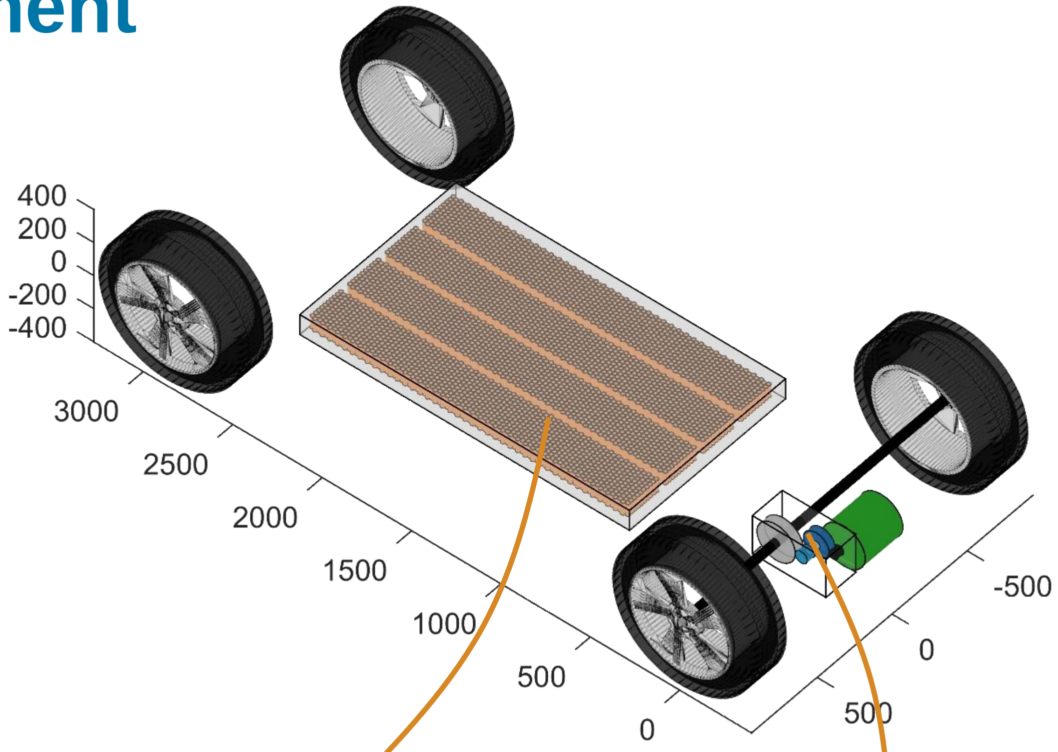
ECR = Energy Consumption Rate [Wh/km]

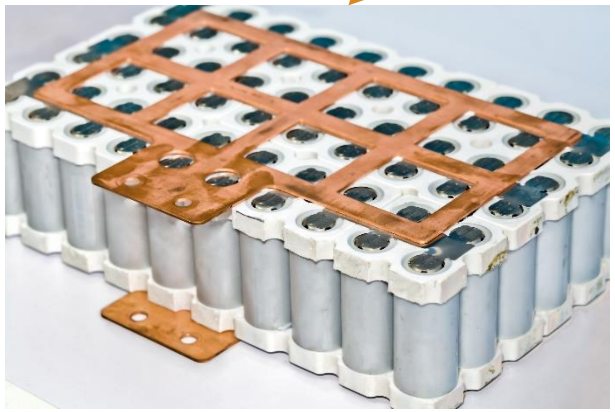
- Constraints:

g_1: DriveCycleFault ≤ 0
g_2: Range ≥ 400 km
g_3: $t_{0\text{-}100} \leq 8$ sec

- Design Variables:

x_1: $20 \leq Np \leq 50$ *(Integer)*
x_2: $320V/3.6V \leq Ns \leq 600V/3.6V$ *(Integer)*
x_3: $2 \leq Nd \leq 10$ *(Continuous)*

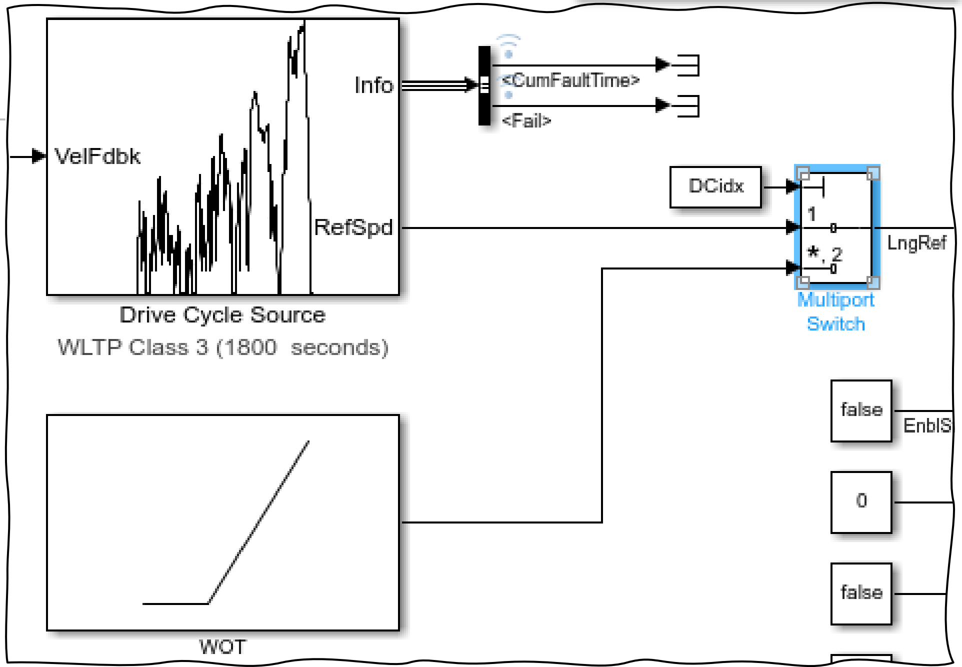




Running simulations as a function call

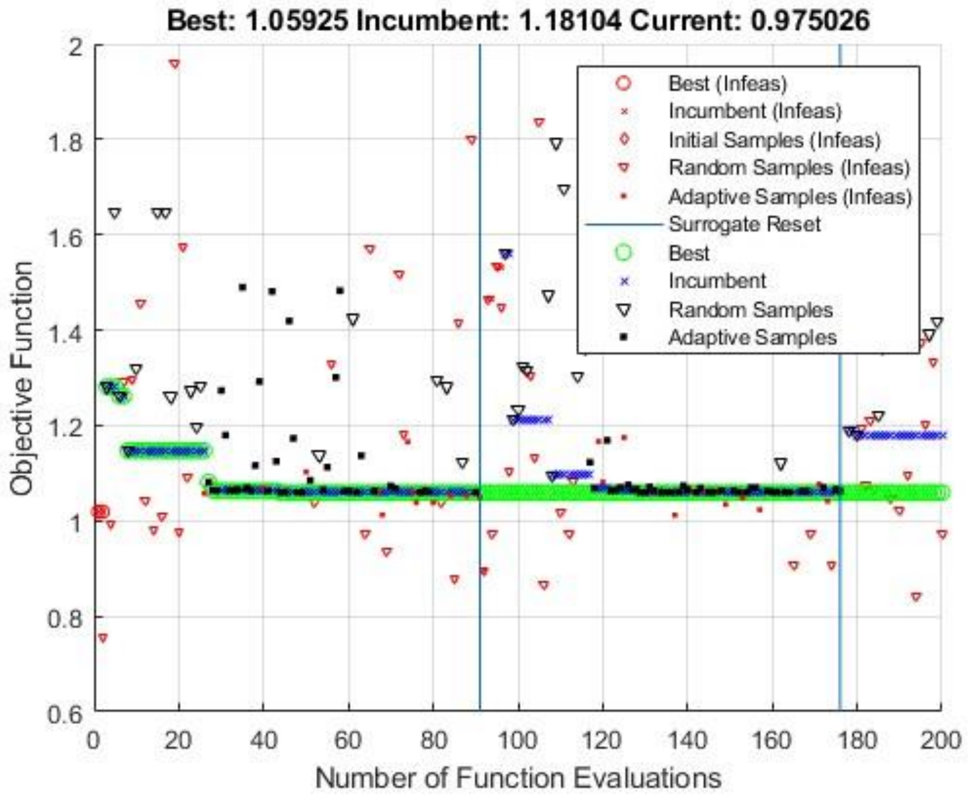
```matlab
function [f, g, ECR, cost] = RunEV(Np, Ns, Ndiff, model)
% RunEV runs a series of EV sims for a given set of parameters

% Do some internal calculations
batt_energy = (4.8*Np)*(3.6*Ns)/1000; % 4.8 Ah/string, 3.6 V/cell
mass = 1250 + batt_energy/145*1000; % 145 Wh/kg
cost = 125 * batt_energy; % assume cell cost of $125/kW.hr

% Create Simulation Input object to store temporary parameter overrides
in = Simulink.SimulationInput(model
in = in.setVariable('PlntVehMass',
in = in.setVariable('PlntBattNumCel
in = in.setVariable('PlntBattNumCel
in = in.setVariable('PlntDiffrntlRa

% Run WLTP drive cycle
in = in.setVariable('DCidx', 1);
in = in.setModelParameter('StopTime
simout = sim(in);

% Post-process WLTP result
logsout = simout.get('logsout');
DCerror = logsout.get('DCFaultTime
DCfail = logsout.get('DCFail').Valu
bp = logsout.get('Battery Power [W]
v = logsout.get('Vehicle Speed [m/s
% Energy consumption rate in [W.hr/
ECR = trapz(bp.Time,bp.Data)/3600/(
range = batt_energy / ECR * 1000; %
```

```matlab
% Run 0-100 kph test
in = in.setVariable('DCidx', 2);
in = in.setModelParameter('StopTime','20');
simout = sim(in)

% Post-process WOT result
logsout = simout.get('logsout');
v = logsout.get('Vehicle Speed [m/s]').Values;
try
    id = find(v.Data>0.1,1,'first');
    t0 = interp1(v.Data(id-1:id),v.Time(id-1:id),0.1);
    id = find(v.Data>27.778,1,'first');
    t100 = interp1(v.Data(id-1:id),v.Time(id-1:id),27.778);
    t0_100 = t100 - t0;
catch
    t0_100 = 100;
end

% Assemble results into objective and constraint values
f=[]; g = struct();
w = [0.5, 0.5]; % relative weights for the objectives
s = [150, 6250]; % scale factor to normalize objective terms

f = ECR*w(1)/s(1) + cost*w(2)/s(2);
g.DCerror = DCerror*DCfail; % total drive cycle fault time (or 0 if passed)
g.range = 300 - range; % range > 300 km
g.t100 = t0_100 - 8.0; % t0_100 < 8.0 sec

end
```



Optimization Results

Metric	Baseline	Target	Optimized (% improvement)
Energy consumption [kWh/100km]	15.1 ❗	< 15	14.4 (-4.6%) ✔
Cost [€]	6428 ✔	< 7500	7232 *(+12.5%)* ✔
Range [km]	340 ❗	> 400	401 (+17.6%) ✔
Acceleration time $t_{0\text{-}100}$ [s]	7.14 ✔	< 8	8.0 (+12.0%) ✔
Gearbox ratio Nd	9		5.05
Cell configuration	96s31p		108s31p
Bus voltage [V]	345.6		388.8
Capacity [kWh]	51.4		57.9



Performed 200 function calls (~2,5 hours)

System Level Test Cases to be performed

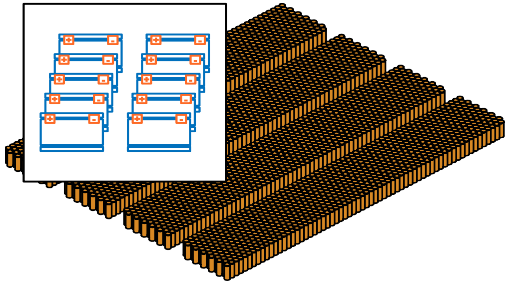
System-Level

- AC-on/off-Humidity/Temp/Elevation
- AC-on/off-Humidity/Temp/Elevation
- Different Drive cycles- MIDC/WOT

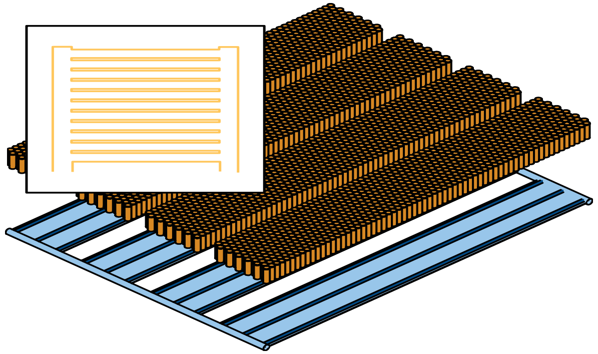
Simulate Battery Thermal Behavior

Today's aim is to show how you can use Simscape Battery to:

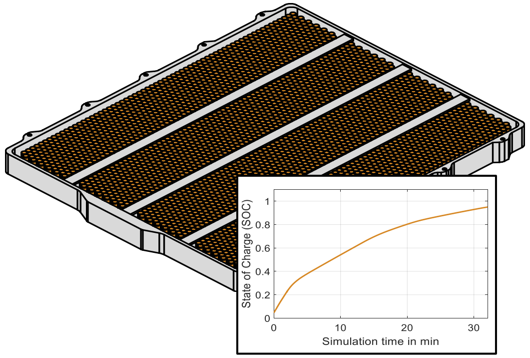
1. Build an electrothermal pack model



2. Set up a liquid cooling system



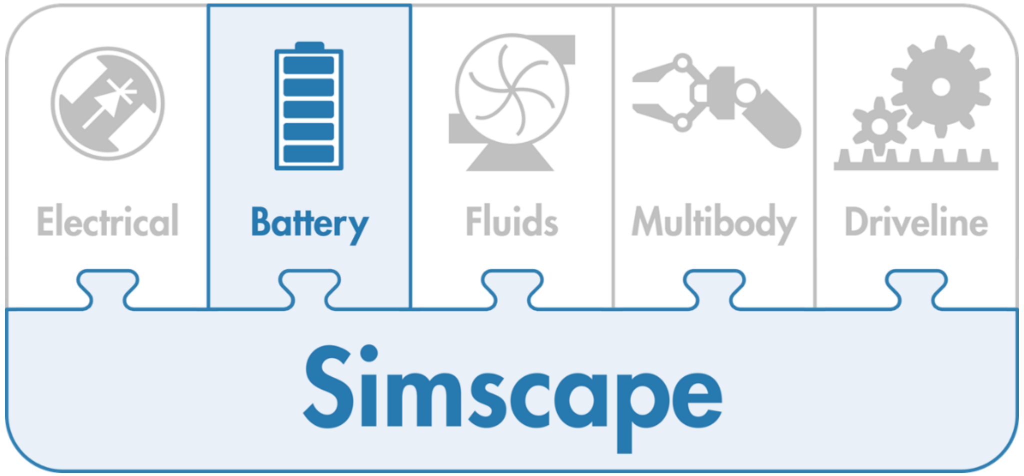
3. Test pack behavior in a fast-charge scenario

