MATLAB EXPO

Going Beyond the Electrical in Modelling Energy Storage Systems

Tom Grimble, MathWorks

MathWorks®

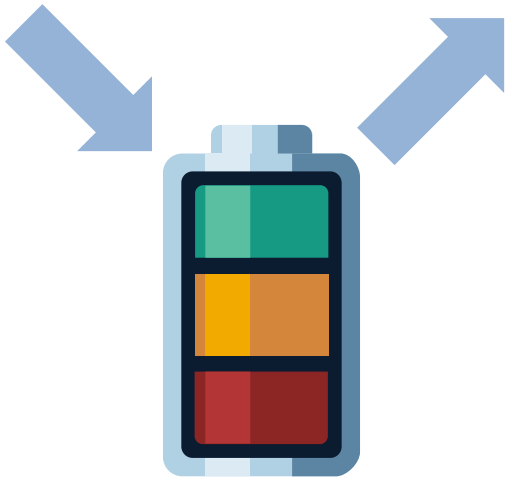
Key Takeaways

- Energy Storage can extend far beyond just electrical modeling
- Critical to simulate real world power storage challenges
- Use MATLAB & Simulink to accelerate problem solving throughout the design cycle

Growth in Grid Connected Energy Storage

The way we generate energy is changing

The way we use energy is changing

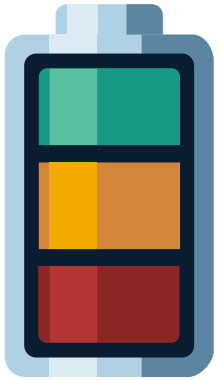


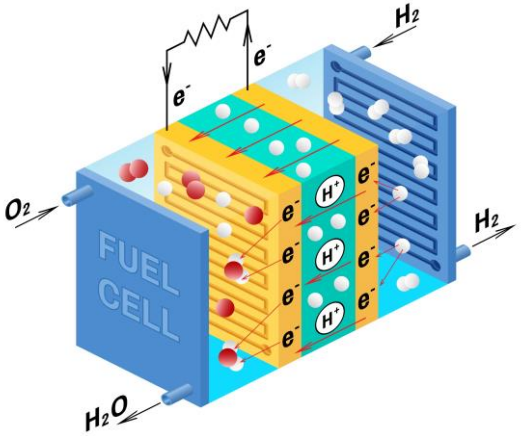
More than 80GW of energy storage projects proposed and under development across the UK

Energy Storage is not just Batteries

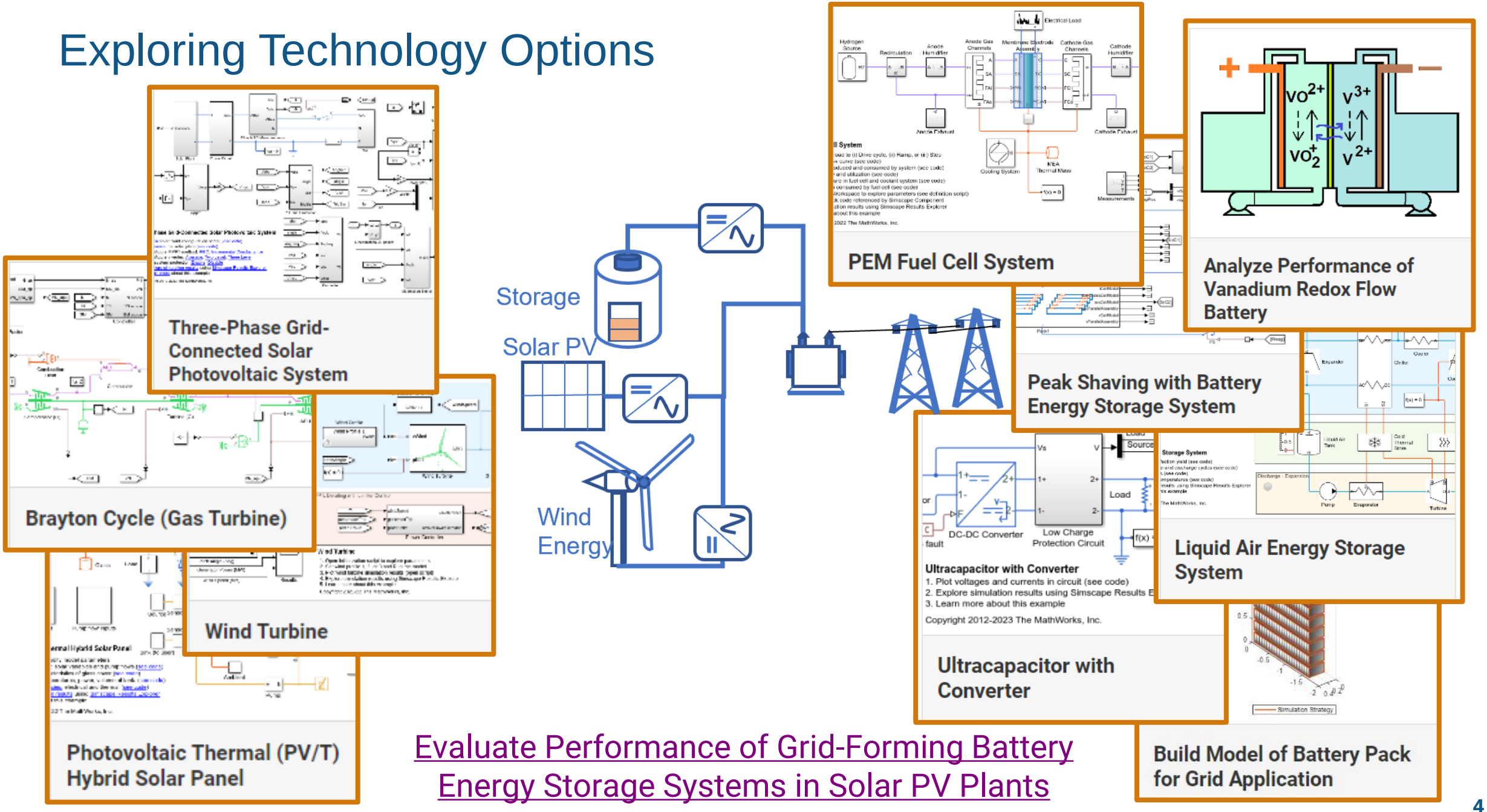
How long do we need to store energy for?

Seconds Minutes Hours Days Weeks Months Years





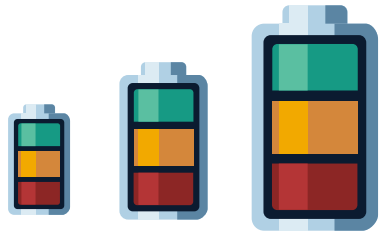
Exploring Technology Options



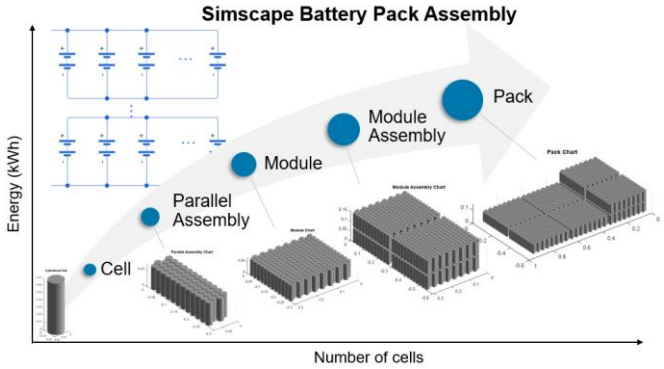
[Evaluate Performance of Grid-Forming Battery Energy Storage Systems in Solar PV Plants]

Different Phases of Design

- System concepts, sizing and costs

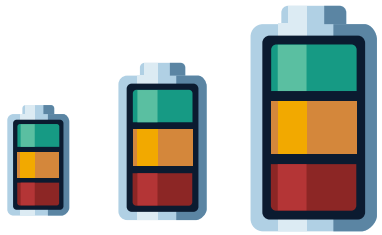


- Detailed component & control design



- Modelling faults to design protection systems

Concept Stage

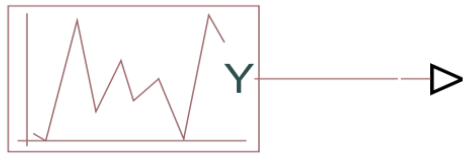


System Exploration

Technoeconomic analysis

Water

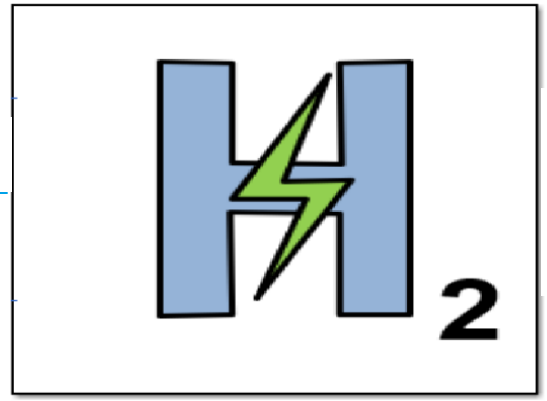
Early design with many assumptions



Sun
(irradiance)

Solar Array

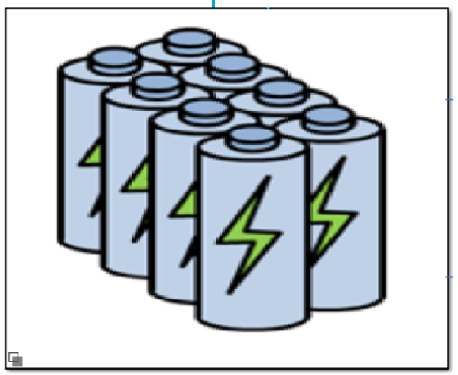
Electricity



Electrolyzer

Hydrogen
(gas)

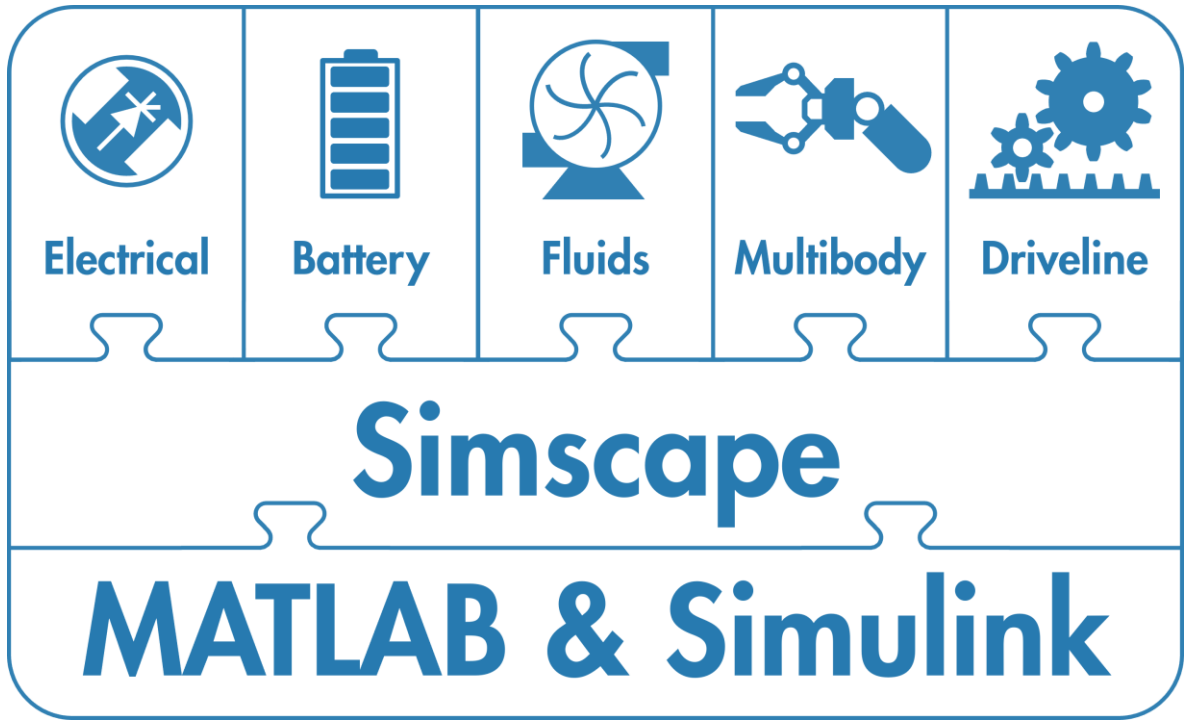
Predict performance over a year

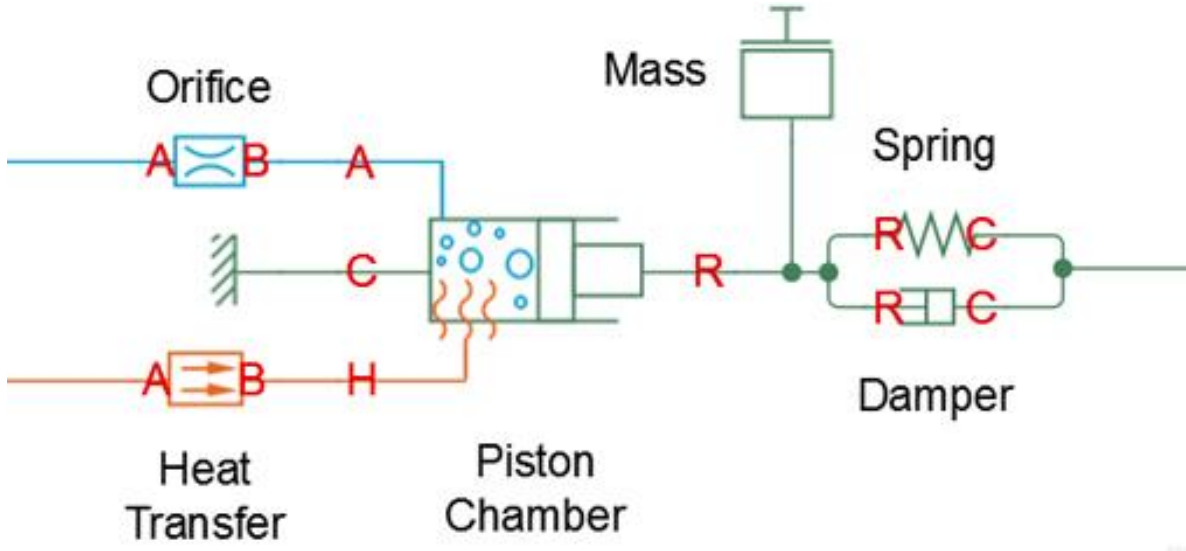


Energy storage

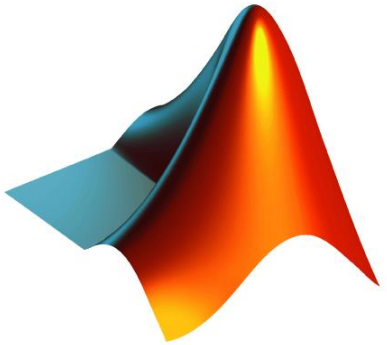
Identify optimal location

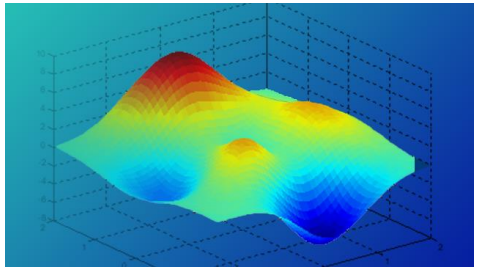
Cost Analysis with MATLAB & Simulink



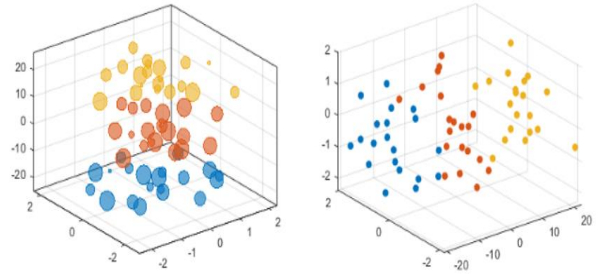


What about £ ?

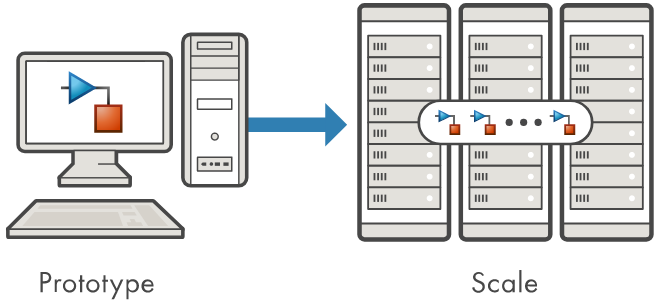




Optimization Algorithms



Visualization



Parallelization & Scaling

MATLAB R2023a

Try the New Desktop | Search Documentation | Tom

New | Open | Save | Compare | Print | Export | NAVIGATE | Text | Normal | B I U M | CODE | SECTION | Run | Step | Stop | FILE | TEXT | RUN

C: ▸ Users ▸ tgrimble ▸ Dev ▸ green-hydrogen-production ▸ 8760 ▸

Live Editor - C:\Users\tgrimble\Dev\green-hydrogen-production\8760\parsimScenariosLive.mlx

parsimScenariosLive.mlx | untitled.mlx * | locatonsSearch.m | parsimScenarios.m

Energy System Design Exploration with MATLAB & Simulink

```
1  loadPriceData;
2
3  load('StationData_UPDATE');
4  vertcat(StationData.Name)
```

Plot a sample

```
5  f = figure;
6  t= tiledlayout(f,2,1);
7
8  a = nexttile;
9  plot(a,1:1:24*365,StationData(1).Irradiance);
10 xlabel("Time (hours)")
11 ylabel("Irradiance (W/m^2)")
12
13 b = nexttile;
14 plot(b,1:1:24,price24)
15 xlabel("Time (hours)")
16 ylabel("Price ($/MWh)")
```

Define scenario input objects

```
17 simIn = Simulink.SimulationInput('green_hydrogen_microgrid_ROM_8760')
```

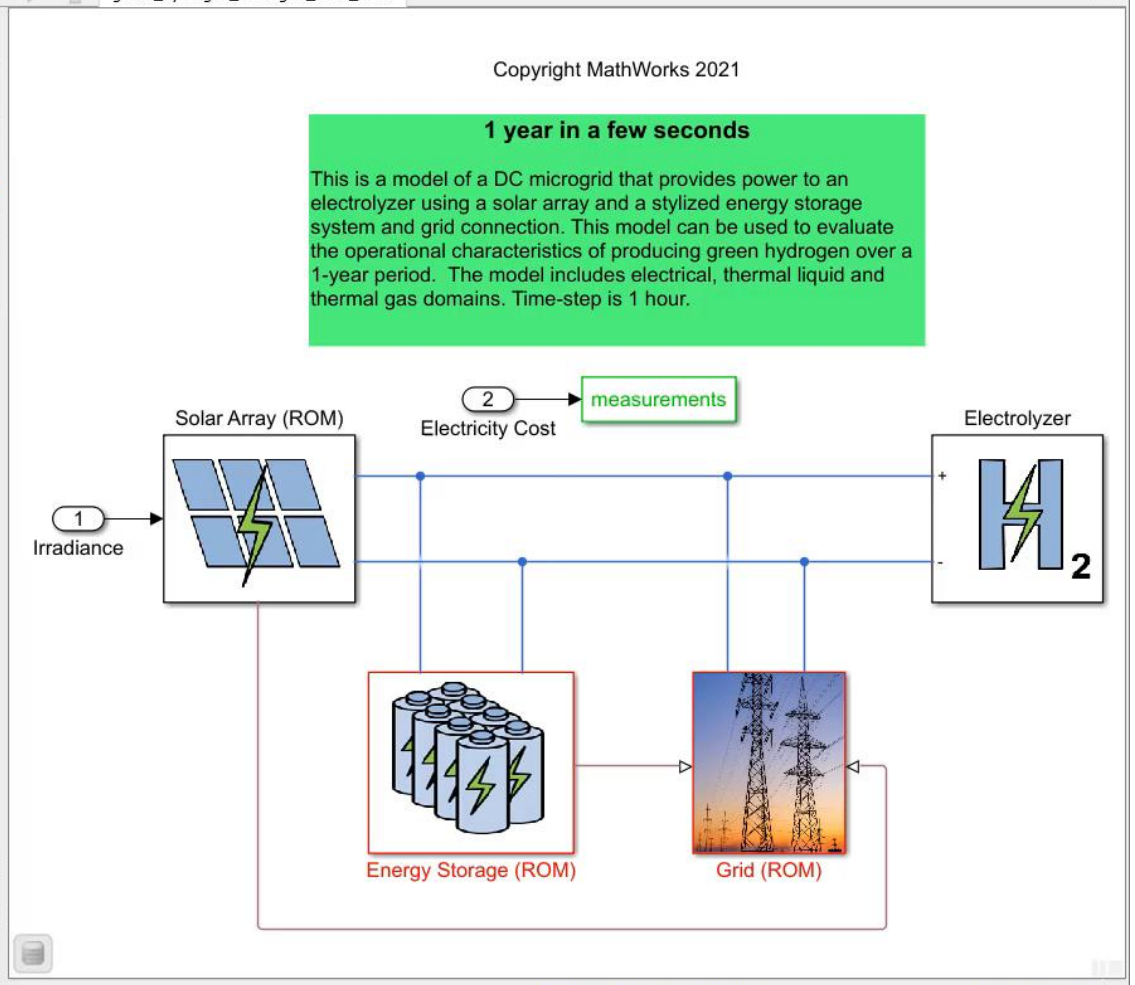
Zoom: 100% | UTF-8 | LF | script | Ln 4 | Col 26

green_hydrogen_microgrid_ROM_8760 - Simulink

SIMULATION | DEBUG | MODELING | FORMAT | APPS

PROJECT | FILE | LIBRARY | PREPARE | Stop Time 24*3600*3 | Normal | Fast Restart | Step Back | Run | Step Forward | Stop | SIMULATE | REVIEW RESULTS

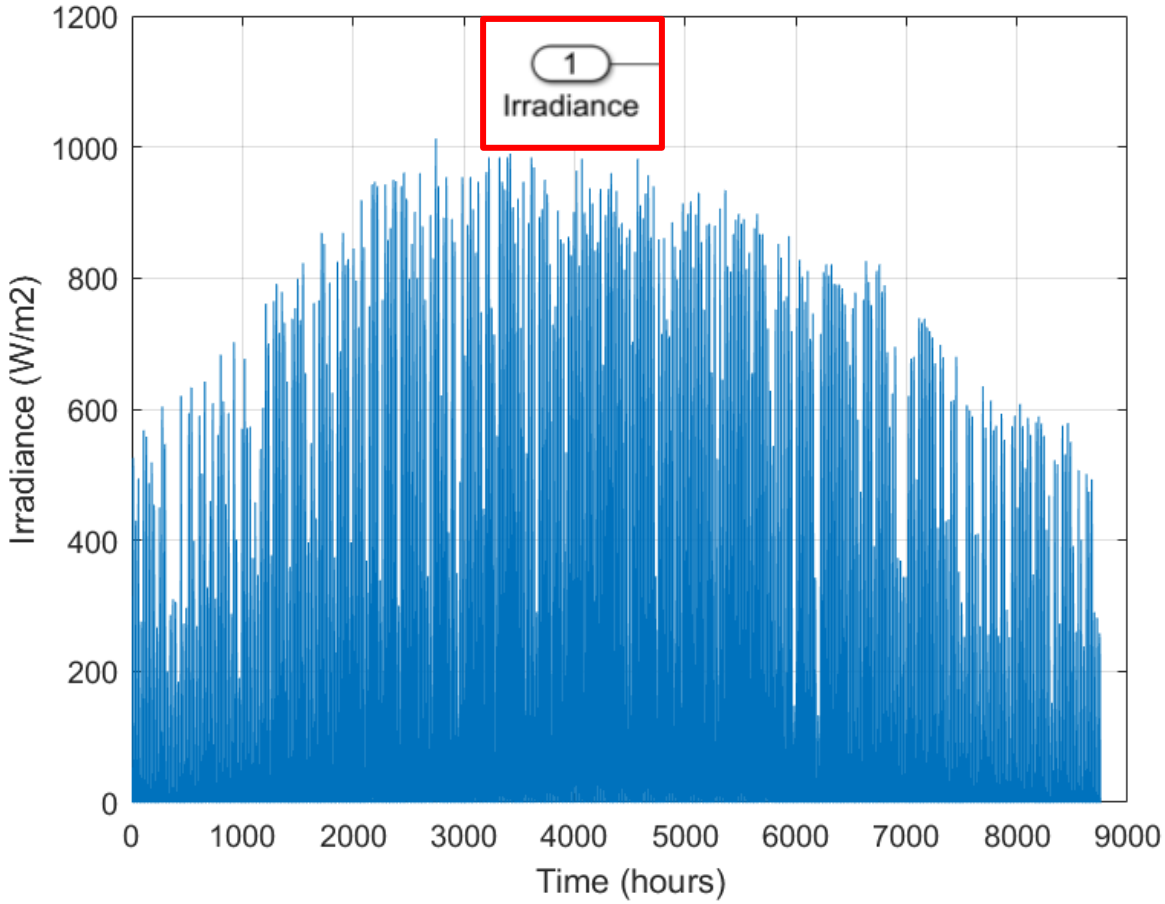
green_hydrogen_microgrid_ROM_8760



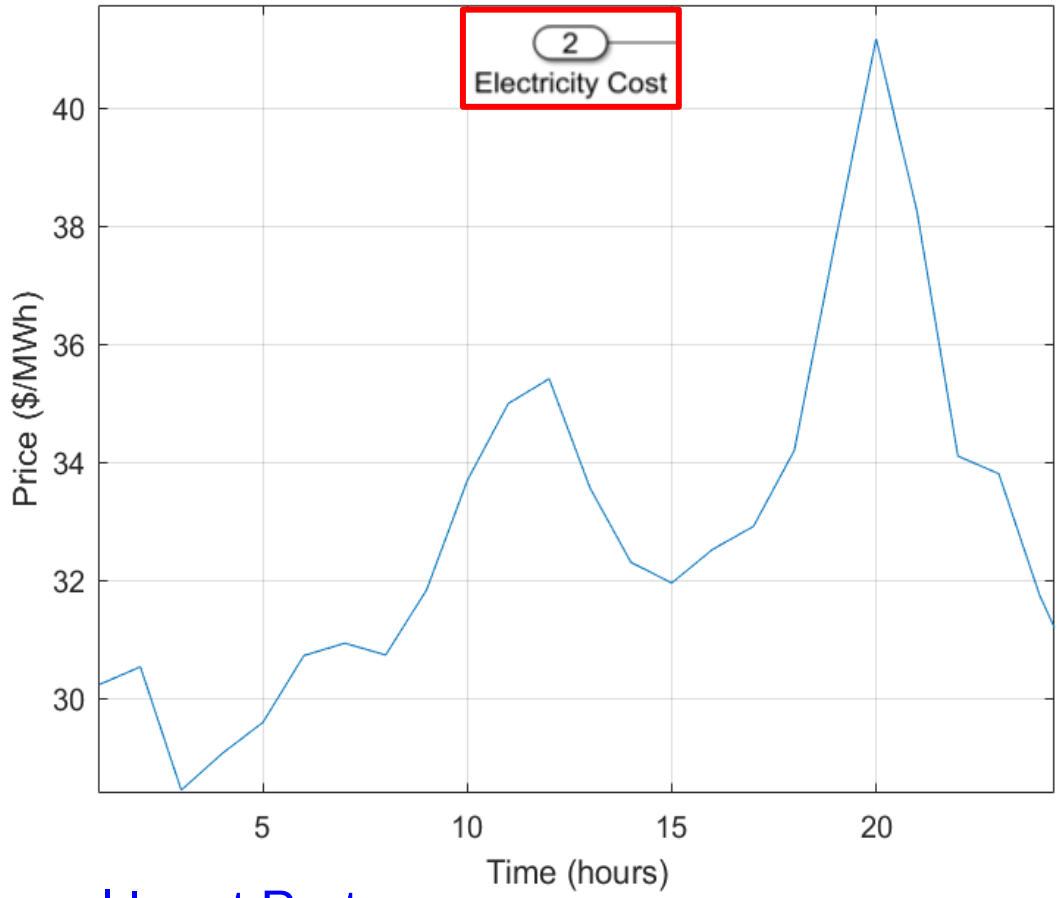
Ready | Completed 242 simulations | 108% | FixedStepAuto

Injecting Real World Data

The irradiance data is 8760 TMY3 from National Renewable Energy Laboratory.



Electricity price data is averaged one day of data from system operators.



Load Data to Root-Level Input Ports

Goal of Simulation / Level of Fidelity

Detailed component modelling — System level modelling

Control Response Dynamics

- Modeling mechanical balance
- Understanding fault scenarios and impacts on performance
- Setting tolerance requirements

Quasi-Steady State

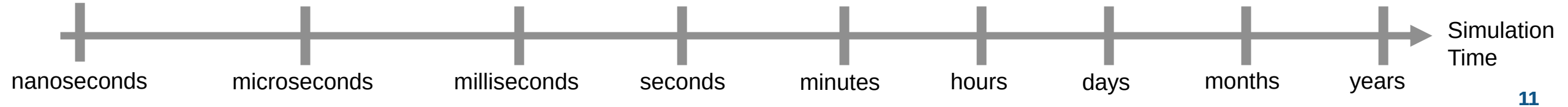
- Energy flow simulation
- Idealized power sources and loads
- Used for sizing & planning purposes (e.g. energy storage)

High Frequency Power Electronic Switching

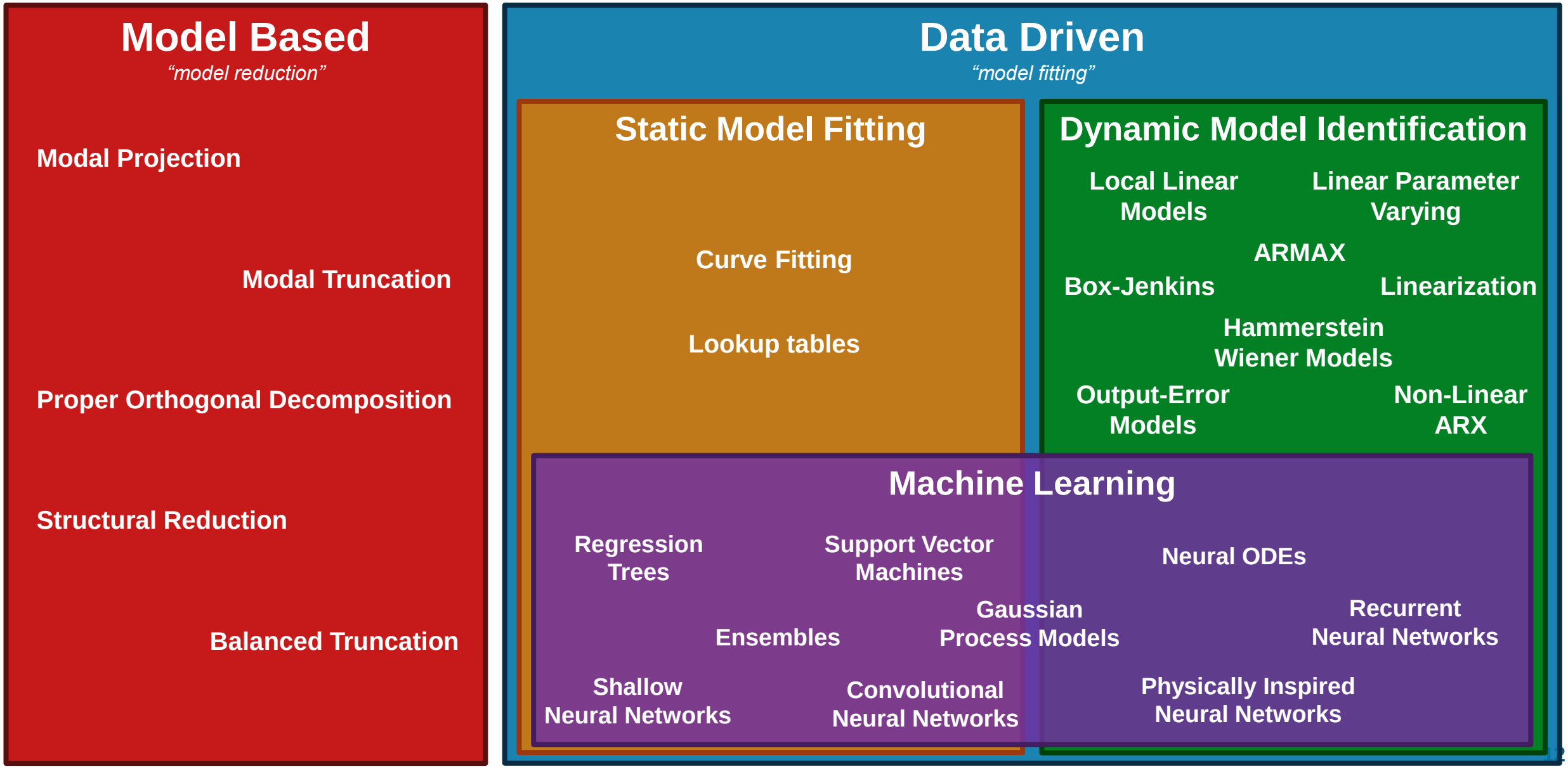
- Detailed modelling of semiconductors and converter dynamics
- Optimizing waveforms and losses at component level

Thermal dynamics

- Transient thermal response
- Coupling thermal dependency to electrical performance