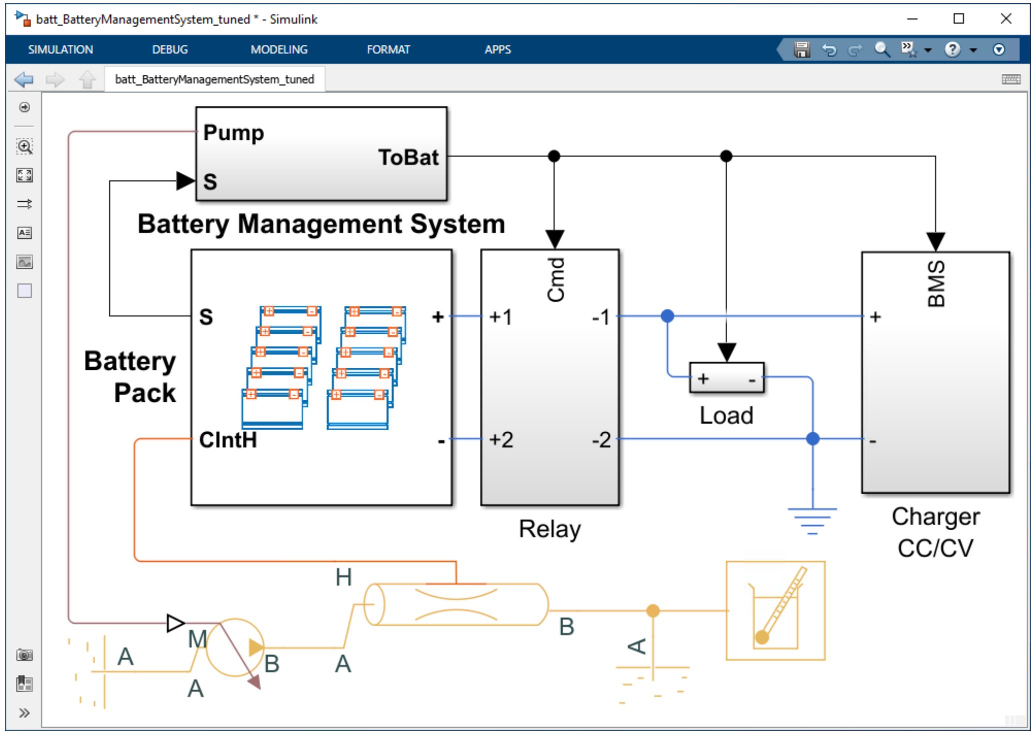


What is Simscape Battery?

Overview

- Add on product of Simscape
- Design and simulate battery and energy storage systems
  - Electrothermal cell behavior
  - Battery pack design
  - Battery management systems (BMS)
- With Simscape Battery you can
  - Test packs for electrical & thermal requirements
  - Test BMS algorithms

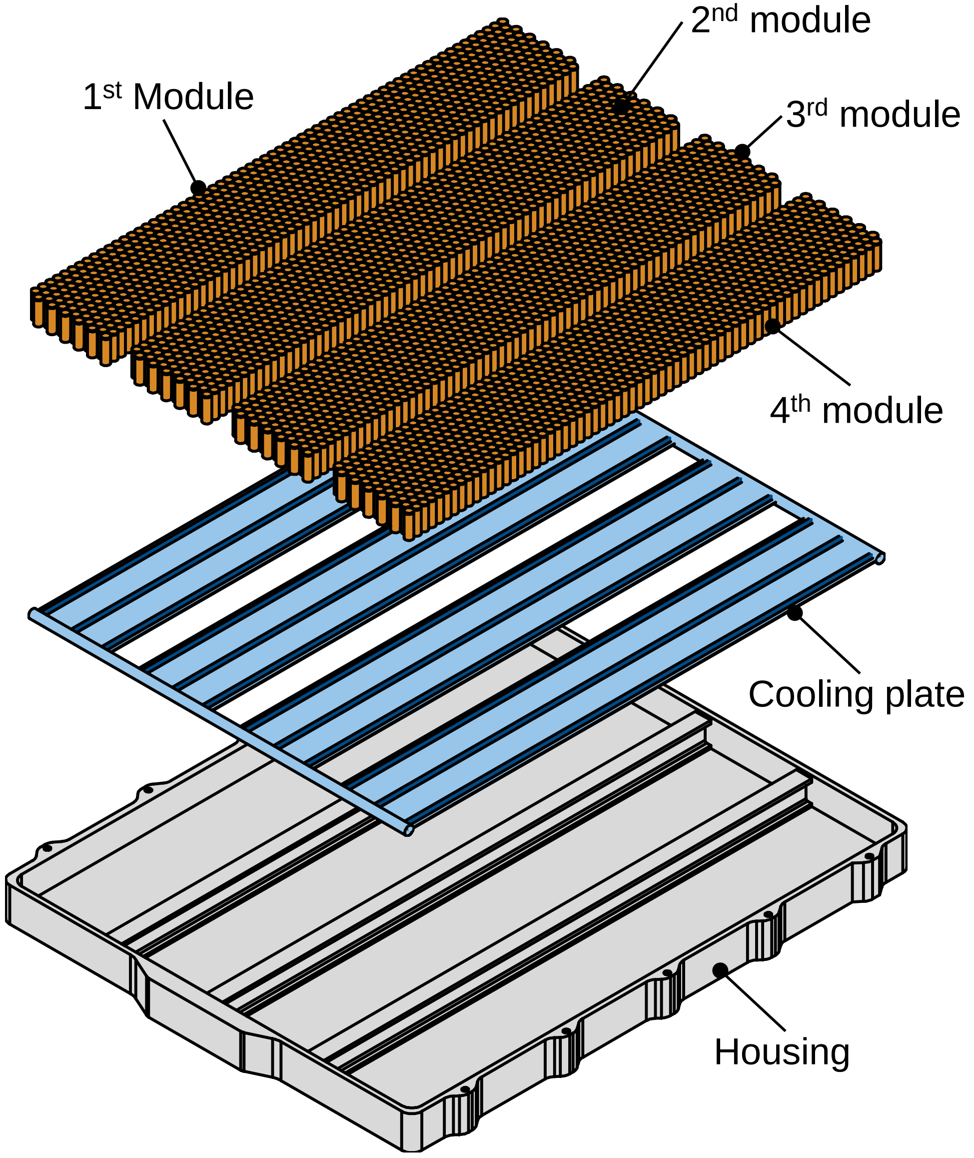




Testing the Limits of a Battery Pack

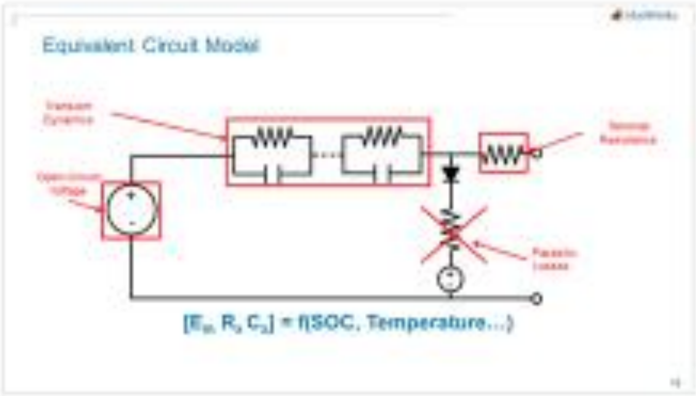
The pack we will use today

- The thermal and electrical modeling will be applied on a previously-sized battery pack
  - 3072 cylindrical cells (21700 format)
  - Electrical scheme 96s32p
  - Cell are disposed in 4 modules
  - Installed energy: 50 kWh
- Generated from an optimization study for a mid-size electric sedan (400 km range)

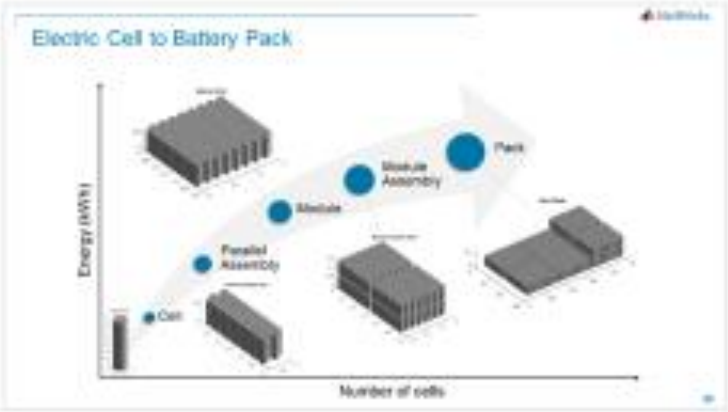


Scaling from Cell to Pack and performing Electro-thermal analysis

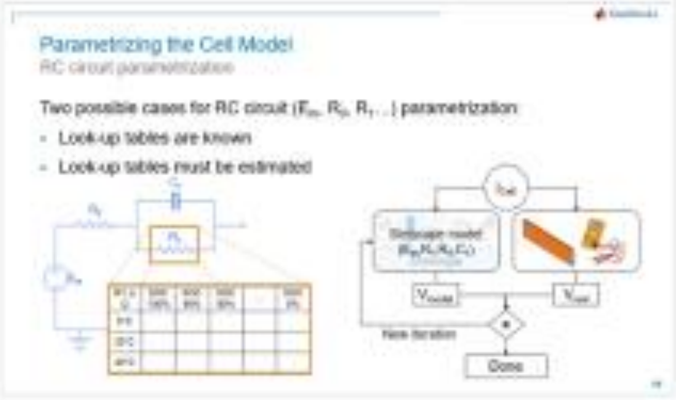
1. Cell Modeling



3. Battery Pack Design



2. Cell Parametrization

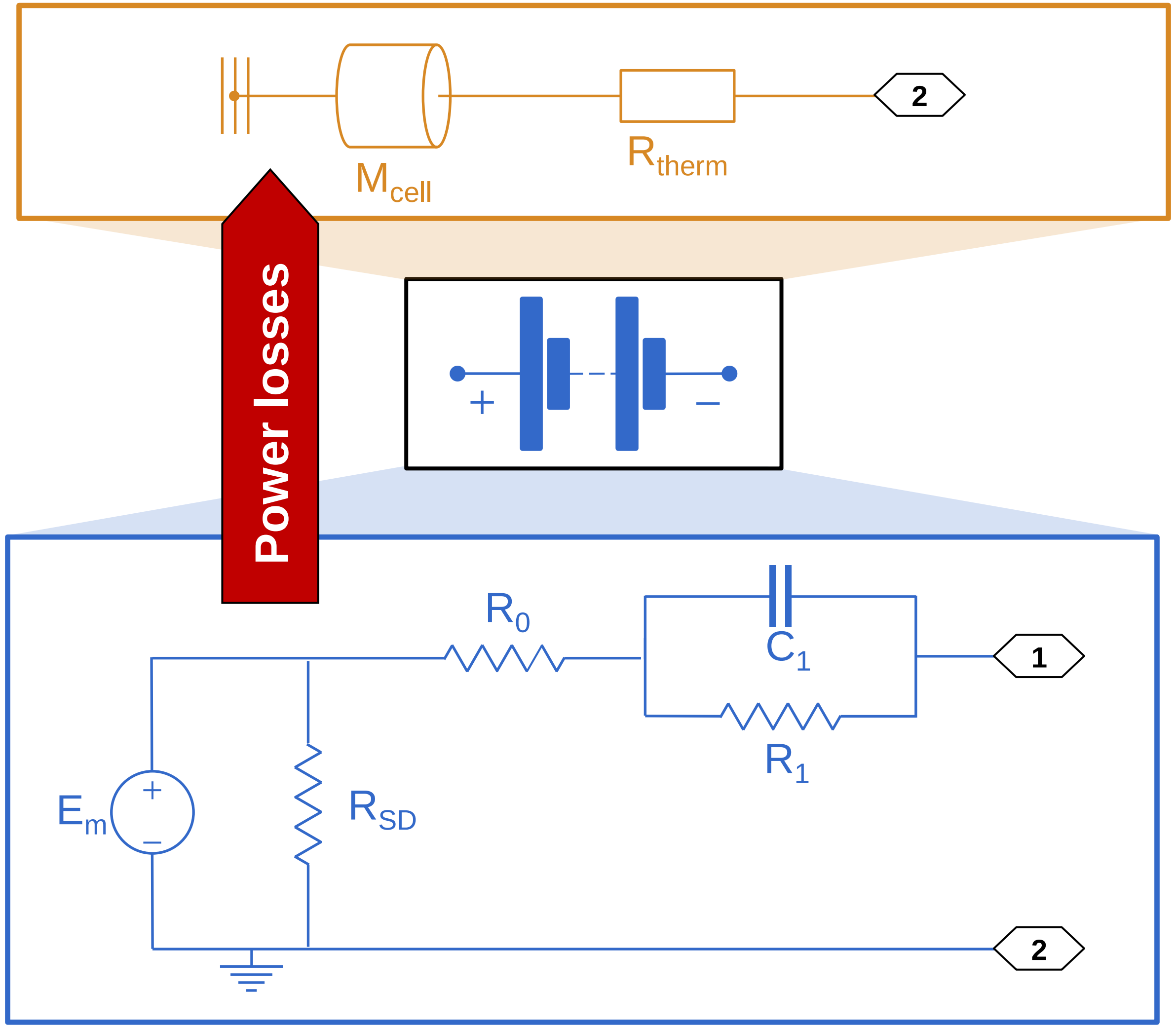


4. Thermal Management System Design

Understanding the Cell Model

Multi-domain physical model

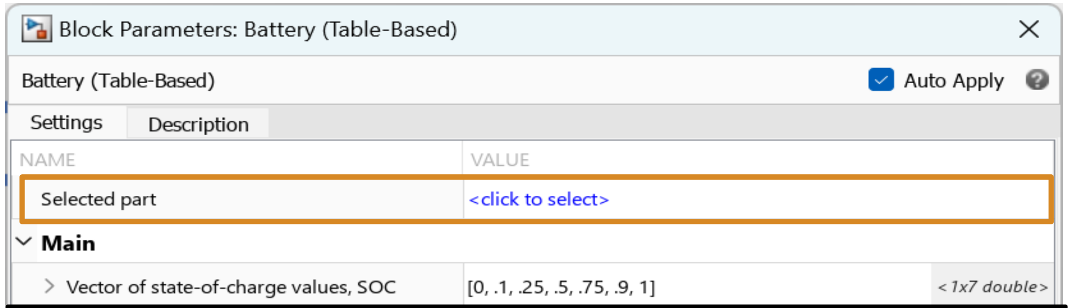
- Multi-domain physical model
- Electrical cell model
  - Cell described with an RC circuit
  - Different levels of detail available
- Thermal lumped cell model
- Power losses calculated from Ohmic losses