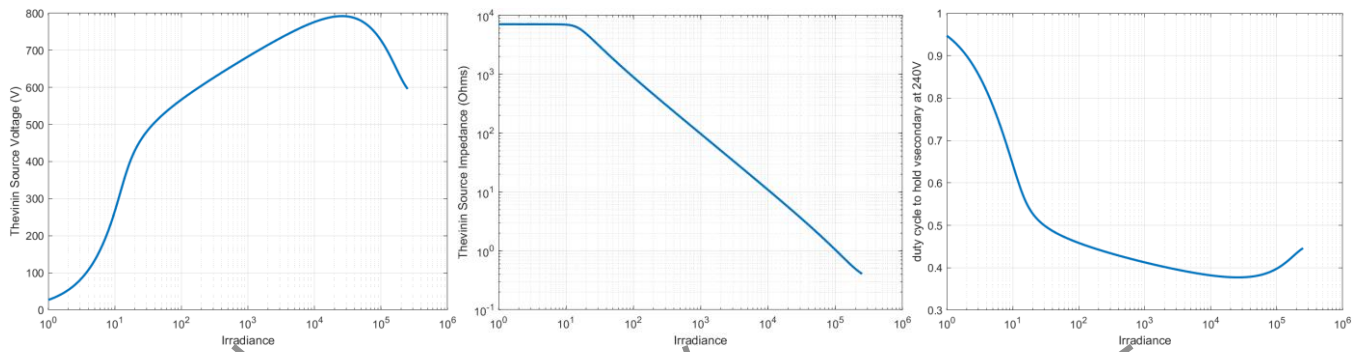
Techniques for Reduced Order Modelling



ROM Implementation

Performance assessment

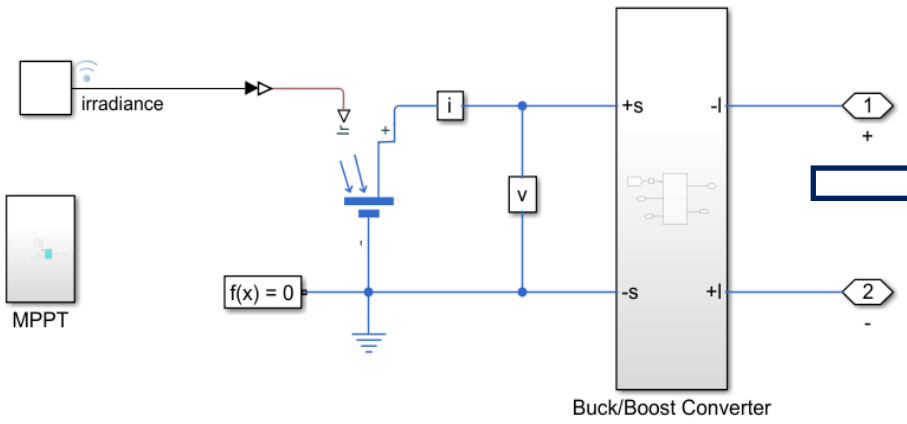
Medium fidelity



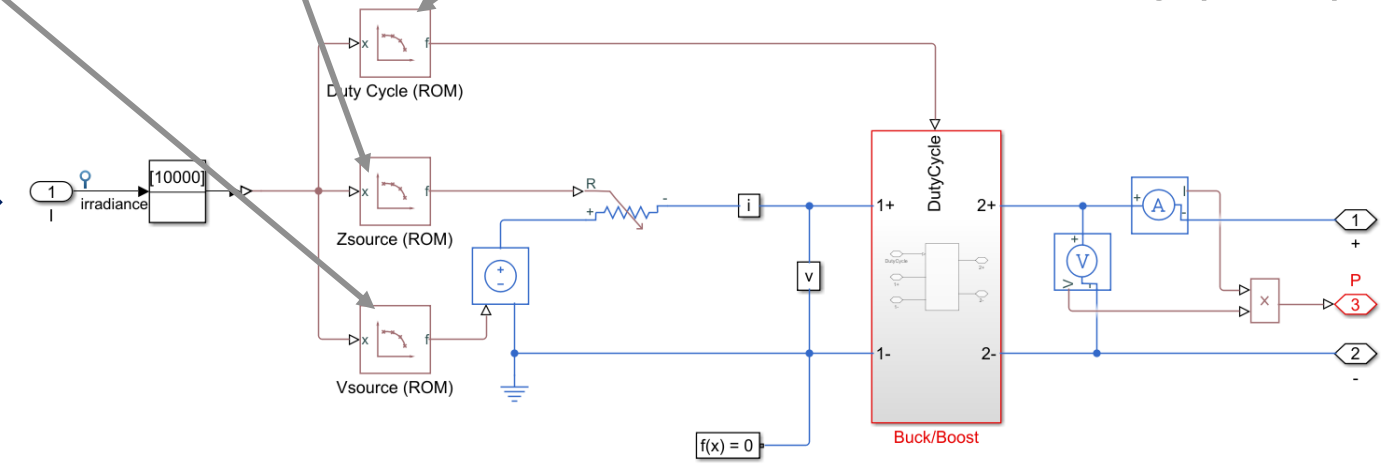
Techno-economic analysis

Low fidelity

Solar cell & MPPT algorithm



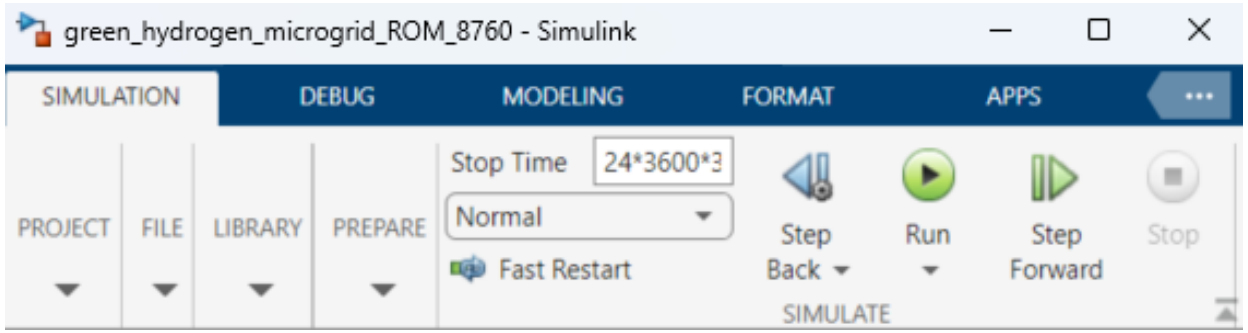
Reduced Order Modeling (ROM)



Capture steady state operating point

Quasi-steady lookup table model

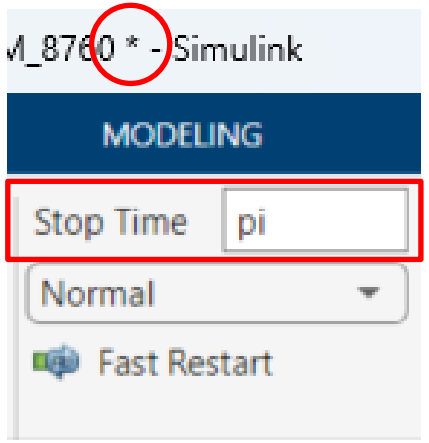
Clean Instancing for Model Setup



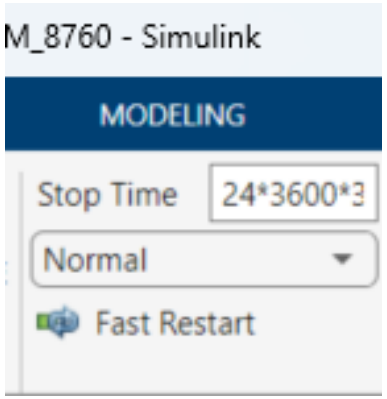

```
StopTime = "24*3600*365"
```

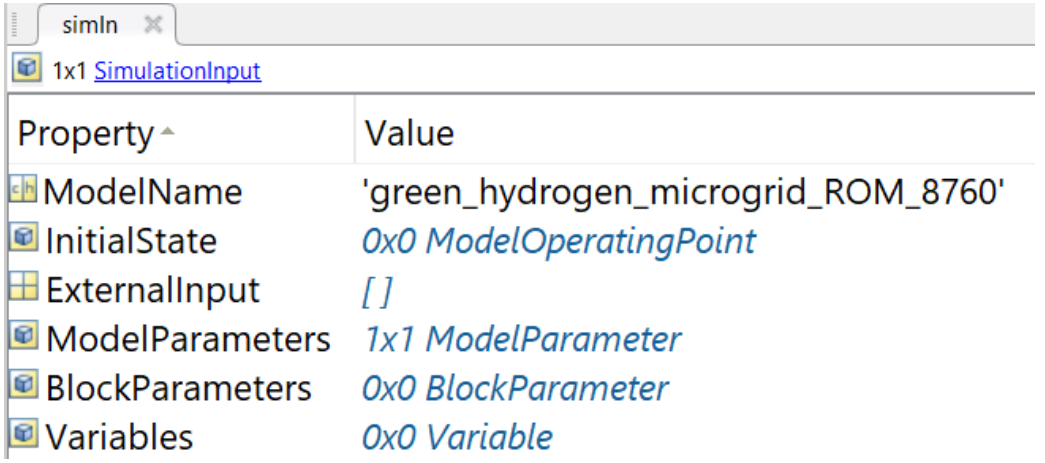
To change this via script:

```
set_param(gcs,StopTime = "pi");
```




```
simIn = Simulink.SimulationInput(gcs);
simIn = simIn.setModelParameter(StopTime = "pi");
```

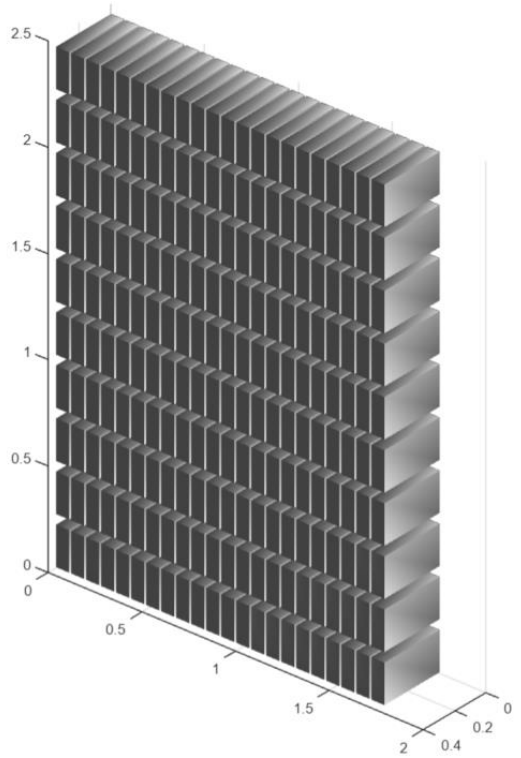




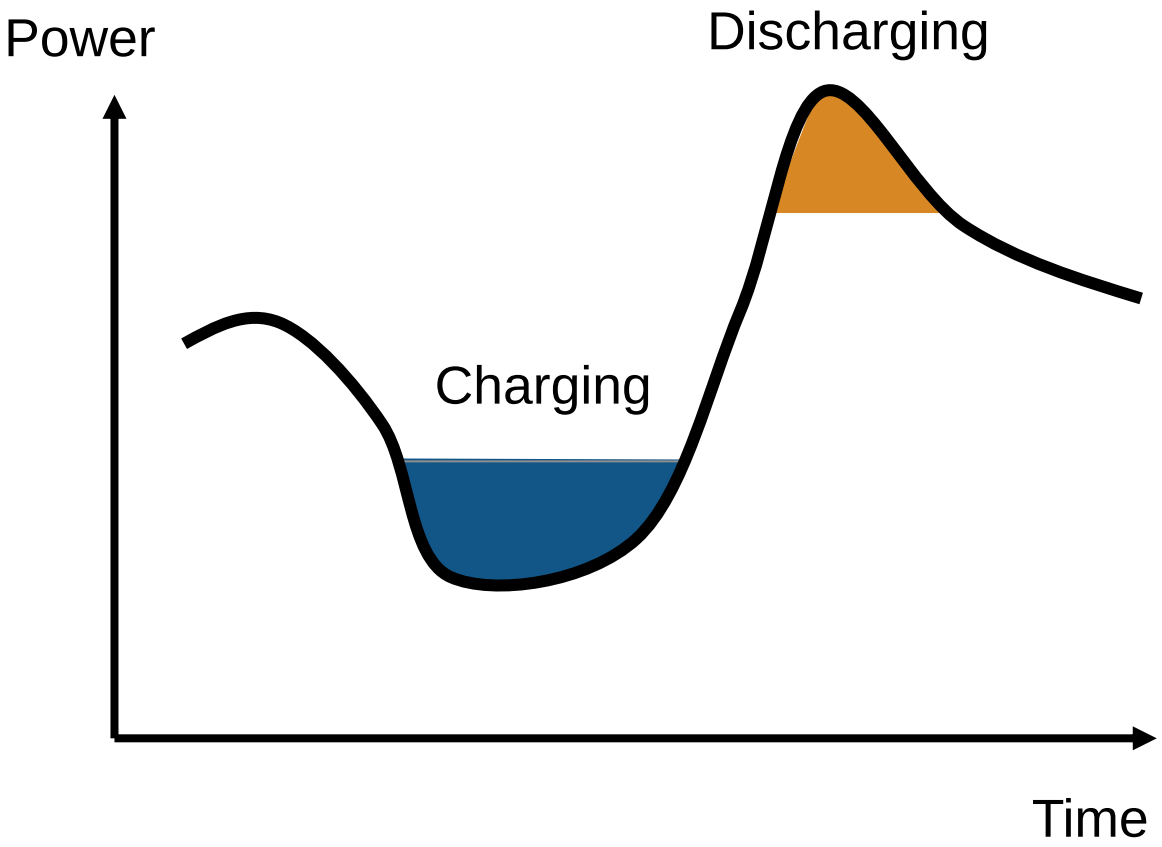
[Create Simulink.SimulationInput objects to make changes to model for multiple or individual simulations]

```
simOut = parsim(simIn);
```

Detailed Design

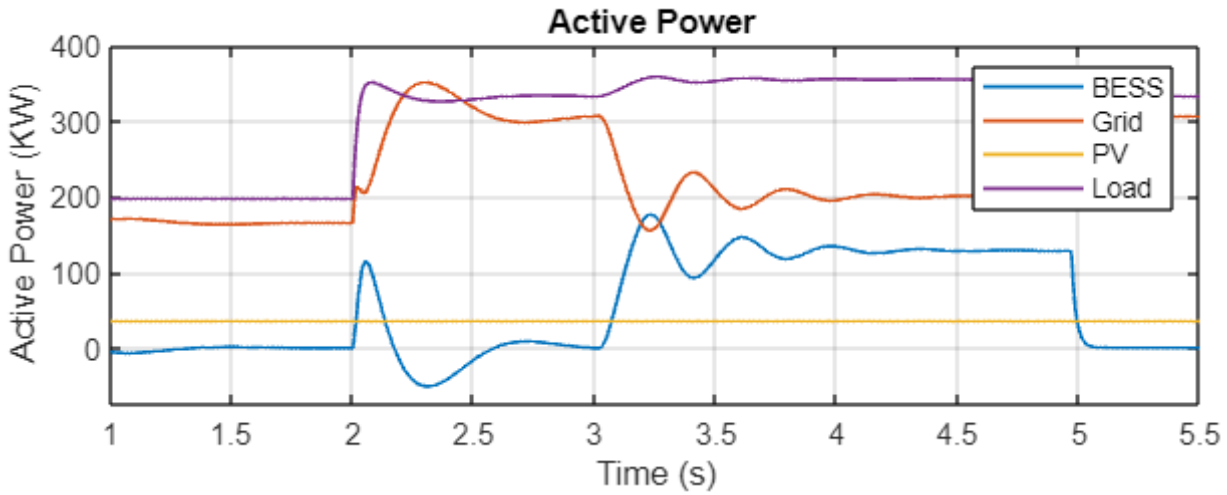


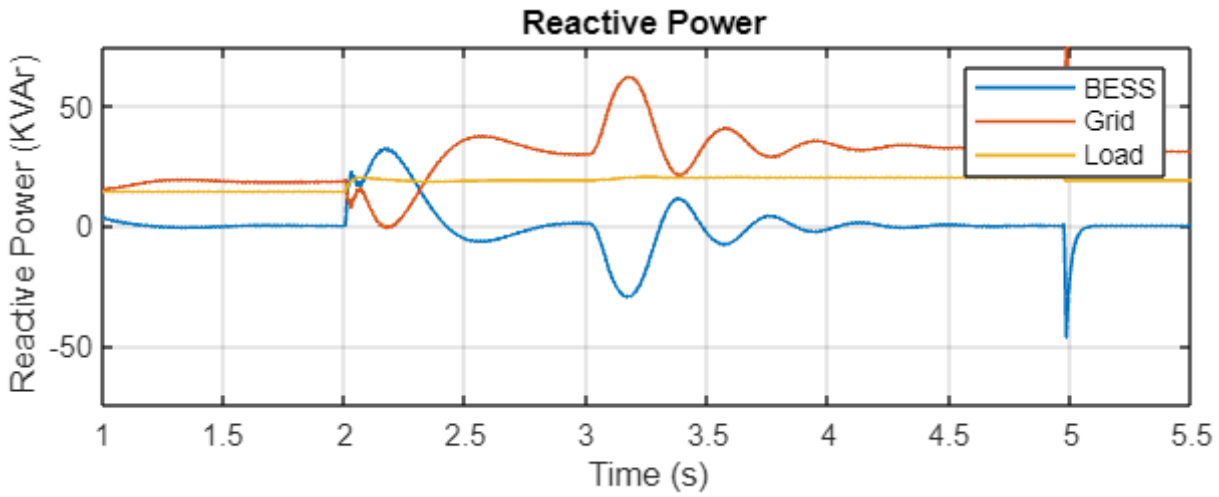
Peak Shaving

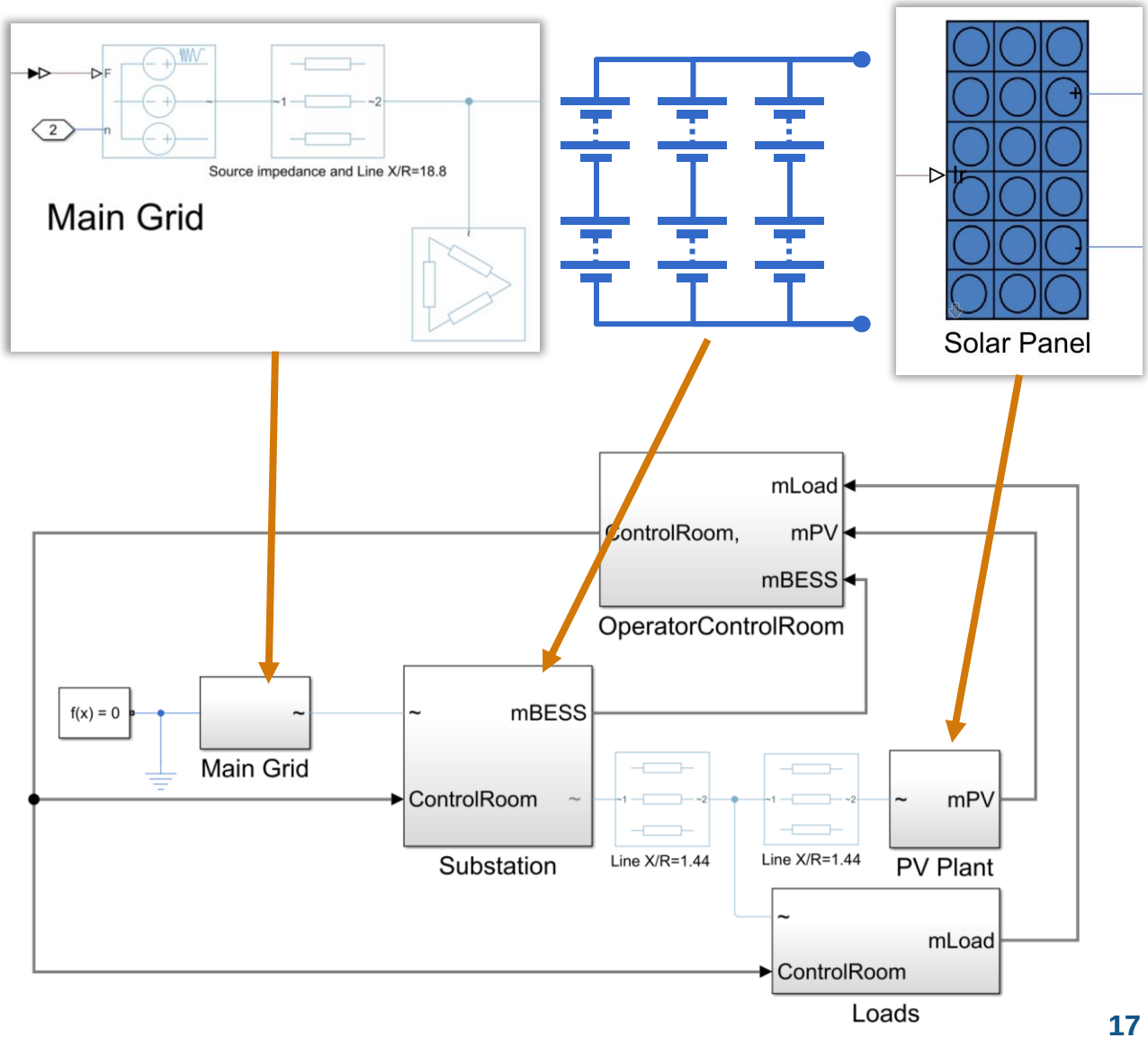


Peak Shaving

How do we model this detailed battery performance?



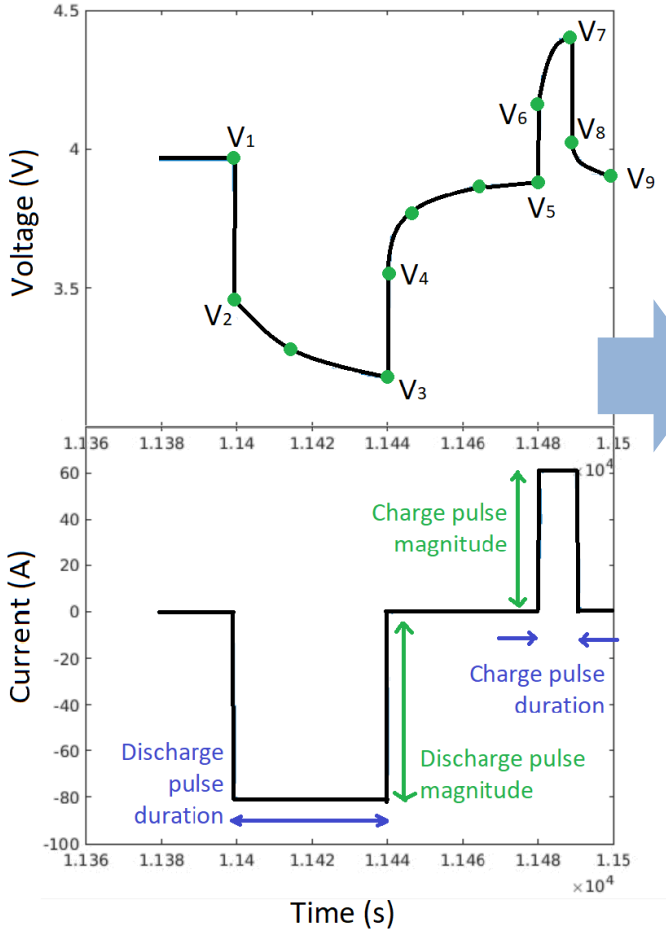


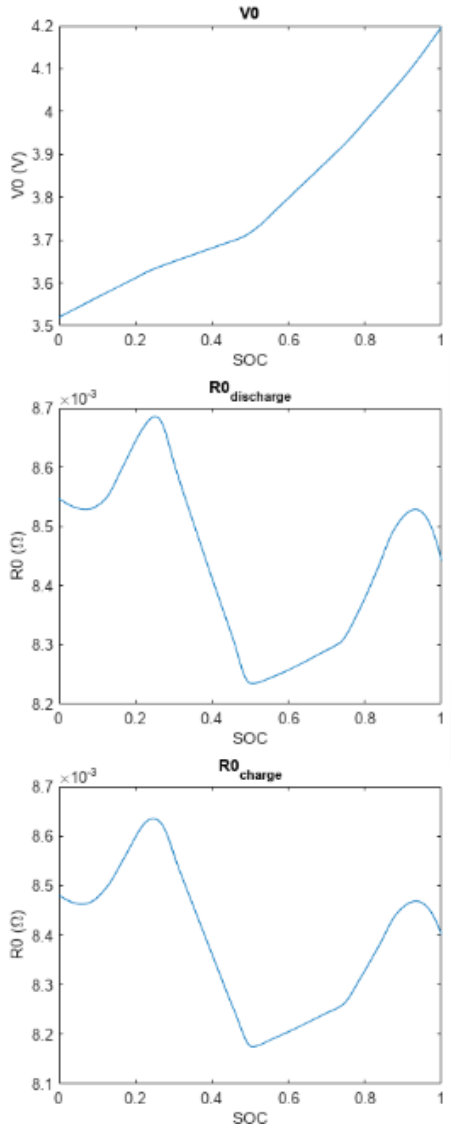


[Peak Shaving with Battery Energy Storage System - MATLAB & Simulink - MathWorks United Kingdom]

Cell Parameters

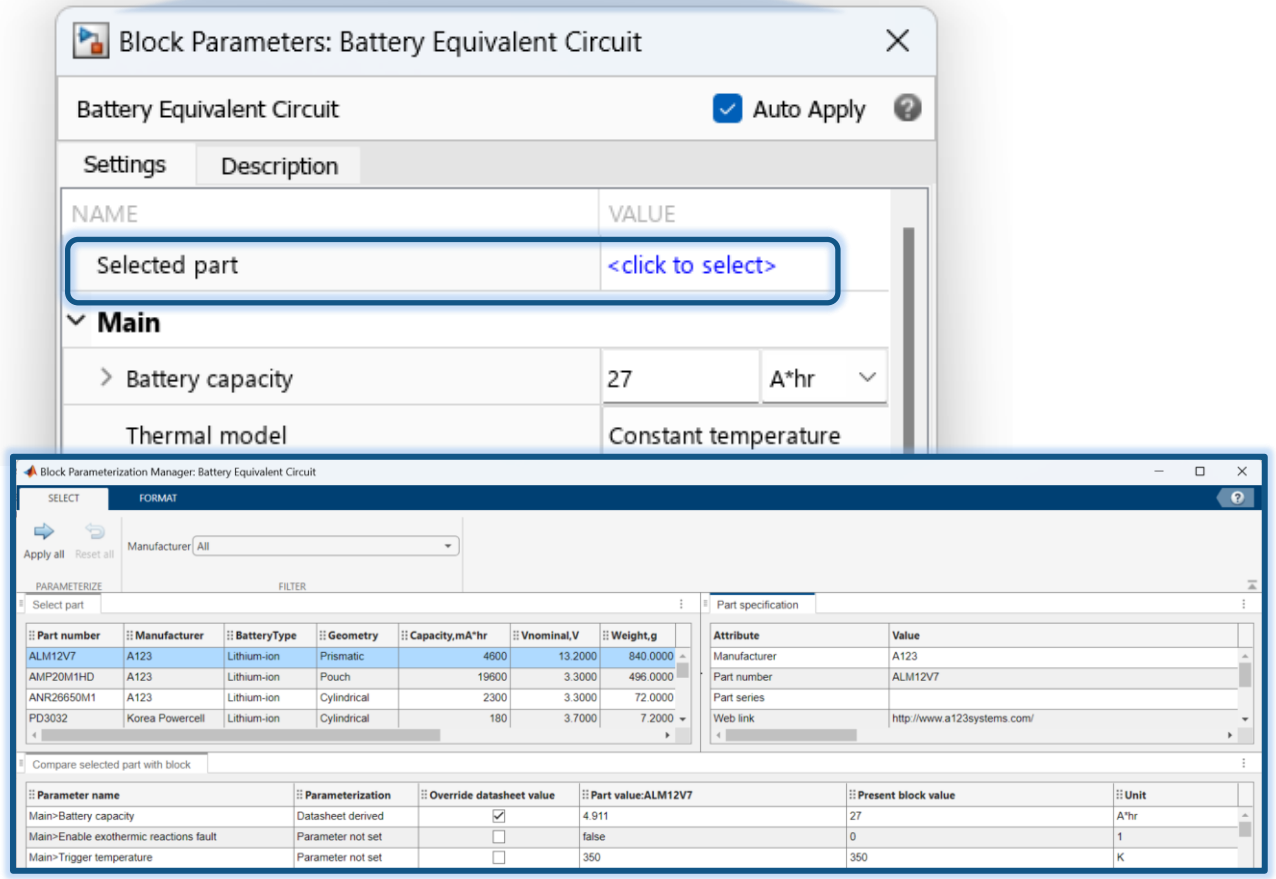
Fit from Data





Pre-parametrized parts

Battery Equivalent Circuit



[Characterize Battery Cell for Electric Vehicles]

Battery Builder

BATTERY BUILDER | BATTERY CHART

Import | Cell | Parallel Assembly | Module | Module Assembly | Pack | Duplicate | Delete | Export | Create Library

FILE | CREATE | BROWSER | EXPORT | LIBRARY

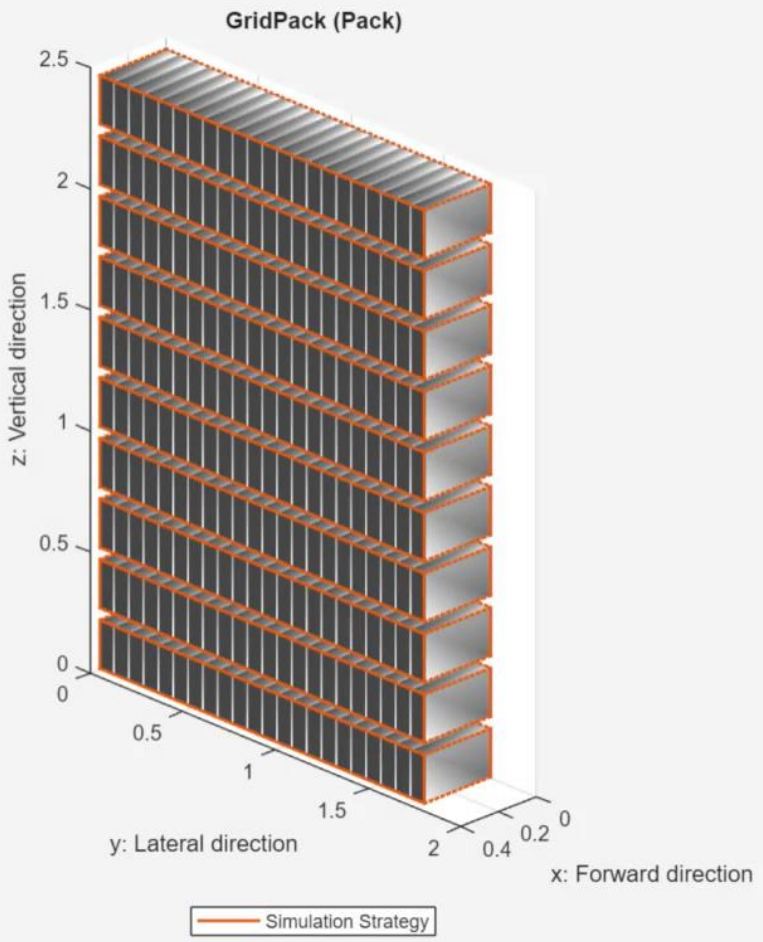
Battery Browser

- Cell
  - ExampleCell
  - GridCell
- Parallel Assembly
  - ExampleParallelAssembly
  - GridParallelAssembly
- Module
  - ExampleModule
  - GridModule
- Module Assembly
  - ExampleModuleAssembly
  - GridModuleAssembly
- Pack
  - ExamplePack

Battery Hierarchy

- Pack (GridPack)
  - ModuleAssembly (GridModuleAssembly)
    - Module (GridModule)
      - ParallelAssembly (GridParallelAssembly)
        - Cell (GridCell)
    - Module (Module2)
      - ParallelAssembly (ParallelAssembly2)
        - Cell (GridCell)
    - Module (Module3)
      - ParallelAssembly (ParallelAssembly3)
        - Cell (GridCell)
    - Module (Module4)
      - ParallelAssembly (ParallelAssembly4)
        - Cell (GridCell)

Selected Battery



Pack Properties

- Read-Only Properties
- Identifier
  - Name: GridPack
- Geometry
  - Position: x 0 y 0 z 0
  - StackingAxis: X
- Pack Properties
  - ModuleAssembly: GridModuleAssembly
  - Select...
  - InterModuleAssemblyGap: 0.001
  - MassFactor: 1
- Model Options
- Thermal Model Options

Apply

Scripted Battery

MATLAB R2023b

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New | Open | Save | Compare | Print | Go To | Find | Bookmark | Refactor | Profiler | Analyze | Run Section | Section Break | Run and Advance | Run to End | Run | Step | Stop