» Battery (Table-Based)

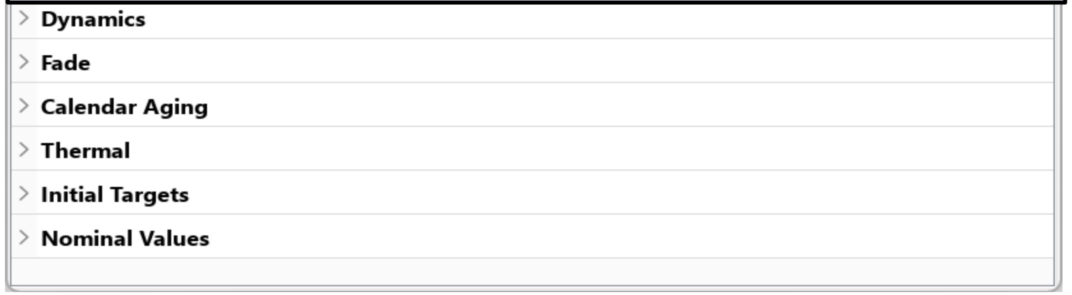
Understanding the Cell Model

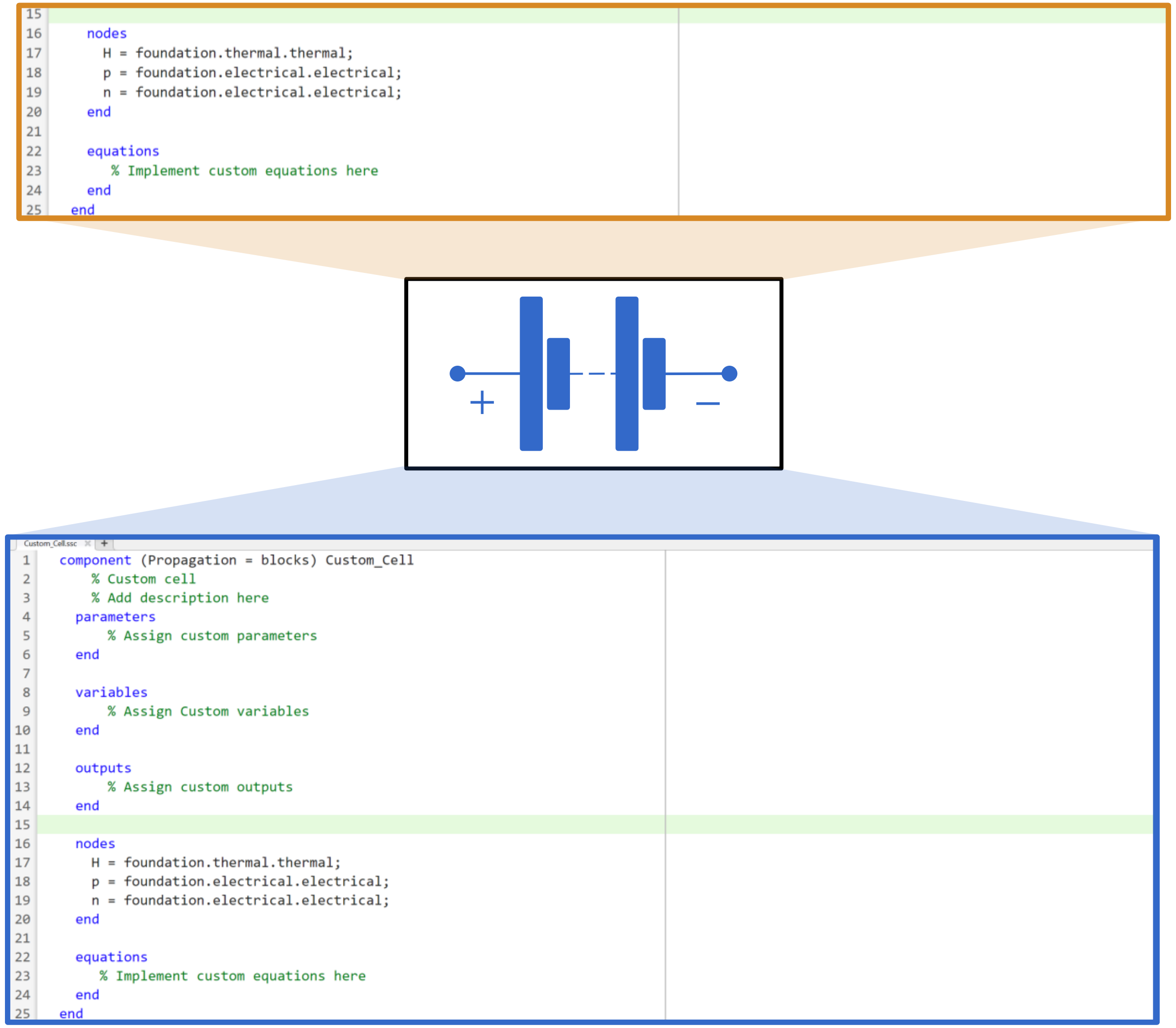
Multi-domain physical model



Implementation

- Pre parametrized cell
- MOLICEL INR 21700 PB4
- Simple model, no dynamics





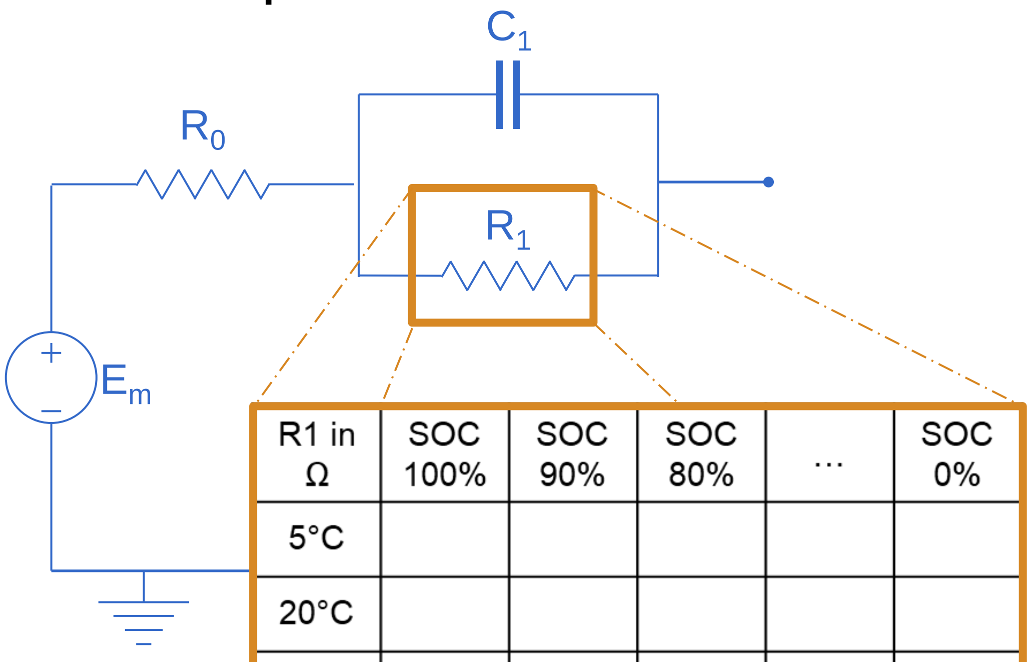
» [Battery (Table-Based)]

Parametrizing the Cell Model

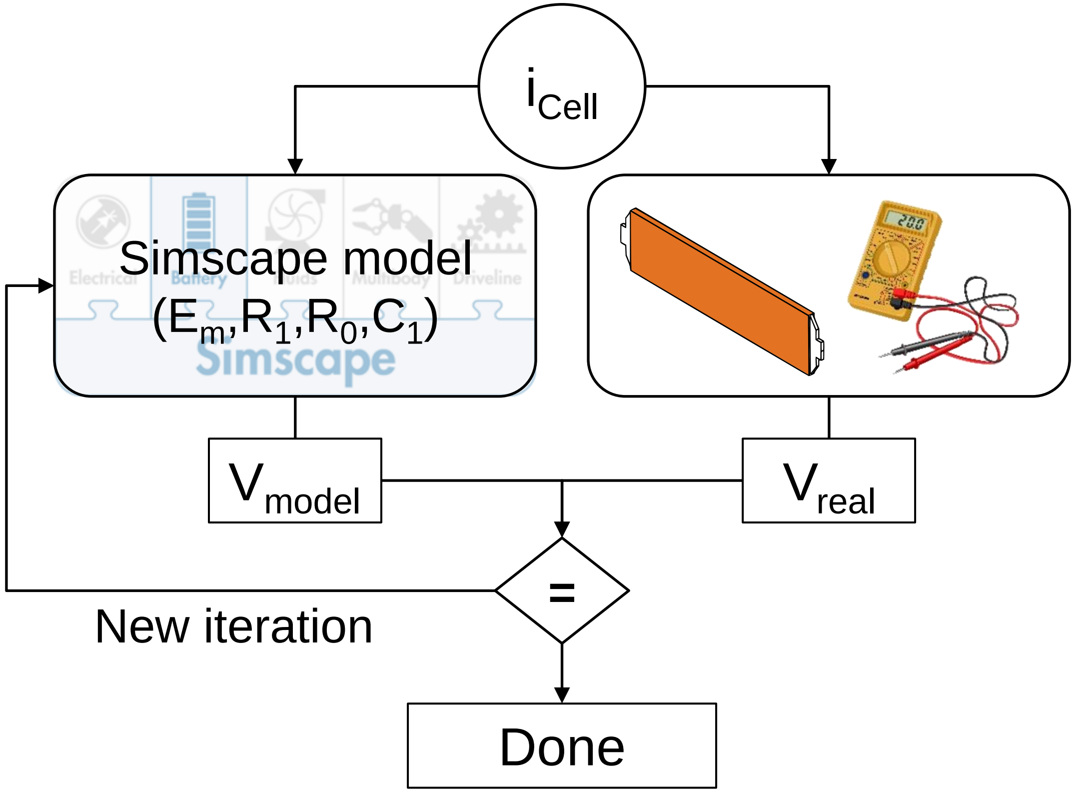
RC circuit parametrization

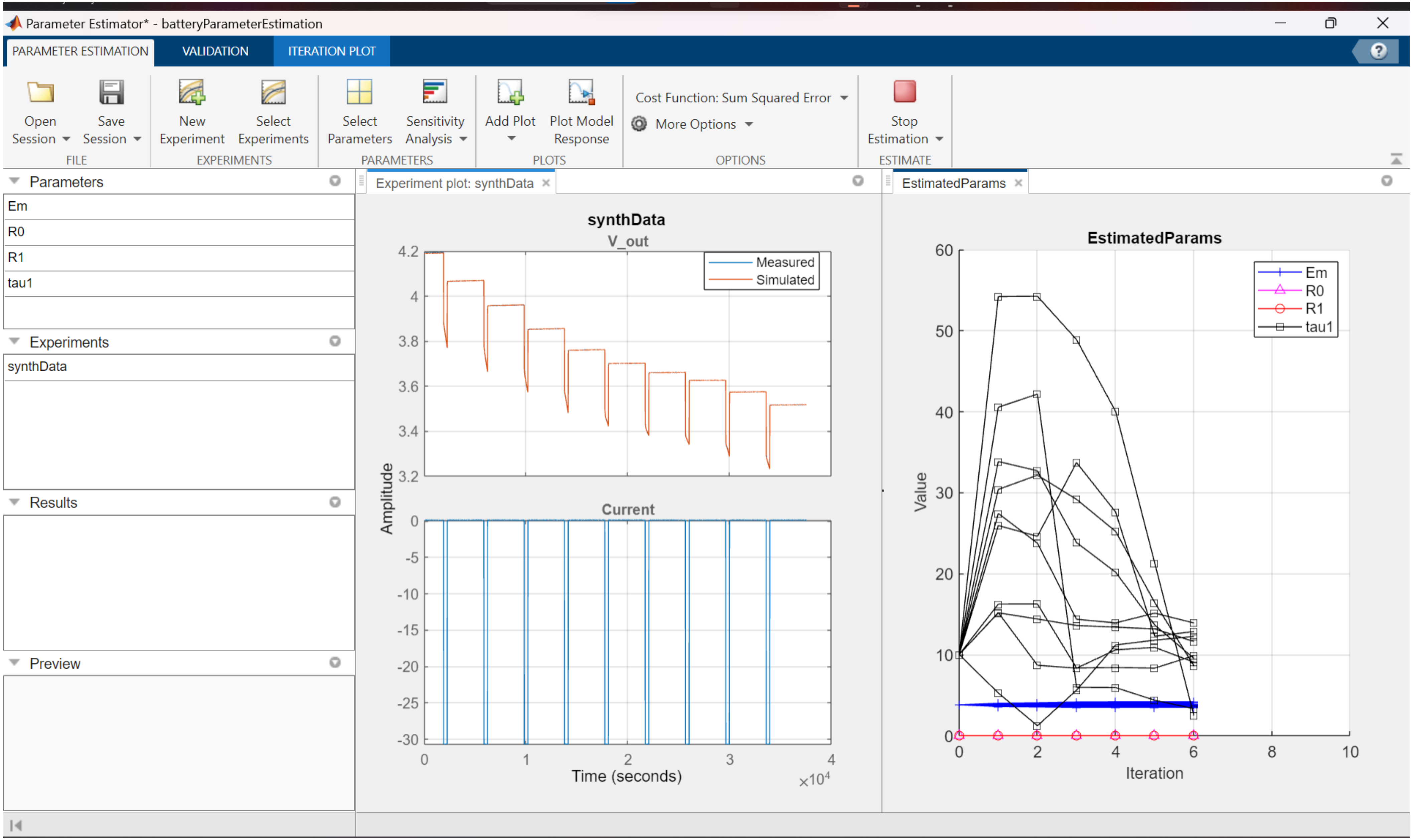
Two possible cases for RC circuit (E_m, R_0, R_1…) parametrization:

- Look-up tables are known
- Look-up tables must be estimated



R1 in Ω	SOC 100%	SOC 90%	SOC 80%	…	SOC 0%
5°C					
20°C					
40°C					

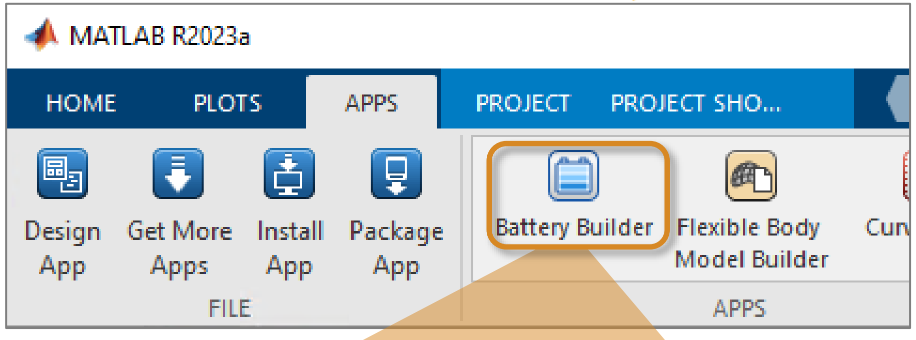




» [Estimate Battery Parameters]

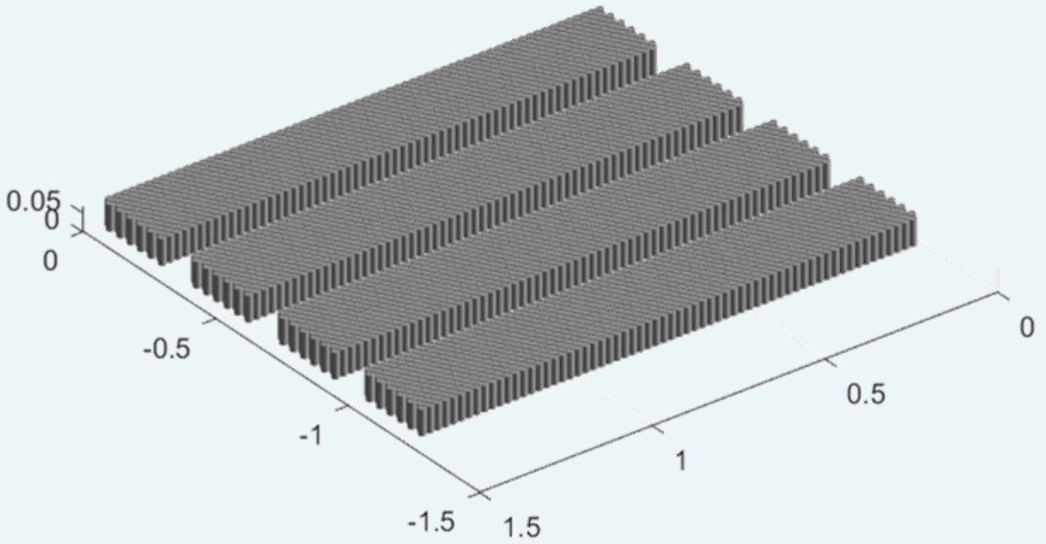
Building a Battery Pack within a Few Minutes

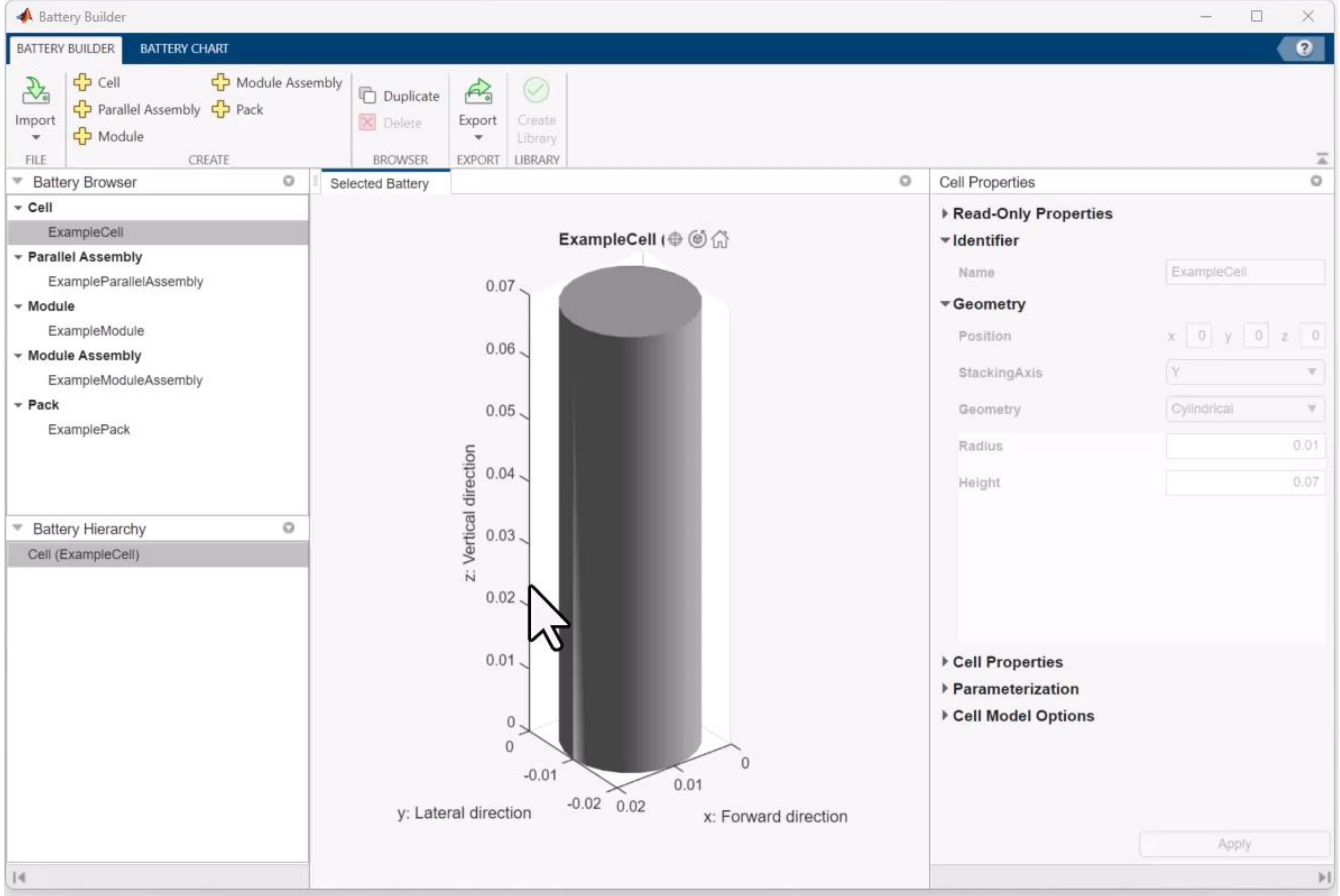
with the Battery Builder App



Implementation

- 3072 cells disposed on four modules
- Electrical scheme 96s32p



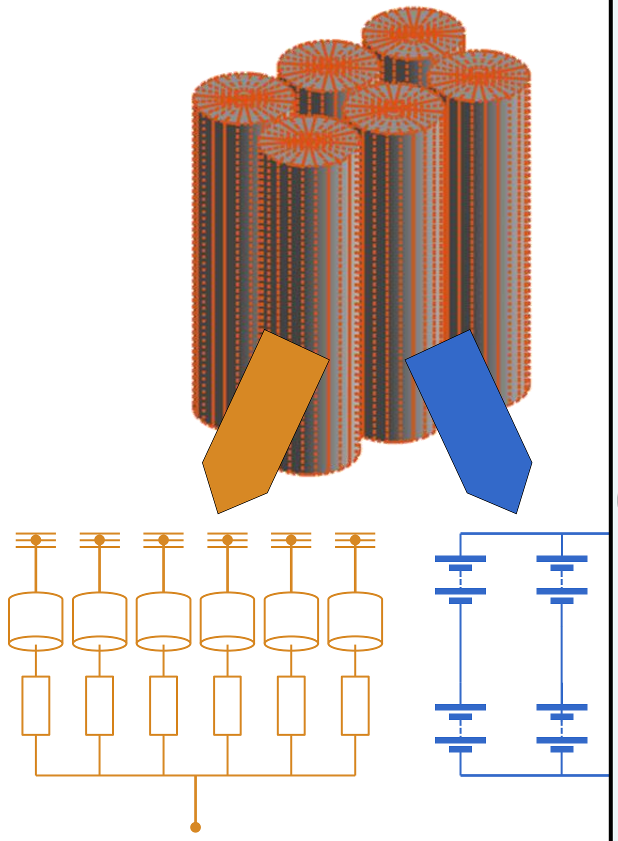


» [Battery Builder]

Finding the Tradeoff Between Calculation Speed and Precision

Choosing the right model fidelity for the pack

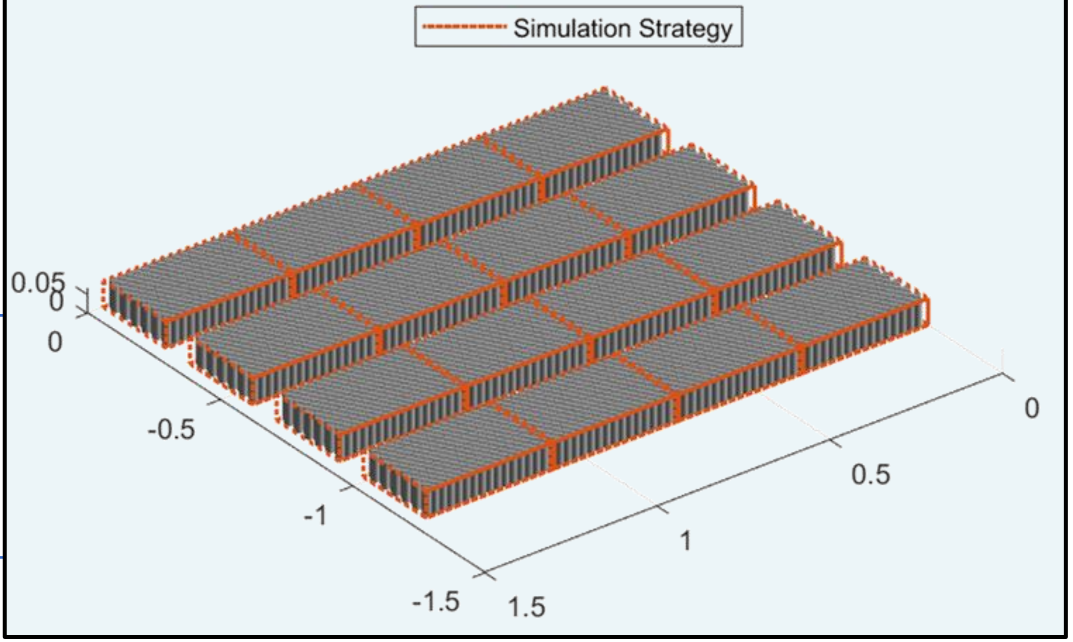
Detailed



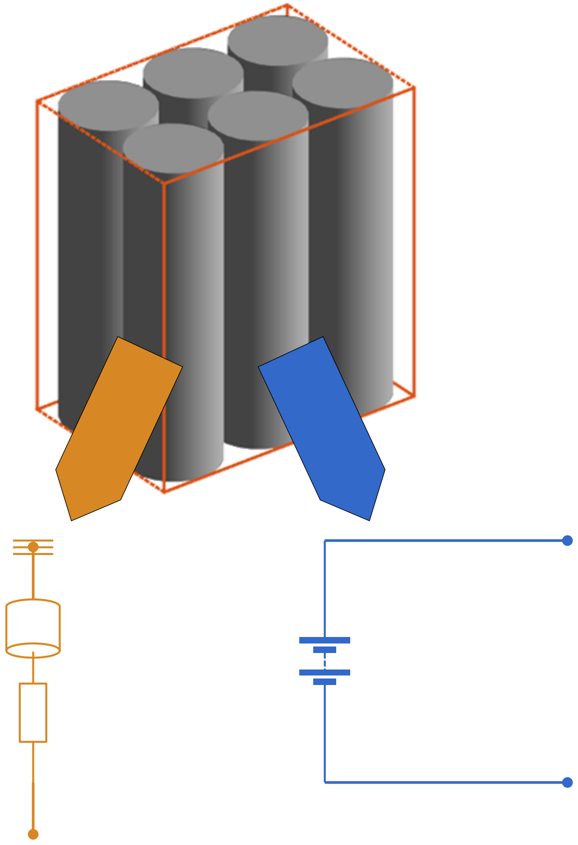
Grouped

Implementation

Selected a *Grouped* model resolution by dividing each module in four cell groups.