FILE | NAVIGATE | CODE | ANALYZE | SECTION | RUN

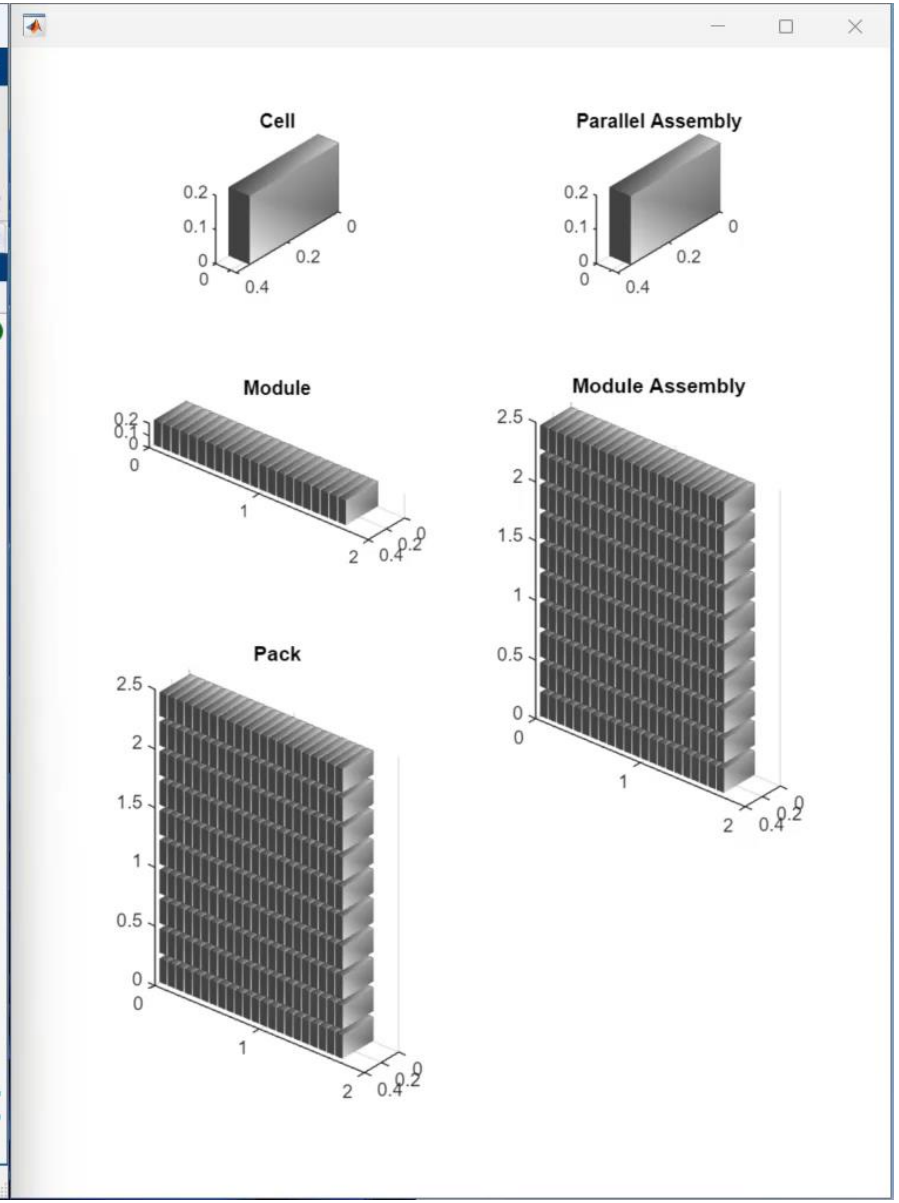
C: ▸ Users ▸ tgrimble ▸ Dev ▸ expo-battery-2023 ▸ 2-Pack

Editor - C:\Users\tgrimble\Dev\expo-battery-2023\2-Pack\packBuildApiPlot.m

packBuildApiPlot.m

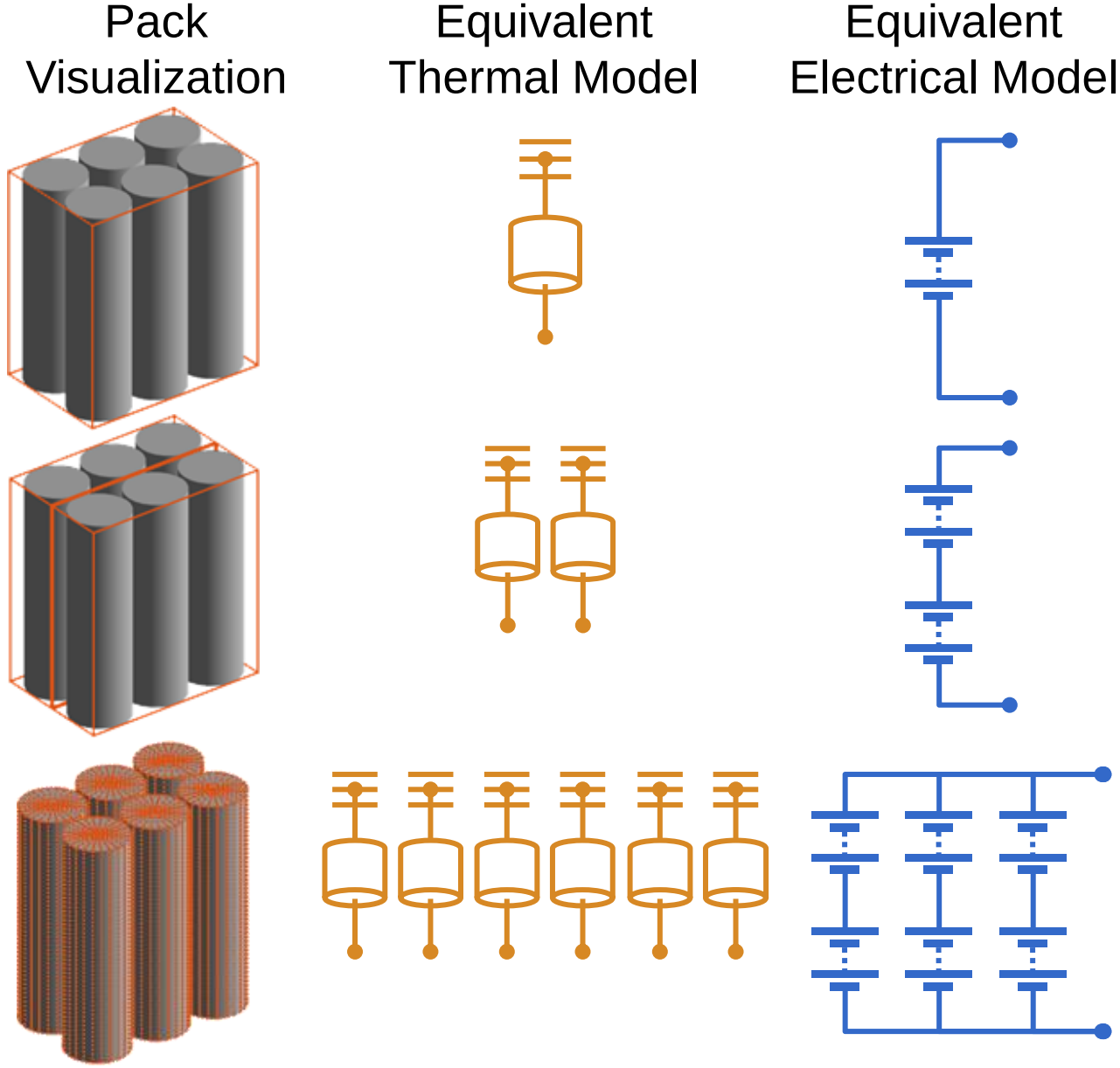
```
nexttile(t,[2,1]);
assemblyChart = simscape.battery.builder.BatteryChart(...
    Parent = t, Battery = batteryModuleAssembly);
title(assemblyChart,"Module Assembly")

%% Pack
batteryPack = simscape.battery.builder.Pack(...
    ModuleAssembly = batteryModuleAssembly);

% Plot
nexttile(t,[2,1]);
packChart = simscape.battery.builder.BatteryChart(...
    Parent = t, Battery = batteryPack);
title(packChart,"Pack")

%% Build Battery Library
libName = "packLibFromMATLAB";
simscape.battery.builder.buildBattery(batteryPack,...
    LibraryName = libName,...
    MaskParameters = "VariableNamesByInstance",...
    MaskInitialTargets = "VariableNamesByInstance");
```

2 usages of "libName" found | Zoom: 100% | UTF-8 | LF | script | Ln 68 | Col 4



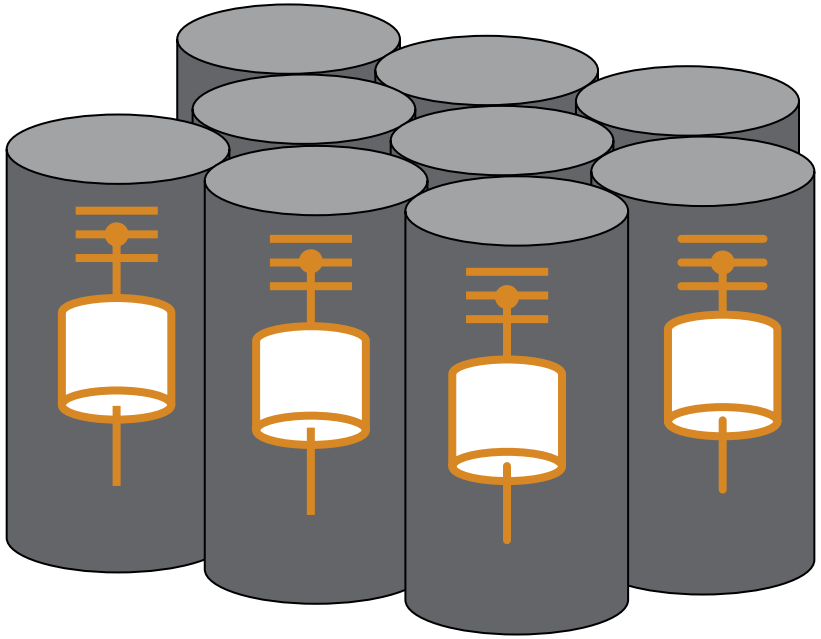
Battery Pack Model Fidelity

- Lumped resolution
  - One electrothermal element
- Grouped resolution
  - Any number of arbitrarily grouped elements
- Detailed resolution
  - Every cell modeled individually



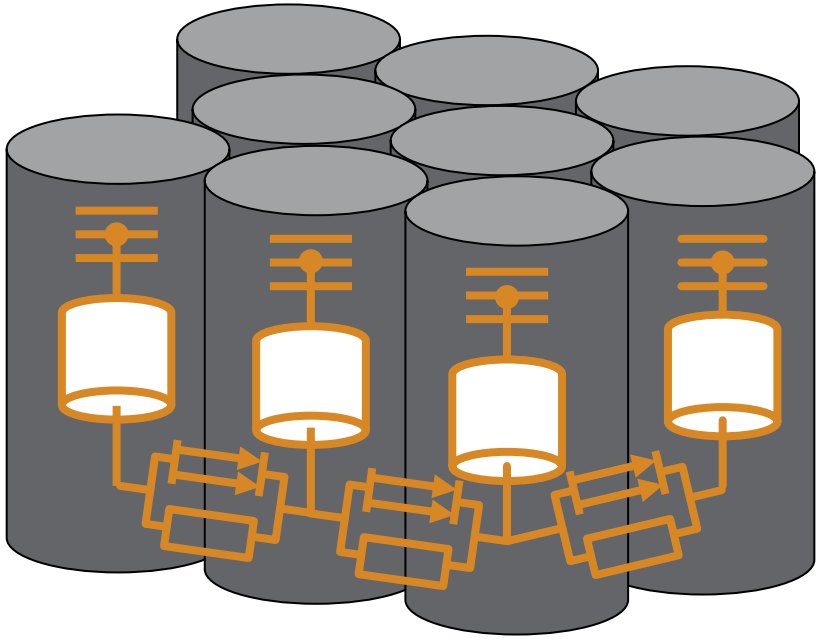
More to Model Resolution

Thermal Connections



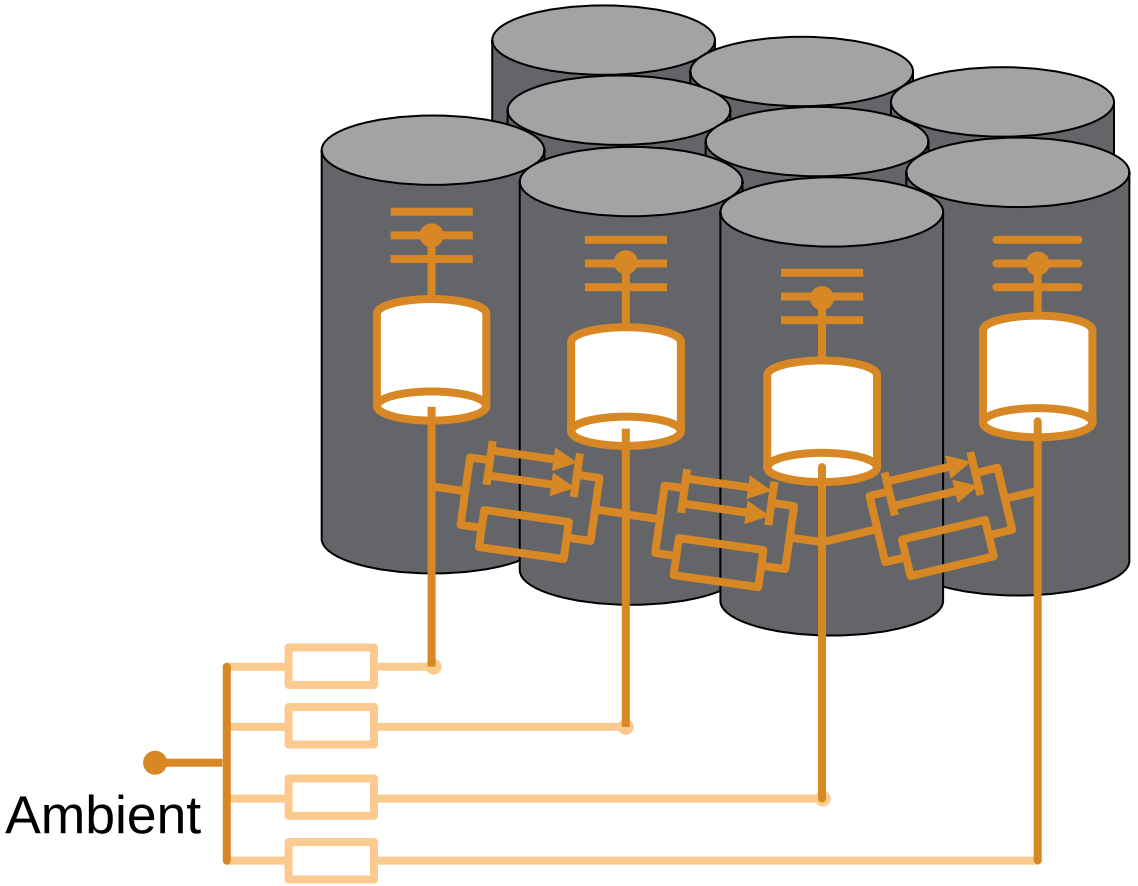
```
batteryModule = simscape.battery.builder.Module(...
    ParallelAssembly = pAssembly,...
    NumSeriesAssemblies = 3,...
    ModelResolution = "Detailed");
```

Thermal Connections



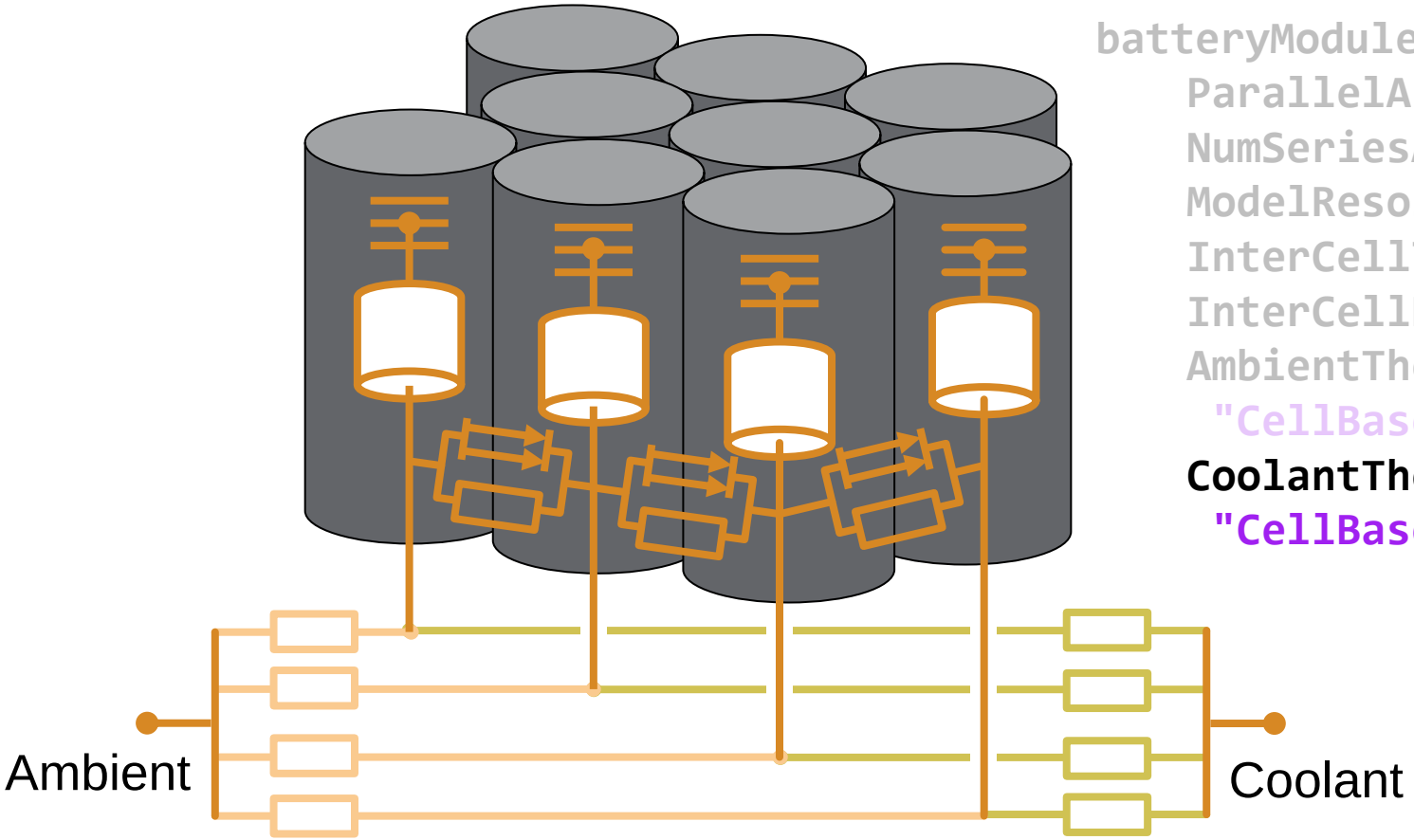
```
batteryModule = simscape.battery.builder.Module(...
    ParallelAssembly = pAssembly,...
    NumSeriesAssemblies = 3,...
    ModelResolution = "Detailed",...
    InterCellThermalPath = "on",...
    InterCellRadiativeThermalPath = "on");
```

Thermal Connections



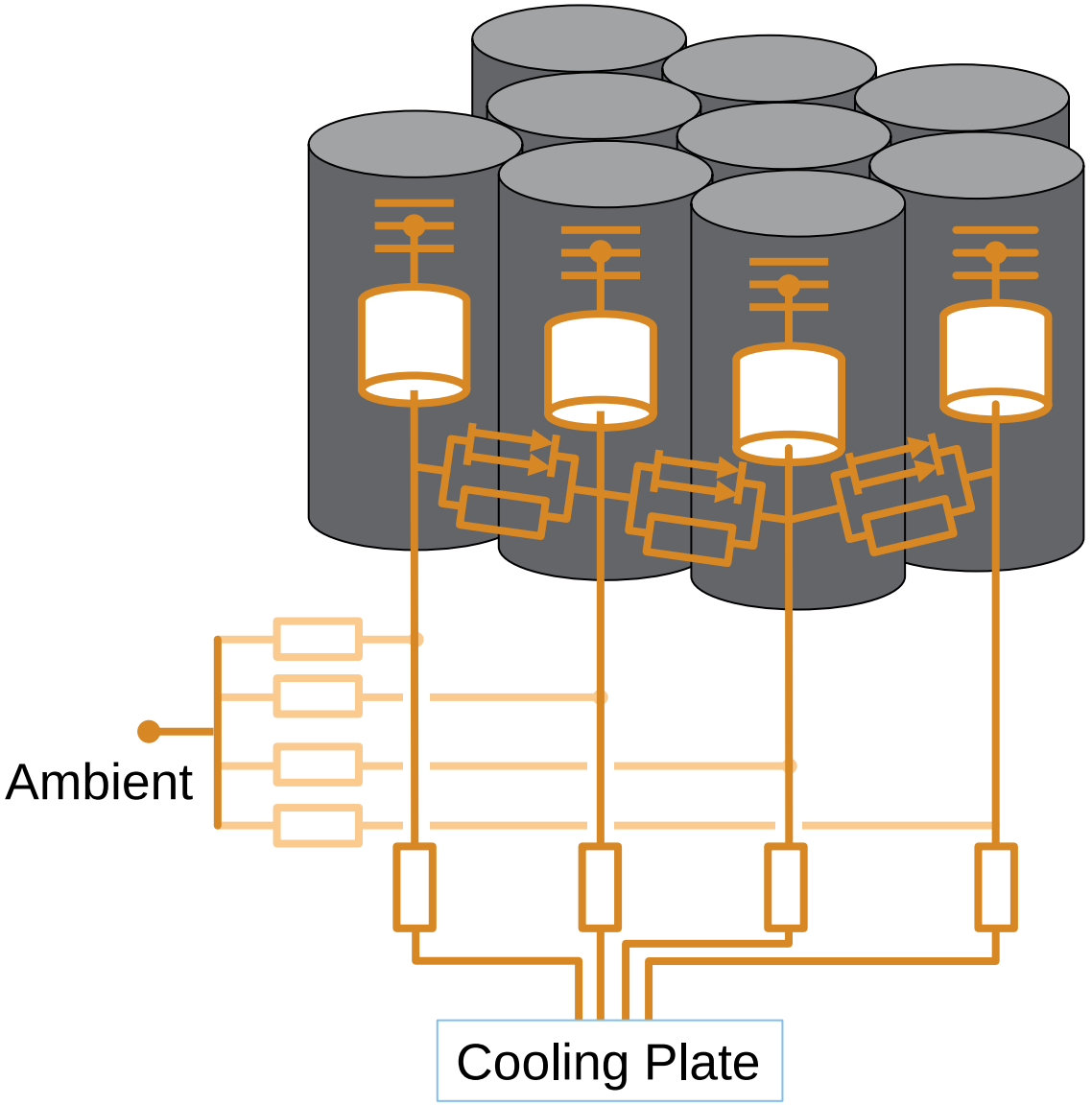

```
batteryModule = simscape.battery.builder.Module(...
    ParallelAssembly = pAssembly,...
    NumSeriesAssemblies = 3,...
    ModelResolution = "Detailed",...
    InterCellThermalPath = "on",...
    InterCellRadiativeThermalPath = "on",...
    AmbientThermalPath = ...
    "CellBasedThermalResistance");
```

Thermal Connections




```
batteryModule = simscape.battery.builder.Module(...
    ParallelAssembly = pAssembly,...
    NumSeriesAssemblies = 3,...
    ModelResolution = "Detailed",...
    InterCellThermalPath = "on",...
    InterCellRadiativeThermalPath = "on",...
    AmbientThermalPath = ...
     "CellBasedThermalResistance",...
    CoolantThermalPath = ...
     "CellBasedThermalResistance");
```

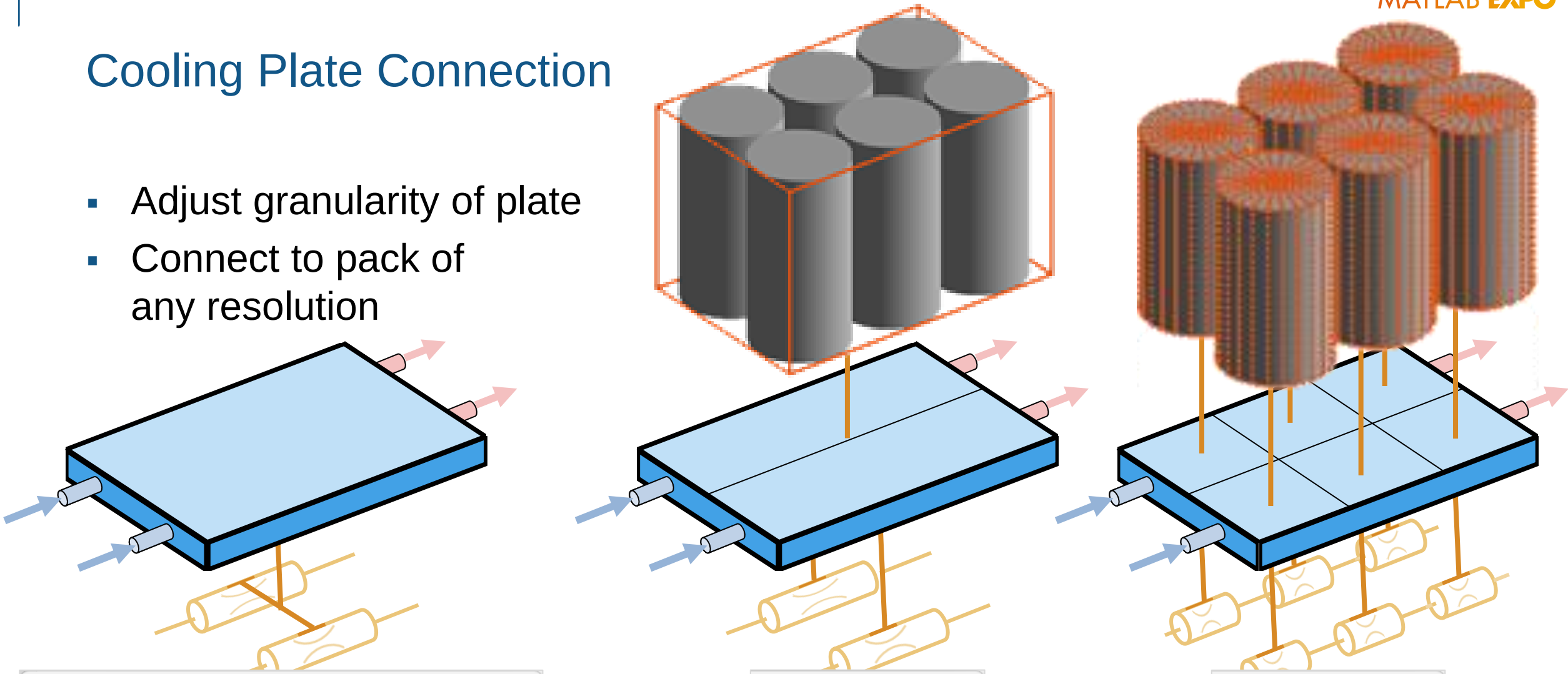
Thermal Connections




```
batteryModule = simscape.battery.builder.Module(...
    ParallelAssembly = pAssembly,...
    NumSeriesAssemblies = 3,...
    ModelResolution = "Detailed",...
    InterCellThermalPath = "on",...
    InterCellRadiativeThermalPath = "on",...
    AmbientThermalPath = ...
     "CellBasedThermalResistance",...
    CoolantThermalPath =...
     "CellBasedThermalResistance",...
    CoolingPlate = "Bottom",...
    CoolingPlateBlockPath = ...
    "batt_lib/Thermal/Parallel Channels");
```

Cooling Plate Connection

- Adjust granularity of plate
- Connect to pack of any resolution



Block Parameters: Parallel Channels

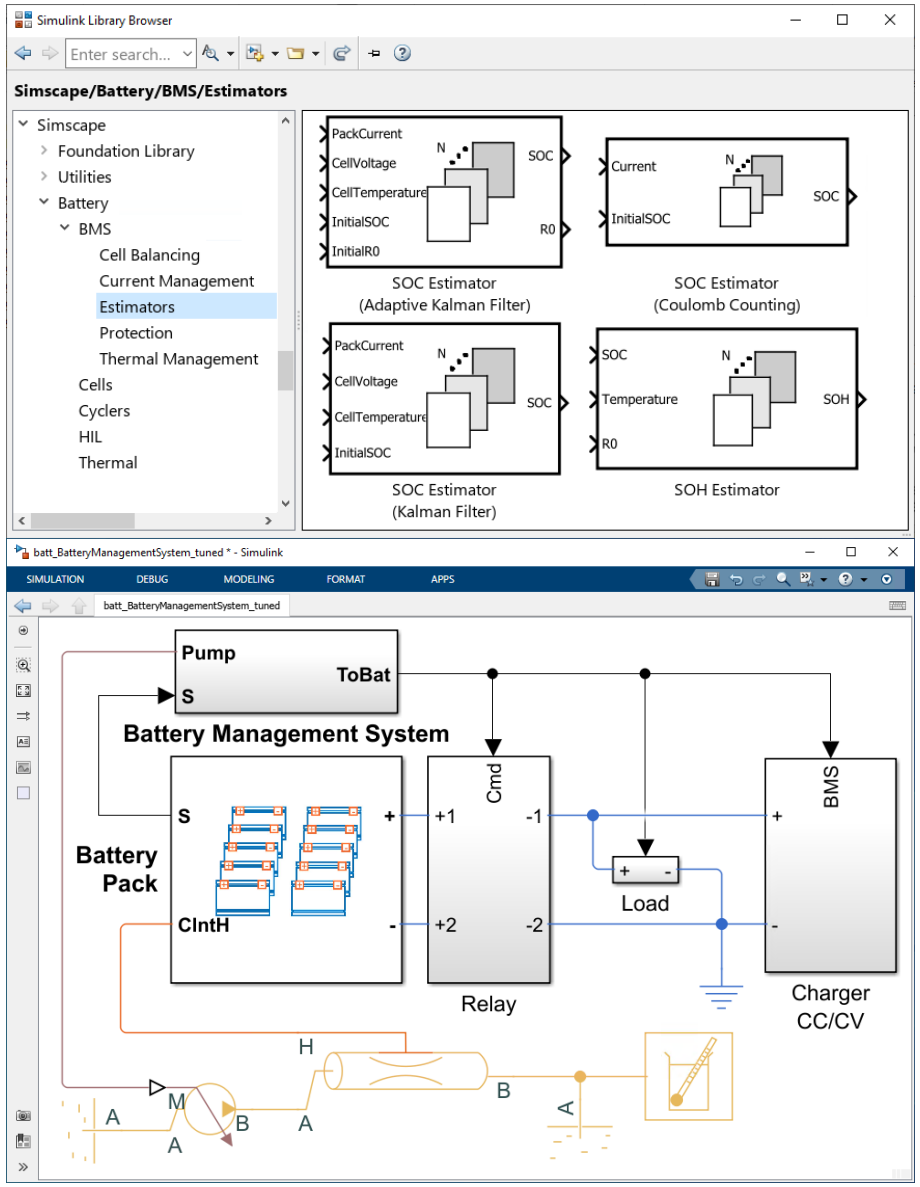
Interface	
Number of partitions in X dimension ...	1
Number of partitions in Y dimension ...	1
Plate Material	

X dimension ...	2
Y dimension ...	1

X dimension ...	2
Y dimension ...	3

[Connect Cooling Plate to Battery Blocks]

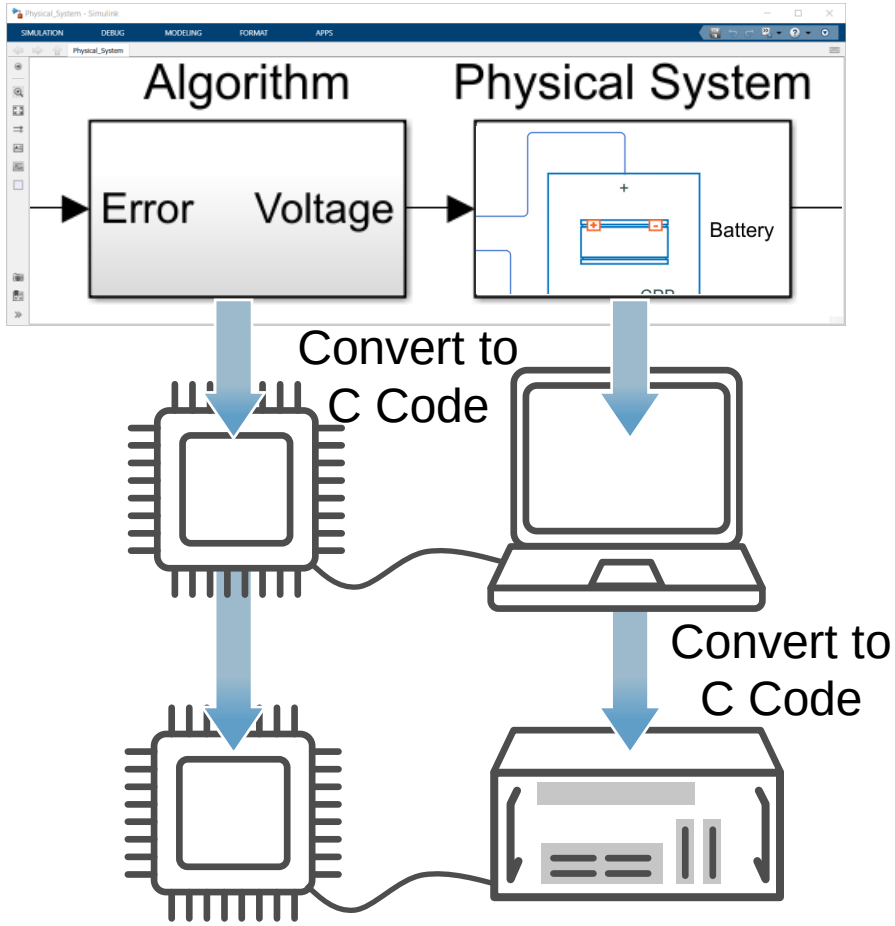
Control Algorithms & Deployment



[Battery Management Systems In Simscape Battery]