Lumped

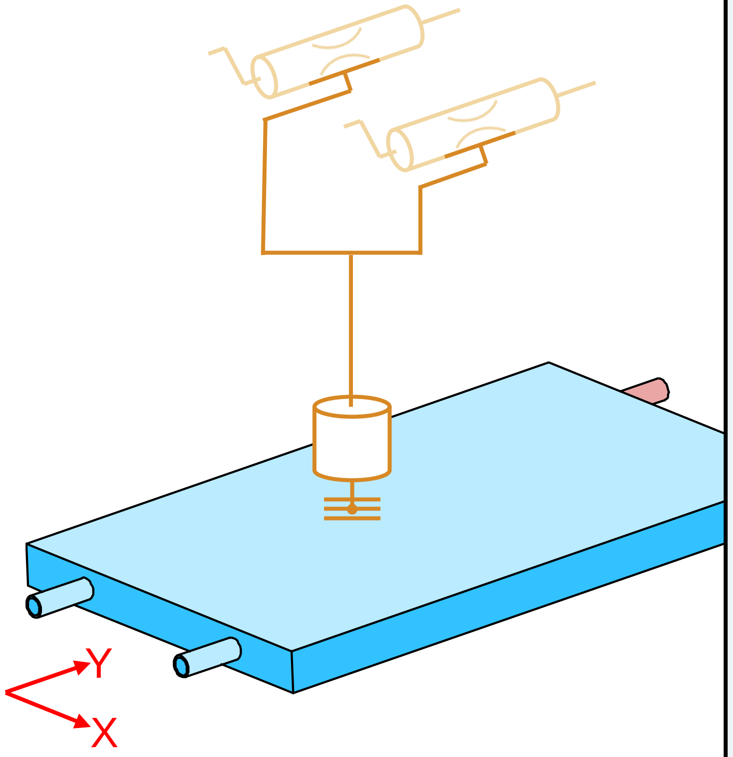


» More to Model Resolution

Finding the Tradeoff Between Calculation Speed and Precision

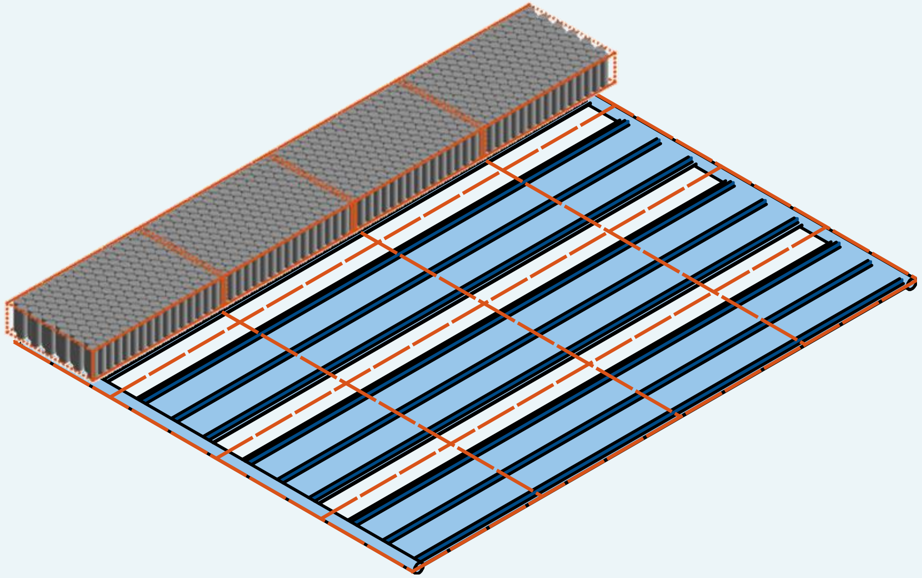
Choosing the right model fidelity for the plate

Lumped plate

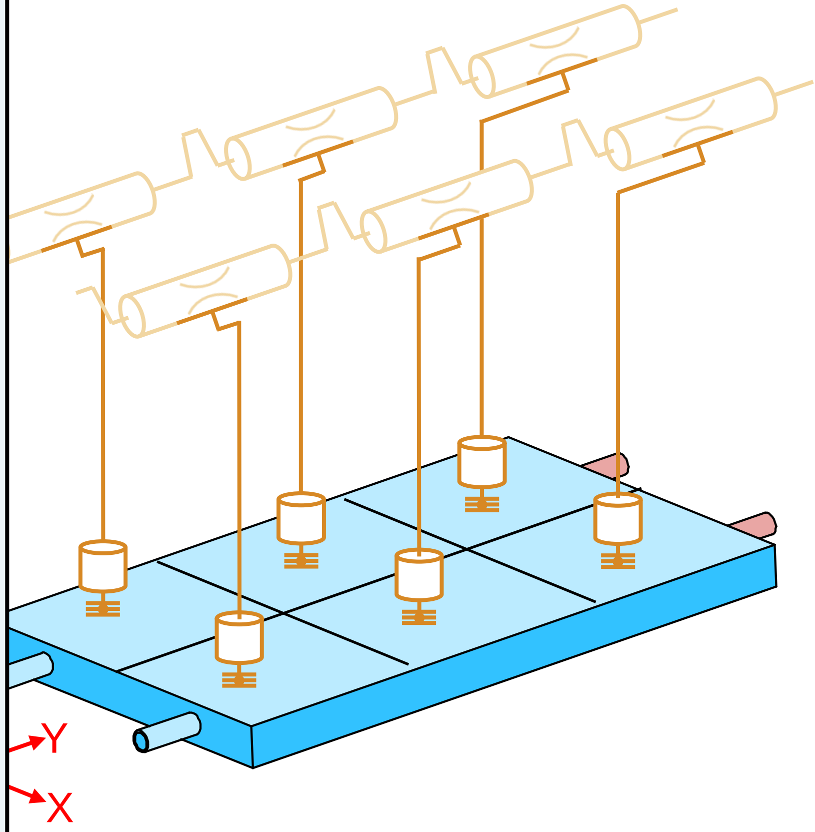


Implementation

The plate was discretized in a 4 by 4 layout as shown below:

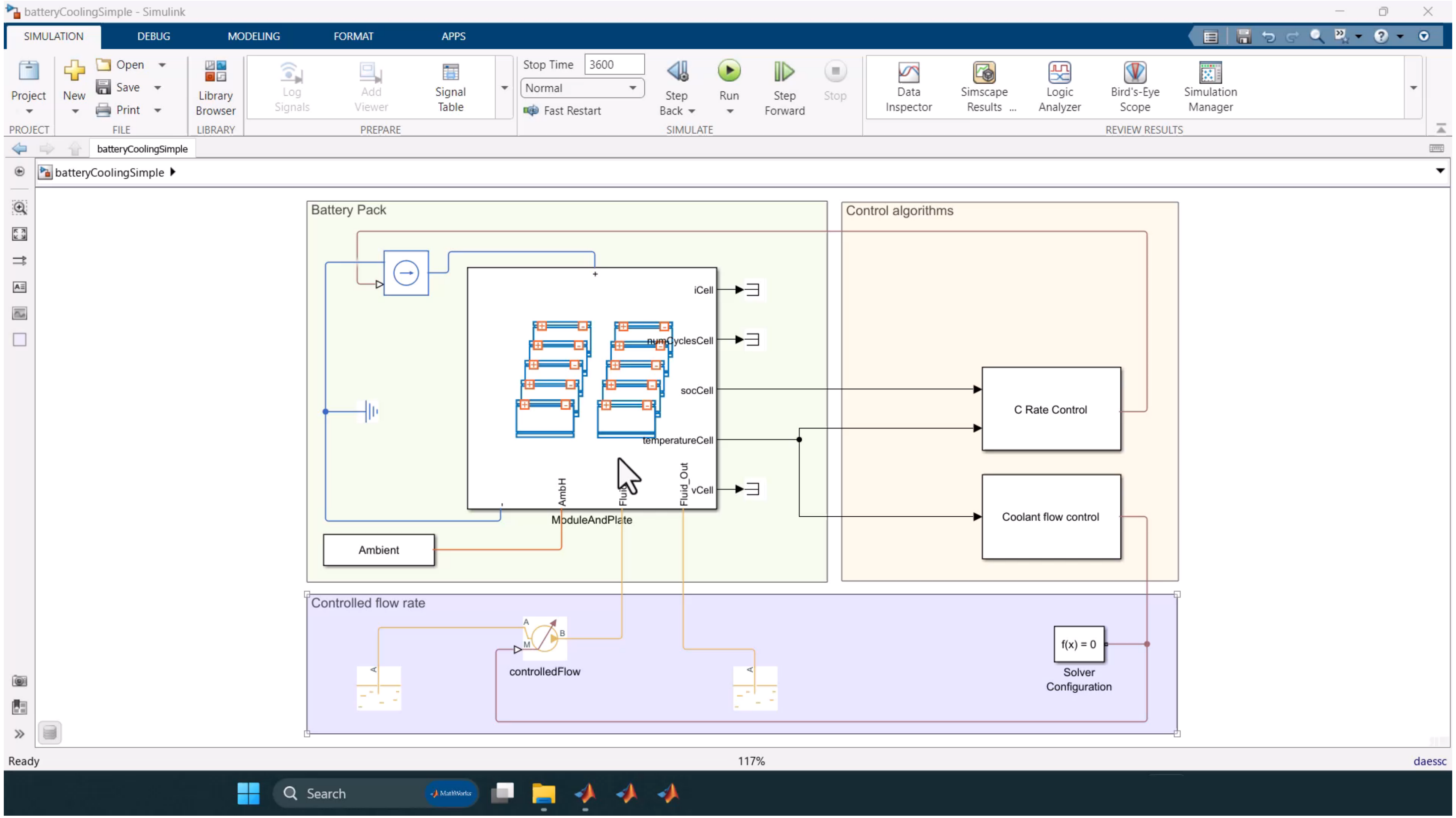


Discretized along X & Y



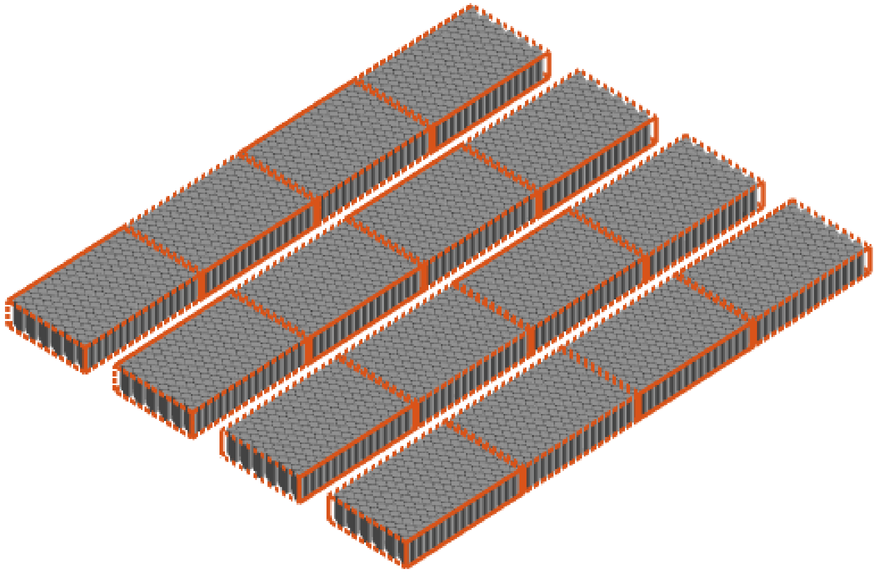
Simulating Fast-Charge Behavior

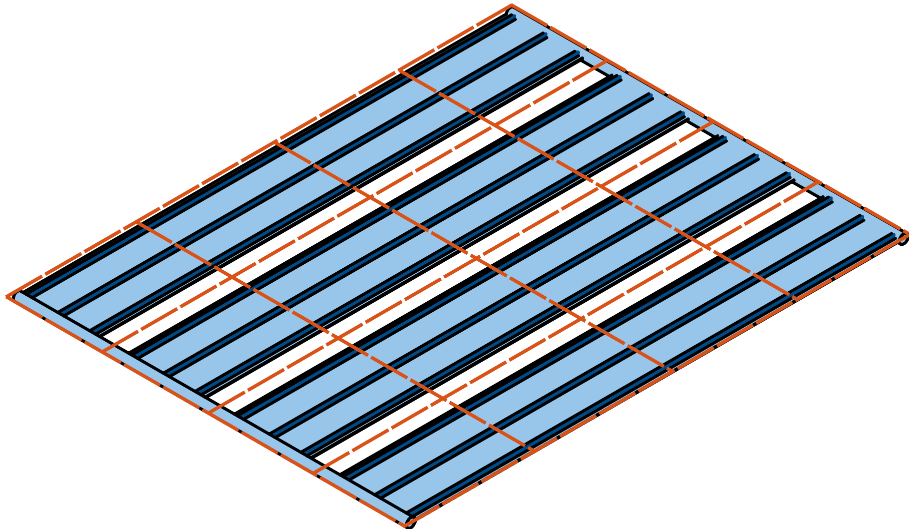
Understanding the model implementation



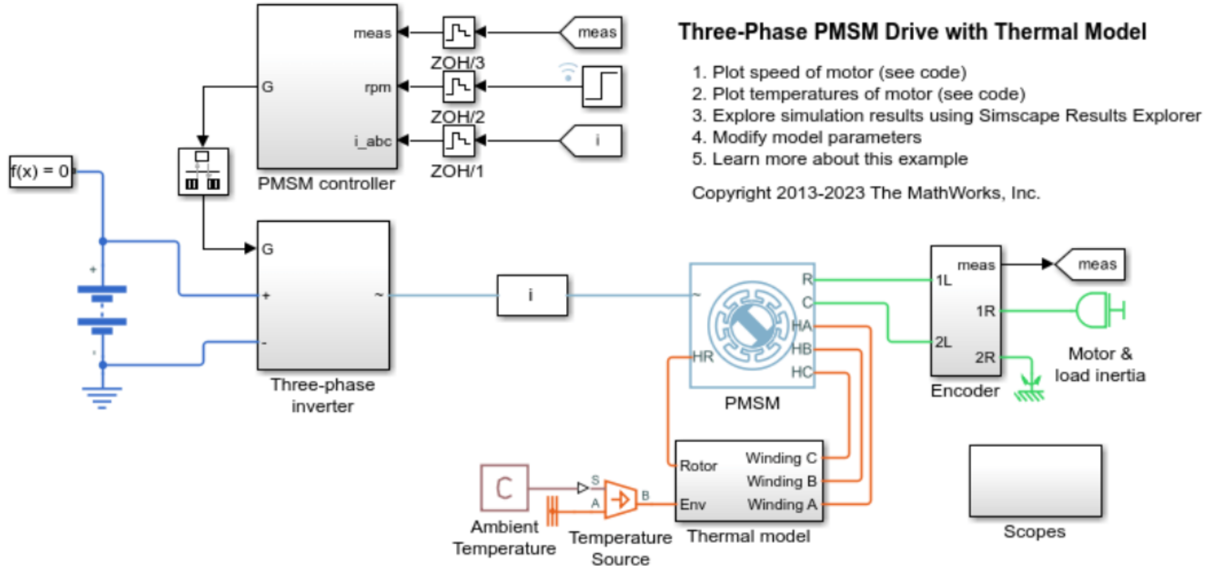
Simulating Fast-Charge Behavior

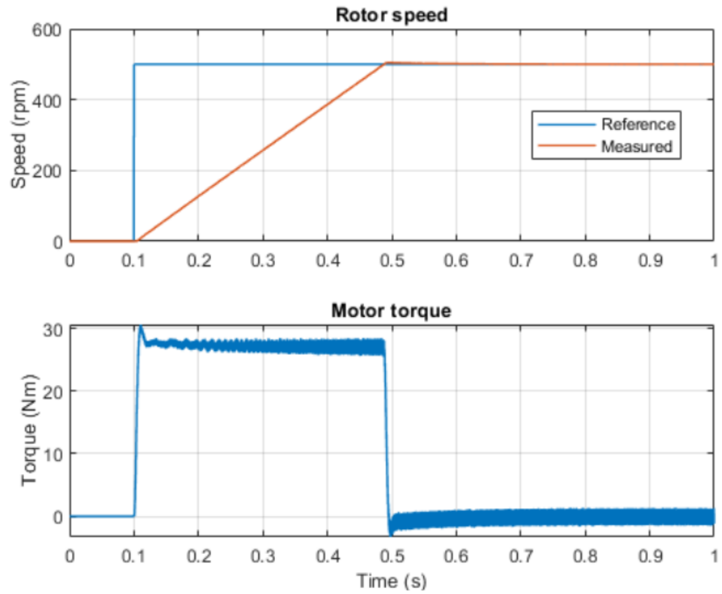
Results

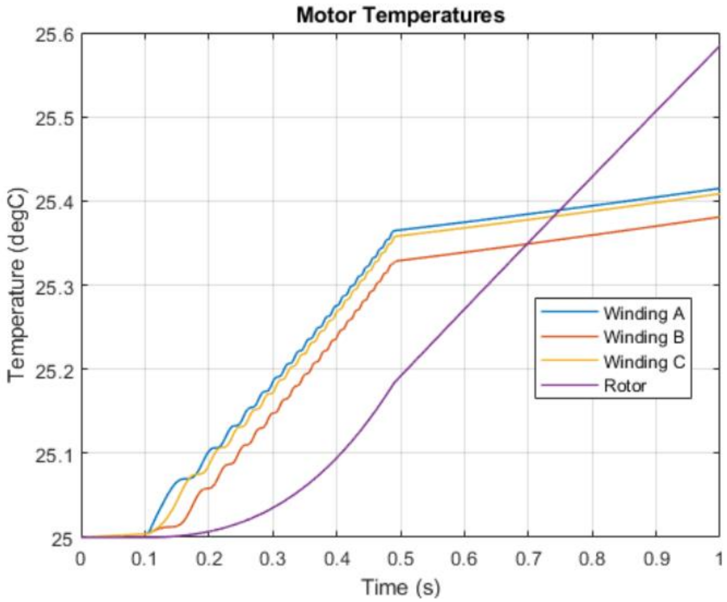




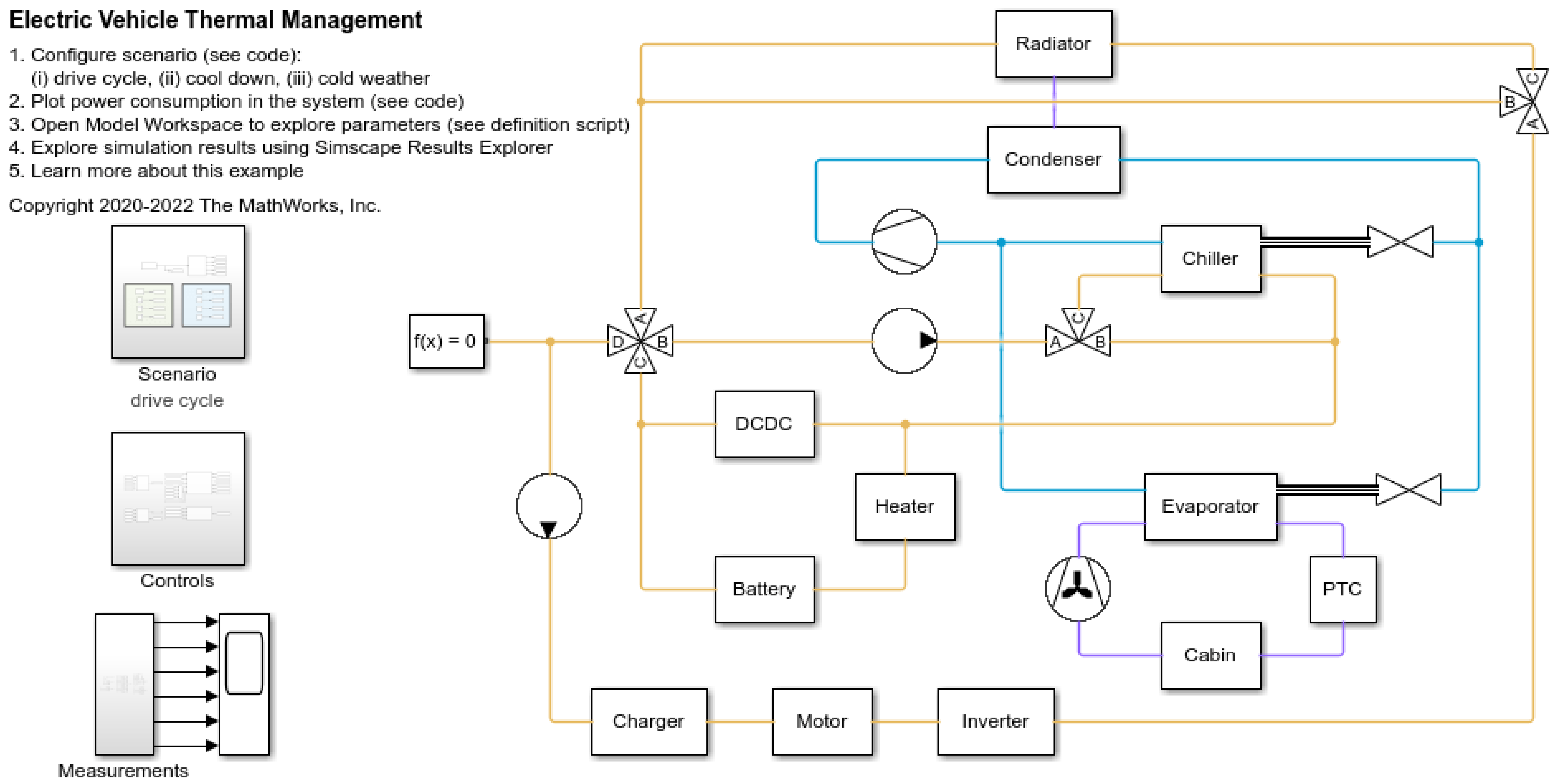
E-Powertrain





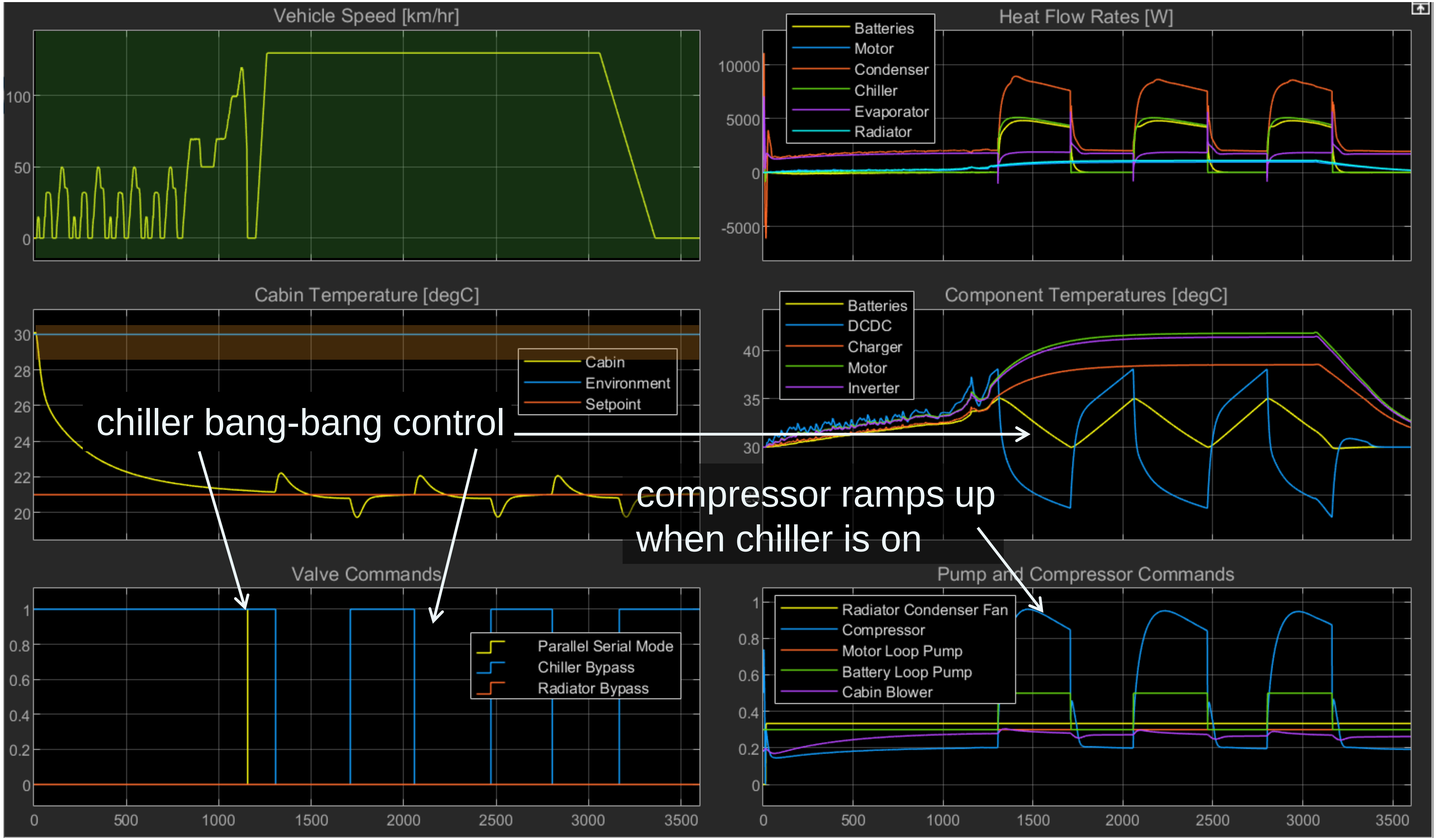


Electric Vehicle Thermal Management



» [EV Thermal Management System]

Drive cycle scenario shows serial to parallel mode transition



Test Cases

Component-level

- Battery Thermal Behaviour for Fast Charing
- PMSM controller simulation for performance
- EV Thermal Management controller performance

Interested to understand the performance of these subsystems when integrated with System Level Simulation!!