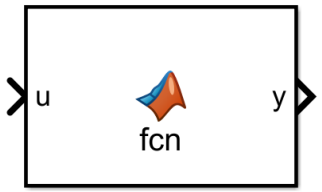
Processor-in-the-Loop (PIL)

Hardware-in-the-Loop (HIL)

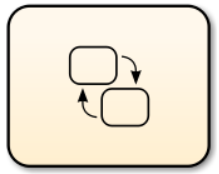


Customization

Customization and flexibility are at the core of MATLAB & Simulink

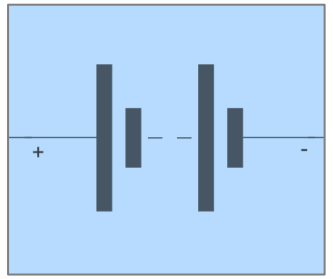


MATLAB Function

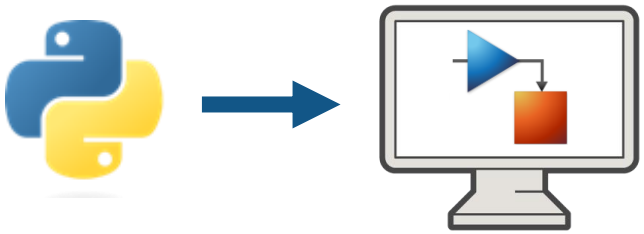


Logic

C Caller



Custom cell



Python Importer

Customize physical models with Simscape language

$$i = (C_0 + C_v v)\frac{dv}{dt} + \frac{v}{r_d}$$

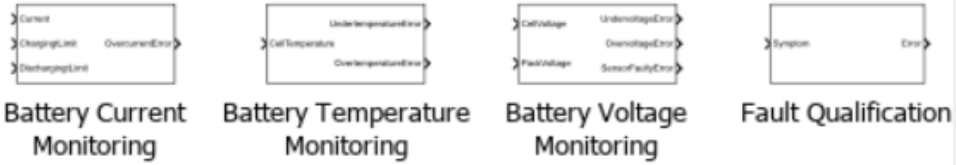

```
34  equations
35    i == (C0 + Cv*vc)*vc.der + vc/Rd;
36    v == vc + i*R;
37  end
```

Simscape Customization

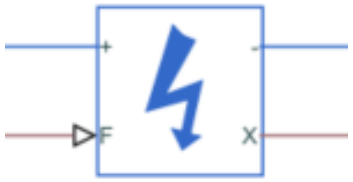
Fault Robustness

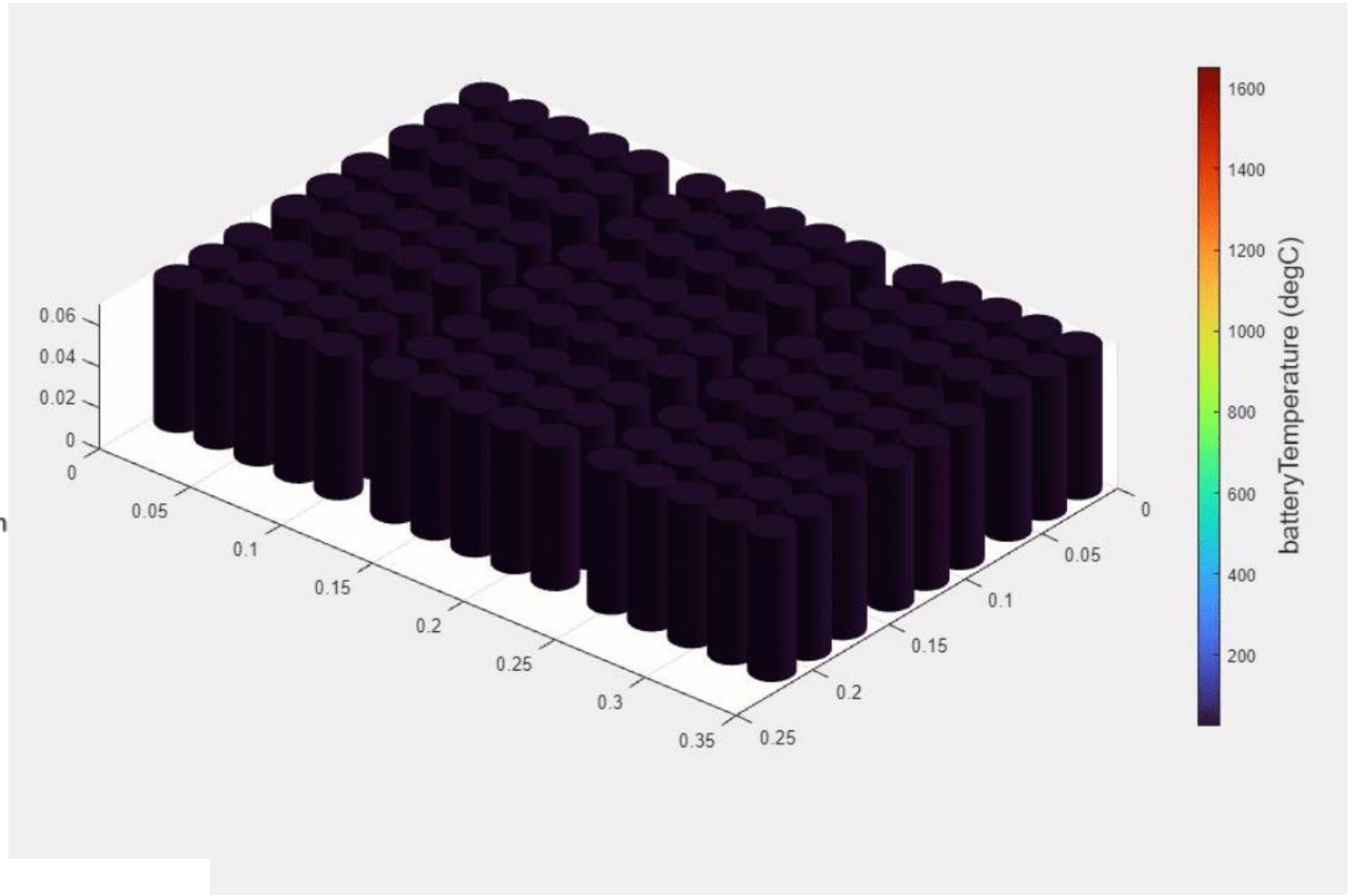
Faults & System Protection

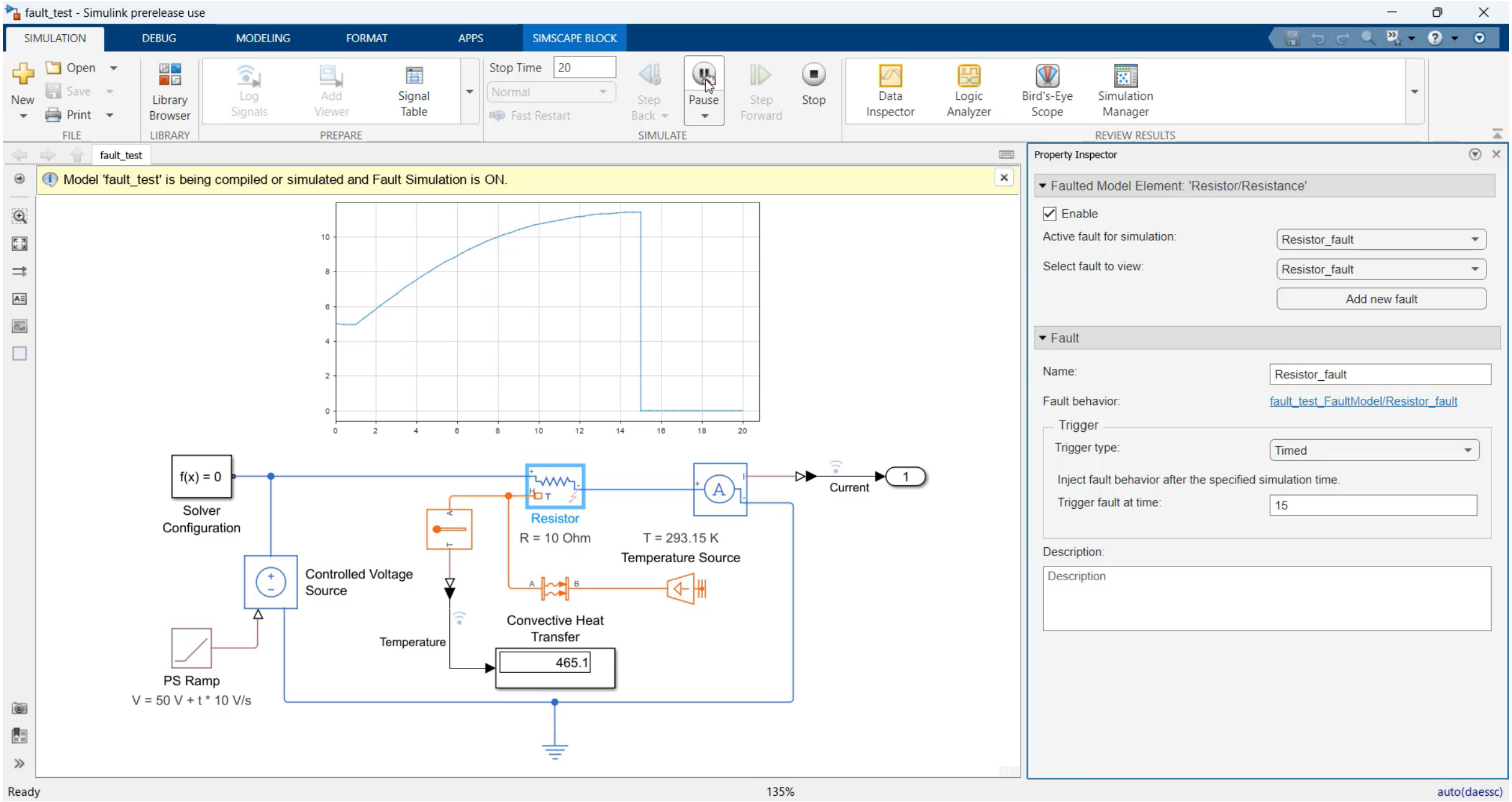
- Battery
  - BMS
    - Cell Balancing
    - Current Management
    - Estimators
    - Protection

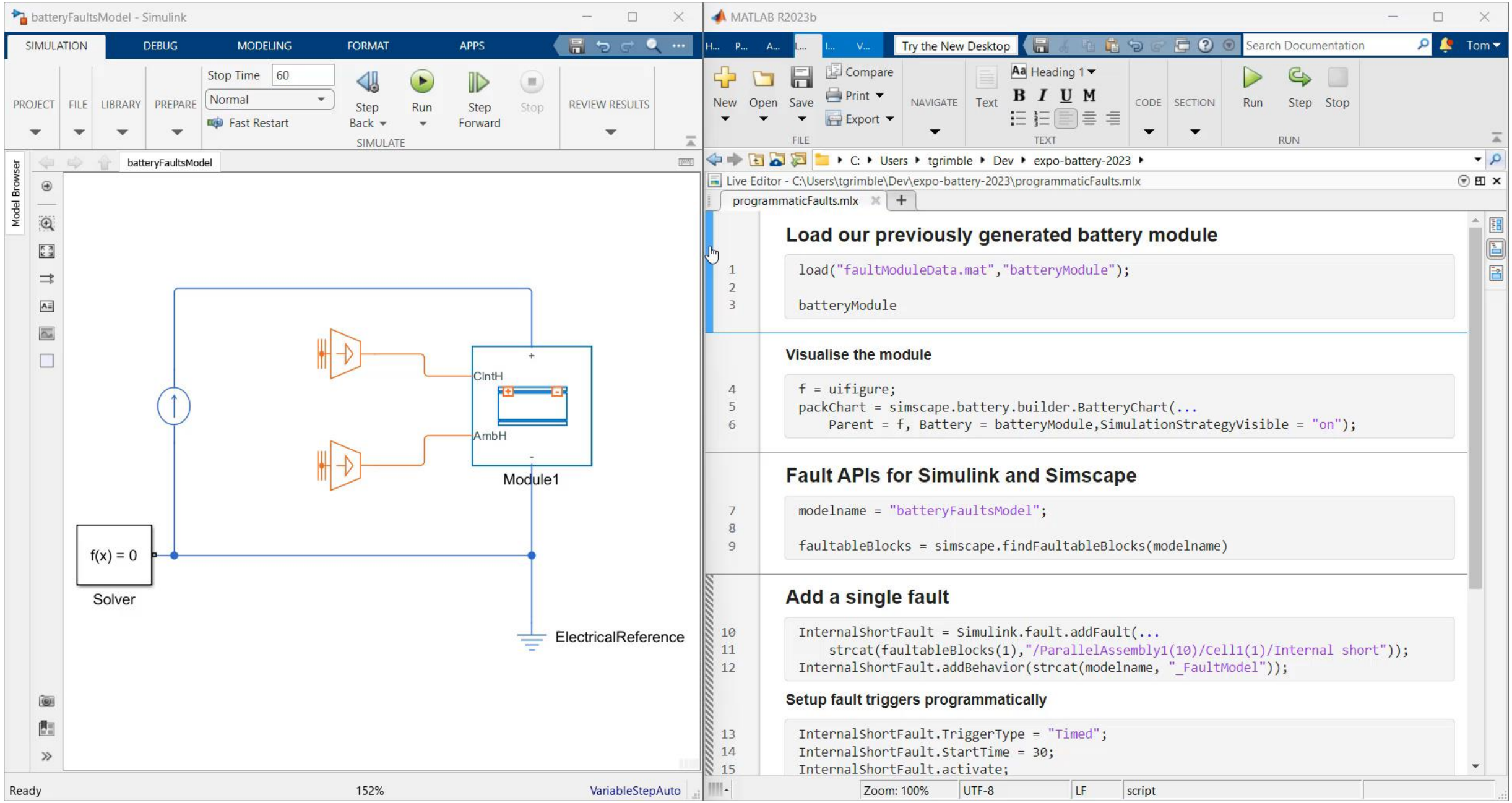


- Thermal Management



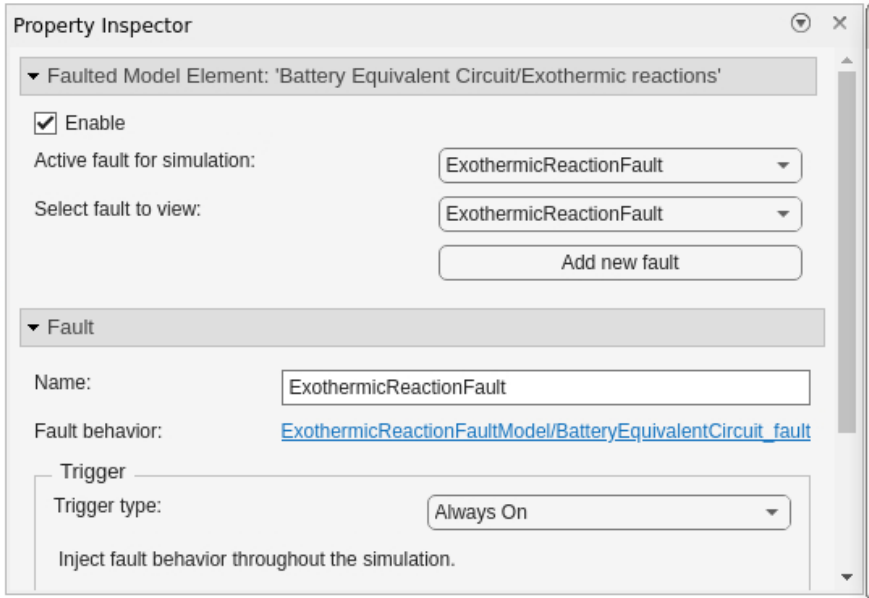


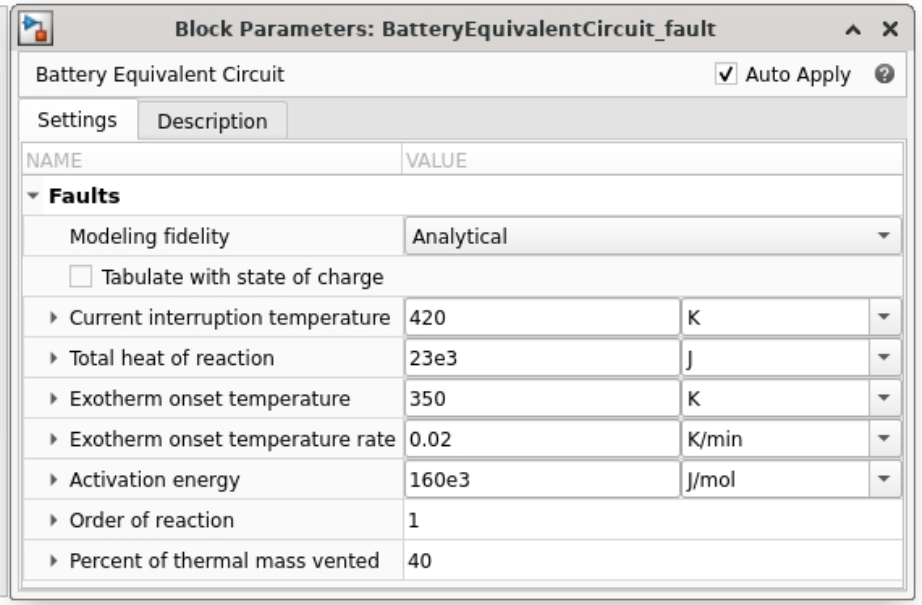

fault_test - Simulink prerelease use
SIMULATION
DEBUG
MODELING
FORMAT
APPS
SIMSCAPE BLOCK
New
Open
Save
Print
FILE
Library Browser
LIBRARY
Log Signals
Add Viewer
Signal Table
PREPARE
Stop Time
20
Normal
Fast Restart
Step Back
Pause
Step Forward
Stop
SIMULATE
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
REVIEW RESULTS
fault_test
Model 'fault_test' is being compiled or simulated and Fault Simulation is ON.
f(x) = 0
Solver Configuration
Resistor
R = 10 Ohm
T = 293.15 K
Temperature Source
Current
1
Controlled Voltage Source
Temperature
Convective Heat Transfer
465.1
PS Ramp
V = 50 V + t * 10 V/s
Property Inspector
Faulted Model Element: 'Resistor/Resistance'
Enable
Active fault for simulation:
Resistor_fault
Select fault to view:
Resistor_fault
Add new fault
Fault
Name:
Resistor_fault
Fault behavior:
fault_test_FaultModel/Resistor_fault
Trigger
Trigger type:
Timed
Inject fault behavior after the specified simulation time.
Trigger fault at time:
15
Description:
Description
Ready
135%
auto(daessc)


batteryFaultsModel - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Stop Time
60
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
SIMULATE
REVIEW RESULTS
Model Browser
batteryFaultsModel
ClntH
AmbH
Module1
f(x) = 0
Solver
ElectricalReference
Ready
152%
VariableStepAuto
MATLAB R2023b
Try the New Desktop
Search Documentation
Tom
New
Open
Save
Compare
Print
Export
FILE
NAVIGATE
Text
Heading 1
TEXT
CODE
SECTION
Run
Step
Stop
RUN
C: Users tgrimble Dev expo-battery-2023
Live Editor - C:\Users\tgrimble\Dev\expo-battery-2023\programmaticFaults.mlx
programmaticFaults.mlx
Load our previously generated battery module
load("faultModuleData.mat","batteryModule");
batteryModule
Visualise the module
f = uifigure;
packChart = simscape.battery.builder.BatteryChart(...
Parent = f, Battery = batteryModule,SimulationStrategyVisible = "on");
Fault APIs for Simulink and Simscape
modelname = "batteryFaultsModel";
faultableBlocks = simscape.findFaultableBlocks(modelname)
Add a single fault
InternalShortFault = Simulink.fault.addFault(...
strcat(faultableBlocks(1),"/ParallelAssembly1(10)/Cell1(1)/Internal short"));
InternalShortFault.addBehavior(strcat(modelname, "_FaultModel"));
Setup fault triggers programmatically
InternalShortFault.TriggerType = "Timed";
InternalShortFault.StartTime = 30;
InternalShortFault.activate;
Zoom: 100%
UTF-8
LF
script

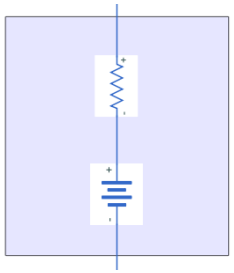
Battery Cell Fault Modeling

Battery Equivalent Circuit

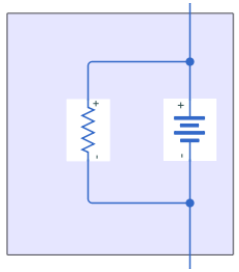




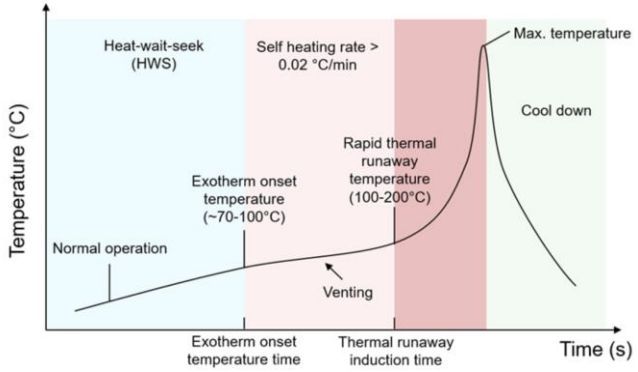
Additional Resistance Fault



Internal Short Fault



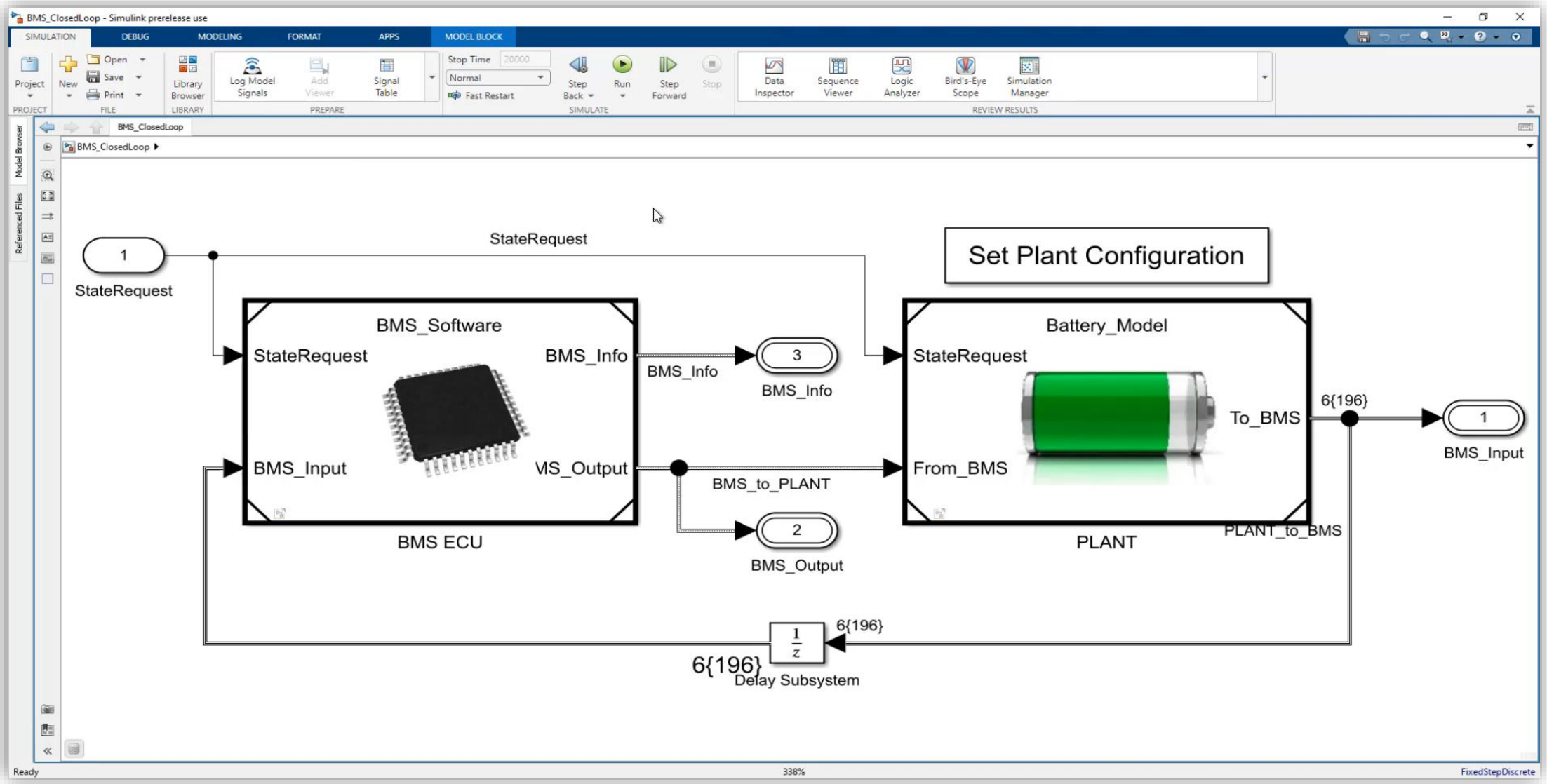
Exothermic Reaction Fault



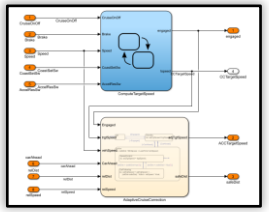
- ✓ Definition of time or condition dependent faults.
- ✓ Support modeling of thermal runaway events.

[Inject Faults in Battery Models]

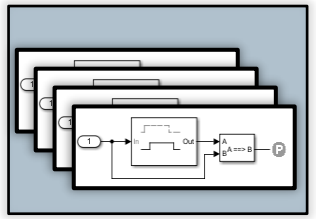
Unified Fault Framework



Design Logic

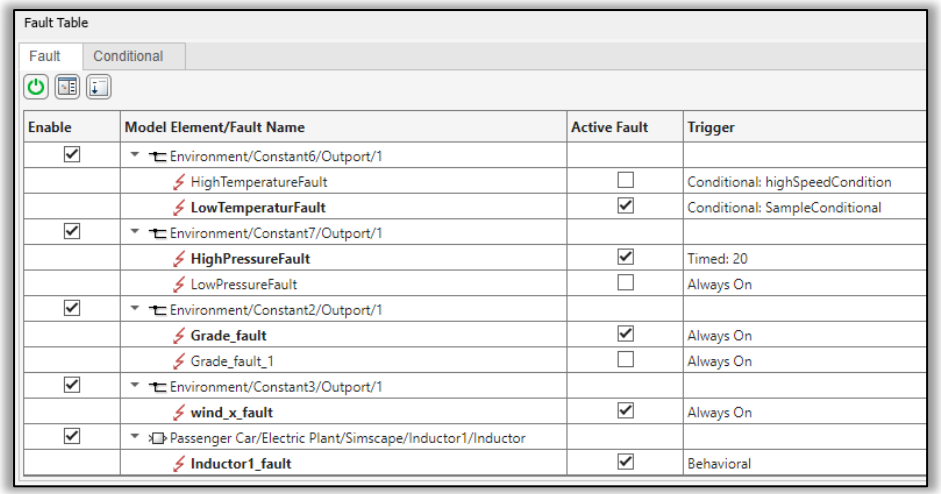


Fault Logic

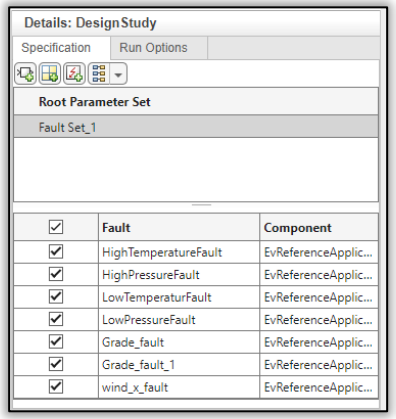


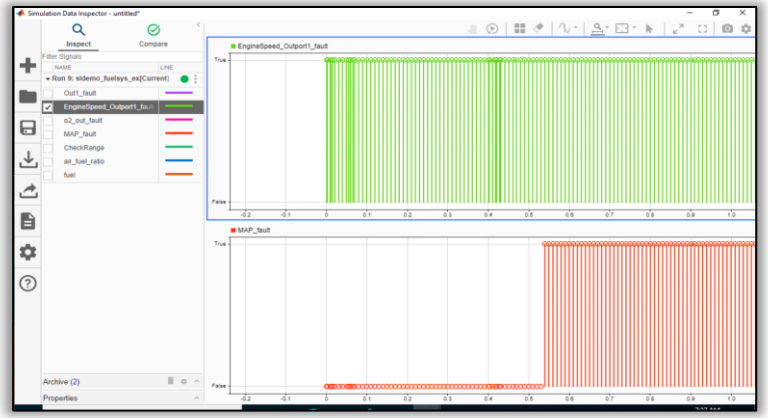
Model faults without modifying the design

Simulink Fault Analyzer™

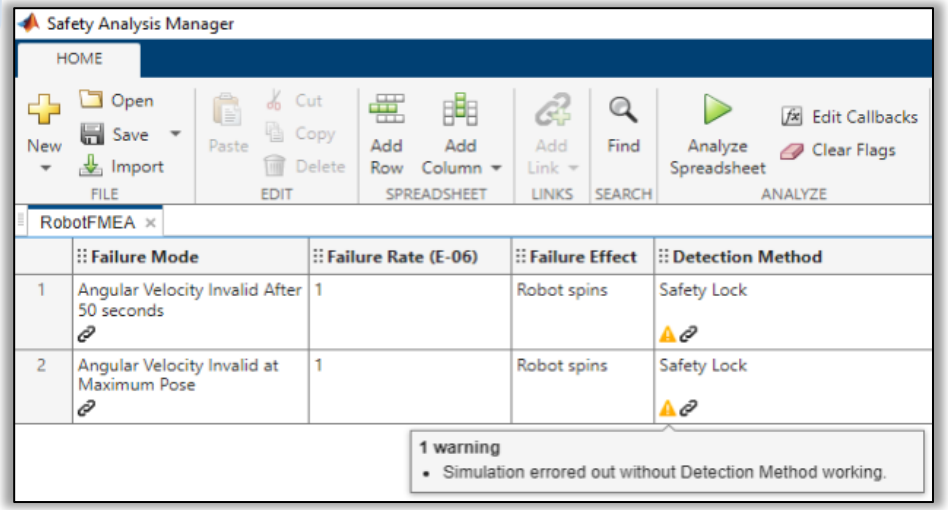


Manage faults across multiple domains





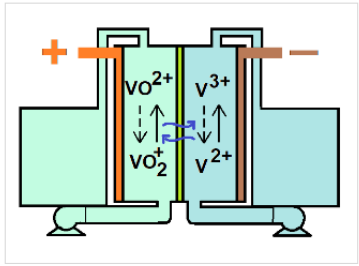
Simulate, explore and analyze fault effects

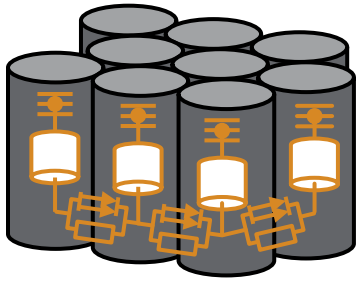


Perform systematic safety analysis using simulation

Conclusions

- Energy Storage can extend far beyond just electrical modelling





- Critical to simulate real world power storage challenges

- Use MATLAB & Simulink to accelerate your design and problem solving throughout the design cycle

Learn More with MathWorks Onramps and Instructor-Led Training

[Training – Courses in MATLAB, Simulink, Stateflow and Simscape]

Power Systems Simulation Onramp

5 modules | 1.5 hours | Languages

Learn how to progressively build and validate power systems using Simscape Electrical.

Power Electronics Simulation Onramp

5 modules | 1 hour | Languages

Learn the basics of simulating power electronics converters in Simscape.

Simscape Onramp

9 modules | 1.5 hours | Languages

Learn the basics of simulating physical systems in Simscape.

Circuit Simulation Onramp

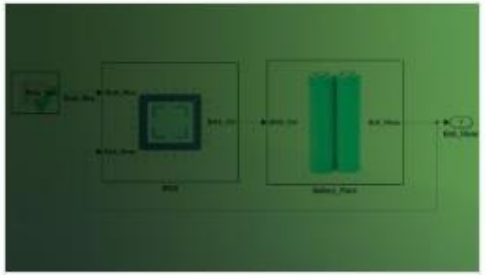
7 modules | 2 hours | Languages

Learn the basics of simulating electrical circuits in Simscape.

Modeling Electrical Power Systems with Simscape

Model three-phase systems, analyze and control electrical power systems, model power electronic components, and speed up simulation of electrical models.

INTERMEDIATE



Battery Modeling and Algorithm Development with Simulink

In this course, you will learn how to use Simscape and Stateflow to model battery packs and develop supervisory controls for battery management systems.

INTERMEDIATE

Come and talk to us at the demo stations!

MATLAB EXPO

Thank you