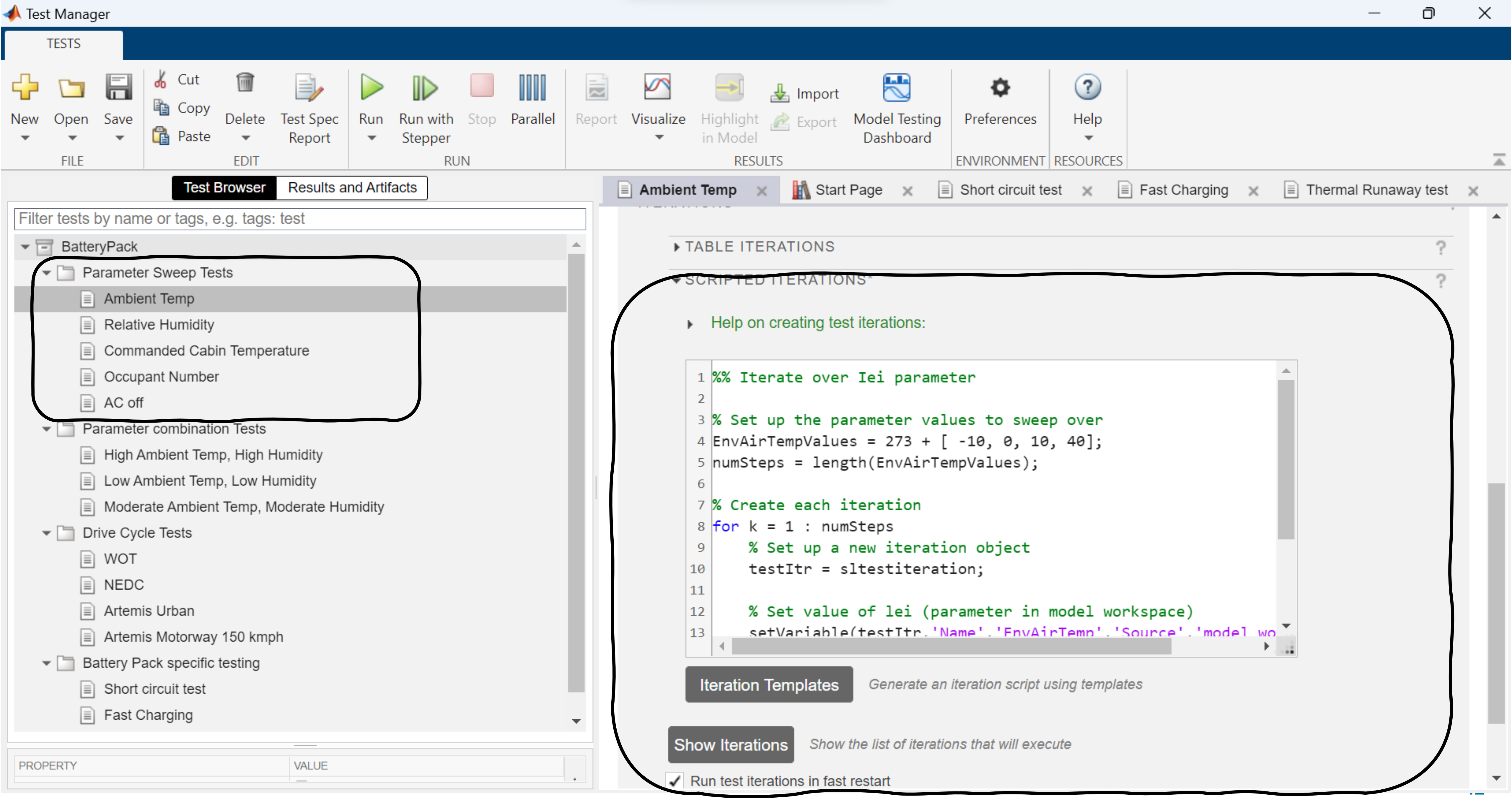
Test Cases

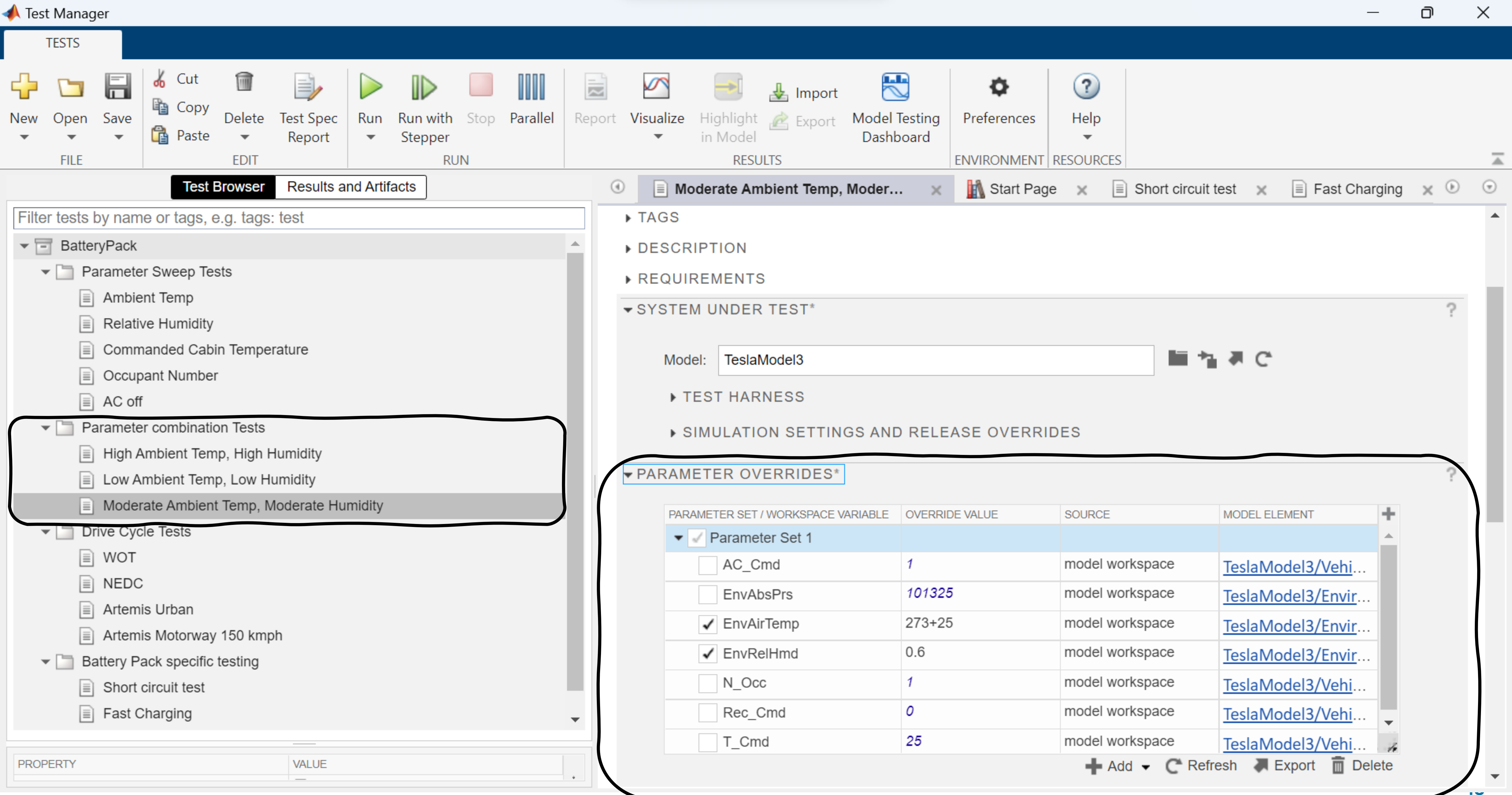
System-Level

- AC-on/off-Humidity/Temp/Elevation
- AC-on/off-Humidity/Temp/Elevation
- Different Drive cycles- MIDC/WOT

Component-level

- Battery Thermal Behaviour for Fast Charing
- PMSM controller simulation for performance
- EV Thermal Management controller performance


Test Manager
TESTS
New
Open
Save
FILE
Cut
Copy
Paste
Delete
Test Spec Report
EDIT
Run
Run with Stepper
Stop
Parallel
RUN
Report
Visualize
Highlight in Model
Import
Export
Model Testing Dashboard
RESULTS
Preferences
ENVIRONMENT
Help
RESOURCES
Test Browser
Results and Artifacts
Filter tests by name or tags, e.g. tags: test
BatteryPack
Parameter Sweep Tests
Ambient Temp
Relative Humidity
Commanded Cabin Temperature
Occupant Number
AC off
Parameter combination Tests
High Ambient Temp, High Humidity
Low Ambient Temp, Low Humidity
Moderate Ambient Temp, Moderate Humidity
Drive Cycle Tests
WOT
NEDC
Artemis Urban
Artemis Motorway 150 kmph
Battery Pack specific testing
Short circuit test
Fast Charging
PROPERTY
VALUE
Ambient Temp
Start Page
Short circuit test
Fast Charging
Thermal Runaway test
TABLE ITERATIONS
SCRIPTED ITERATIONS*
Help on creating test iterations:
%% Iterate over Iei parameter
% Set up the parameter values to sweep over
EnvAirTempValues = 273 + [-10, 0, 10, 40];
numSteps = length(EnvAirTempValues);
% Create each iteration
for k = 1 : numSteps
% Set up a new iteration object
testItr = sltestiteration;
% Set value of Iei (parameter in model workspace)
Iteration Templates
Generate an iteration script using templates
Show Iterations
Show the list of iterations that will execute
Run test iterations in fast restart


Test Manager
TESTS
New
Open
Save
FILE
Cut
Copy
Paste
Delete
Test Spec Report
EDIT
Run
Run with Stepper
Stop
Parallel
RUN
Report
Visualize
Highlight in Model
Import
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RESULTS
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Ambient Temp
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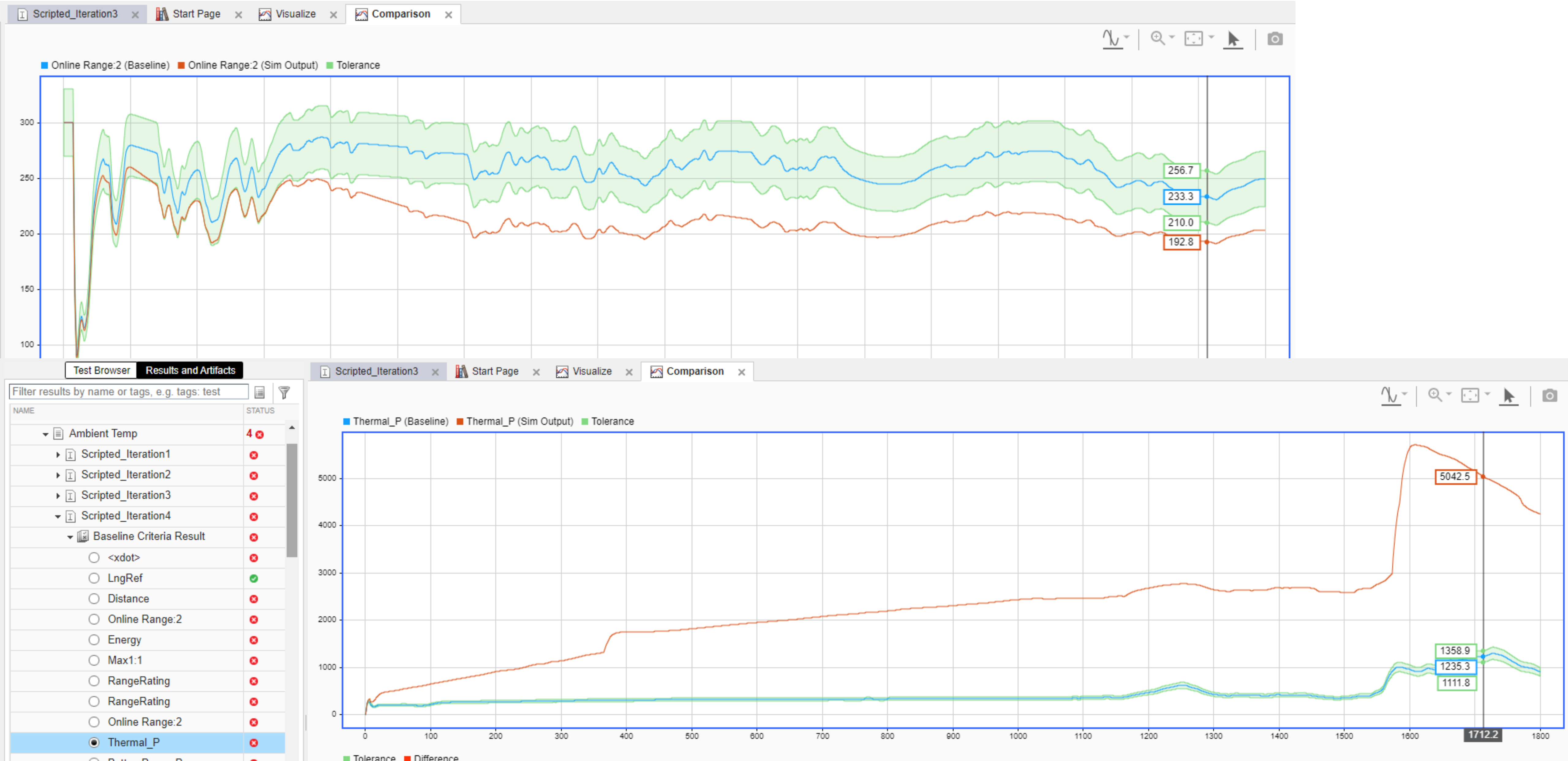
Occupant Number
AC off
Parameter combination Tests
High Ambient Temp, High Humidity
Low Ambient Temp, Low Humidity
Moderate Ambient Temp, Moderate Humidity
Drive Cycle Tests
WOT
NEDC
Artemis Urban
Artemis Motorway 150 kmph
Battery Pack specific testing
Short circuit test
Fast Charging
PROPERTY
VALUE
Moderate Ambient Temp, Moder...
Start Page
Short circuit test
Fast Charging
TAGS
DESCRIPTION
REQUIREMENTS
SYSTEM UNDER TEST*
Model:
TeslaModel3
TEST HARNESS
SIMULATION SETTINGS AND RELEASE OVERRIDES
PARAMETER OVERRIDES*
PARAMETER SET / WORKSPACE VARIABLE
OVERRIDE VALUE
SOURCE
MODEL ELEMENT
Parameter Set 1
AC_Cmd
1
model workspace
TeslaModel3/Vehi...
EnvAbsPrs
101325
model workspace
TeslaModel3/Envir...
EnvAirTemp
273+25
model workspace
TeslaModel3/Envir...
EnvRelHmd
0.6
model workspace
TeslaModel3/Envir...
N_Occ
1
model workspace
TeslaModel3/Vehi...
Rec_Cmd
0
model workspace
TeslaModel3/Vehi...
T_Cmd
25
model workspace
TeslaModel3/Vehi...
Add
Refresh
Export
Delete

Baseline results:

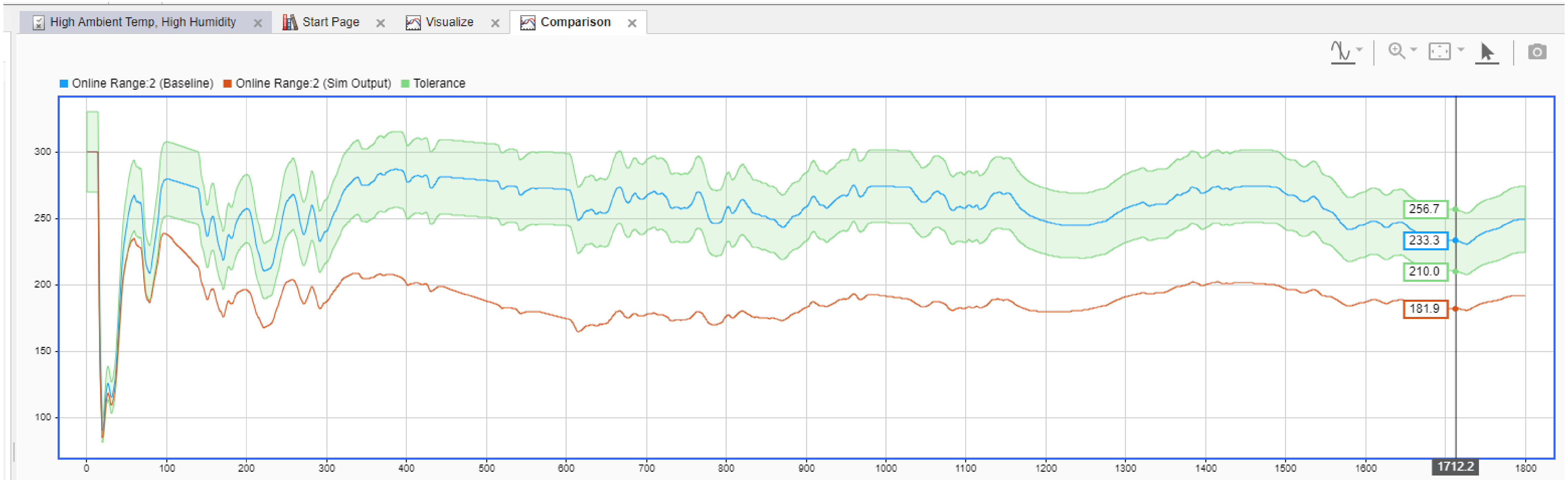
- 30 degC
- 0.4 relative humidity
- Cabin Temp: 25 degC
- WLTP Class 3
- 1 passenger

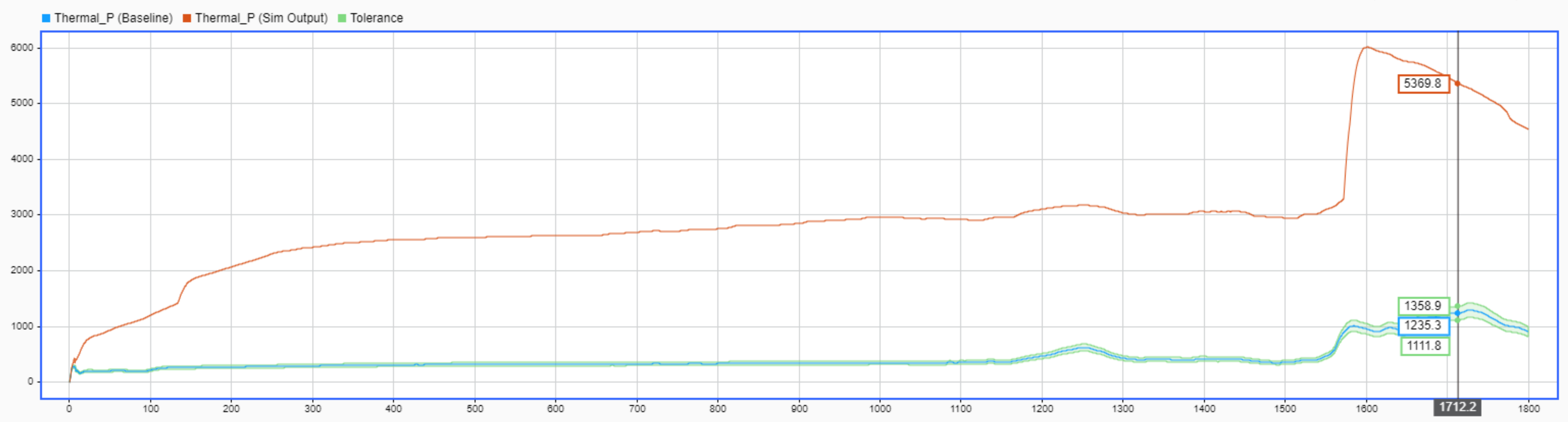
on Data Inspector - SDIsession.mldatx
Inspect
Compare
er Signals
NAME
LI...
Run 1: TeslaModel3
Signals
TeslaModel3/Range Estima
TeslaModel3/Range Estima
chive
operties
<xdot>
LngRef
SOC Ratio to %:1
SS_batt_current
T_cabin
T_env
T_setpoint
Thermal_P
BatteryPump_P
Blower_P
Compressor_P
Condenser_P
MotorPump_P
cmd_fan
cmd_comp
cmd_motor_pump
cmd_battery_pump
cmd_blow
467.4
30.0
25.7
25.0
38.4
38.1
36.8
31.5
30.1
99.89
0.6
314.5
243.5
65.1
2.9
1.3
0.33*
0.30*
0.30*
0.15

Effect of Ambient Temperature: 45 degC



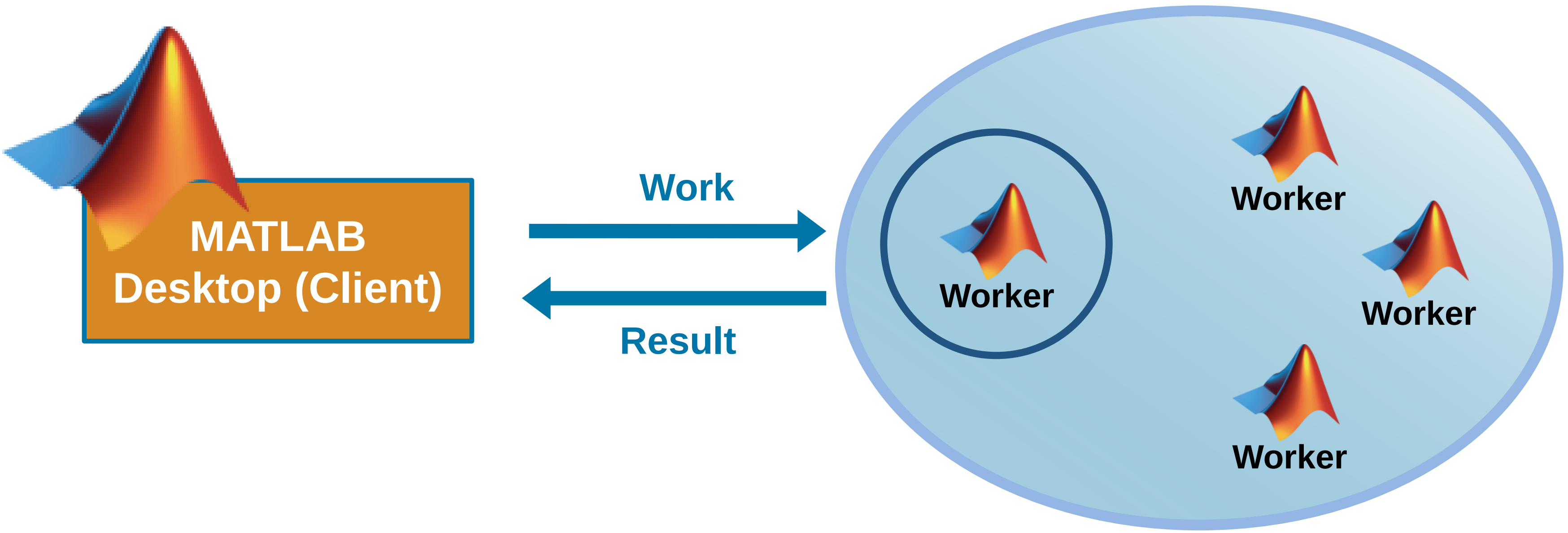
Effect of High Ambient Temperature and High Humidity





Offloading Serial Computations

- `job = batch(...);`



Simulation Manager

Live Editor - /home/lgarcia/Documents/MATLAB/ai-with-mbd-reduced-order-modeling/Part 0 - Synthetic Data Generation/DataGeneration_DoE.mlx *

Parameter initialization and Variation Parameter Range

Sampling time

```
dt = 0.1;
```

We need each parameter's min-max range to create a DoE list.

```
parameterVariationRangeFilename = fullfile(projectPath, "Part 0 - Synthetic Data Generation", "ParameterVariationRange.xlsx");
parameterVariationRange = readtable(parameterVariationRangeFilename);
```

Set initial Parameters

```
EngTrqReq  = parameterVariationRange.init(parameterVariationRange.names == "EngTrqReq");
EngSpdReq  = parameterVariationRange.init(parameterVariationRange.names == "EngSpdReq");
SpkAdvOfst = parameterVariationRange.init(parameterVariationRange.names == "SpkAdvOfst");
```

Set the maximum rate of change for each parameter

```
d_EngSpd = 1000;
d_EngTrq = 100;
d_SpkAdv = 10;
```

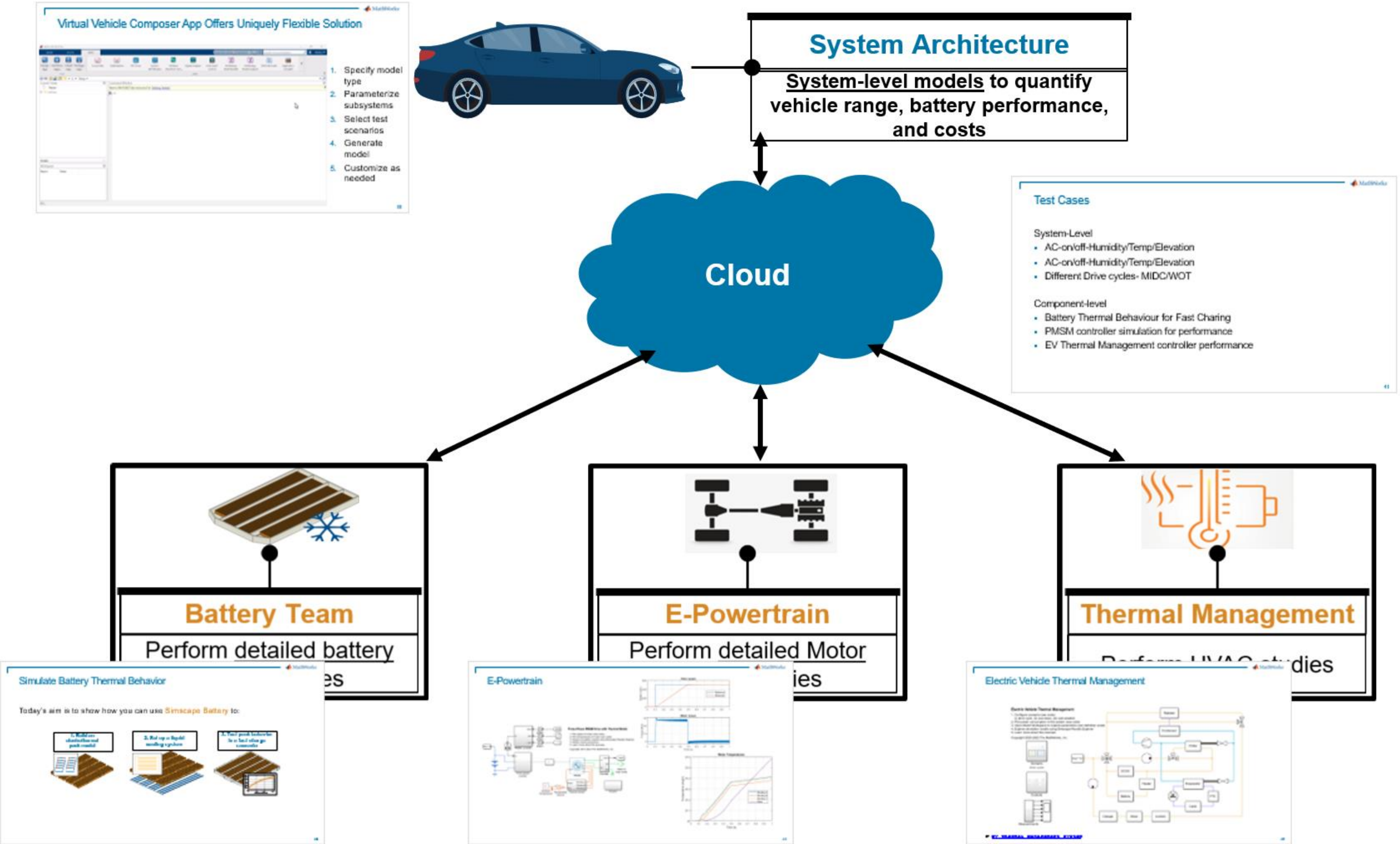
Create DoE List

Choose a method to create a DoE list

```
DoE_num = 512;
DoE_type = "Sobol Sequence";
library = "stats";

if library == "stats" % Requires Statitics and Machine Learning Toolbox
    DoE = helper.DoE_sbl(parameterVariationRange, DoE_num);
else                  % Requires Model Based Calibration Toolbox
    DoE = helper.DoE_mbc(parameterVariationRange, DoE_num, DoE_type);
end

f = figure('Name', 'DoE_Plot');
ax3d = axes('Position', [0.12 0.12 0.3 0.3]);
helper.multi_plot(DoE{:,:},'r.','r-',1,ax3d,parameterVariationRange.names);
```


Virtual Vehicle Composer App Offers Uniquely Flexible Solution
1. Specify model type
2. Parameterize subsystems
3. Select test scenarios
4. Generate model
5. Customize as needed
System Architecture
System-level models to quantify vehicle range, battery performance, and costs
Cloud
Test Cases
System-Level
AC-on/off-Humidity/Temp/Elevation
AC-on/off-Humidity/Temp/Elevation
Different Drive cycles- MIDC/WOT
Component-level
Battery Thermal Behaviour for Fast Charing
PMSM controller simulation for performance
EV Thermal Management controller performance
Battery Team
Perform detailed battery
E-Powertrain
Perform detailed Motor
Thermal Management
Simulate Battery Thermal Behavior
Today's aim is to show how you can use Simscape Battery to:
E-Powertrain
Electric Vehicle Thermal Management

Start the transformation with the right support

- ► Trials and evaluations
- ► Consulting services
- ► Training services
- ► Technical support

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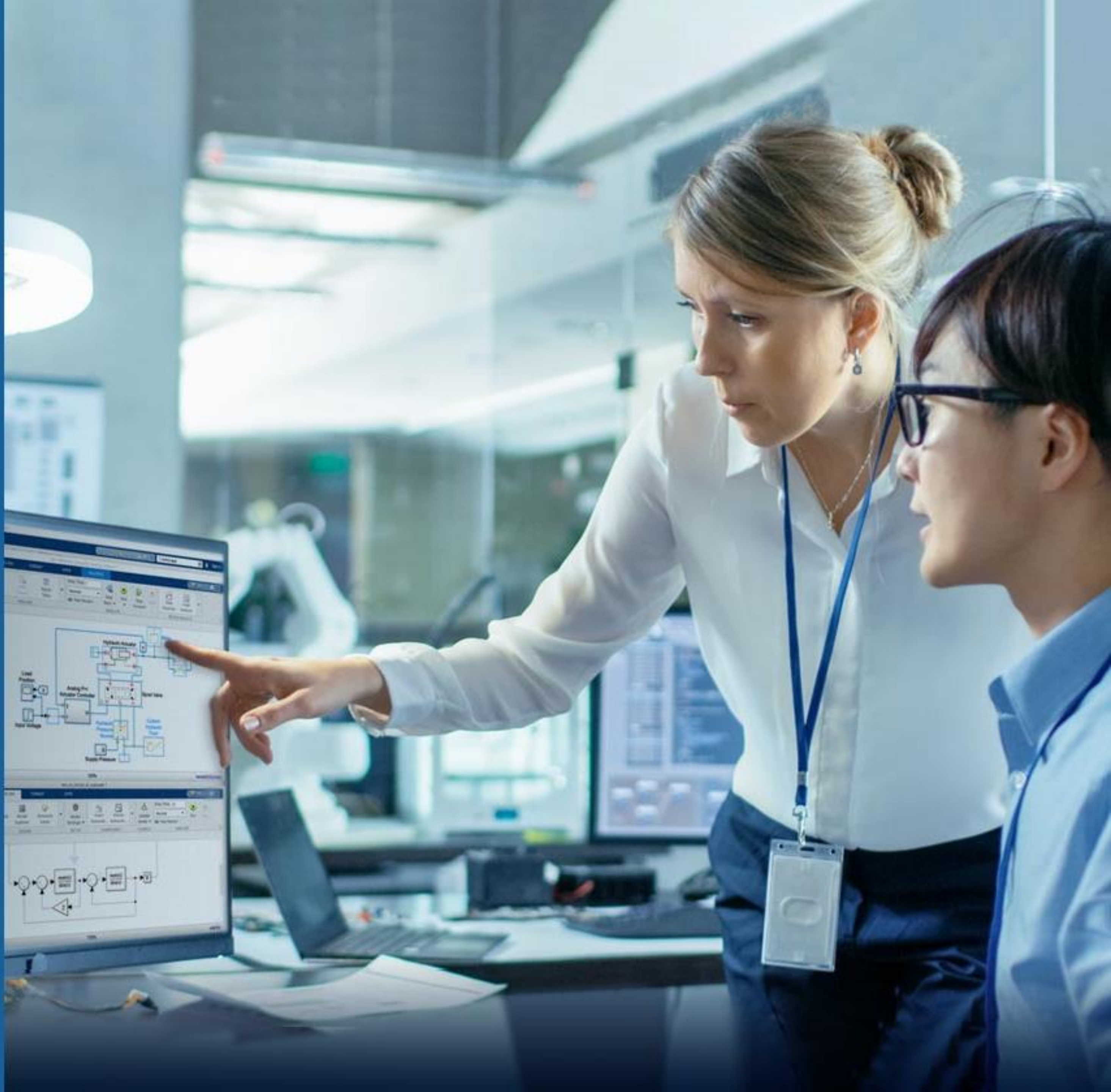

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