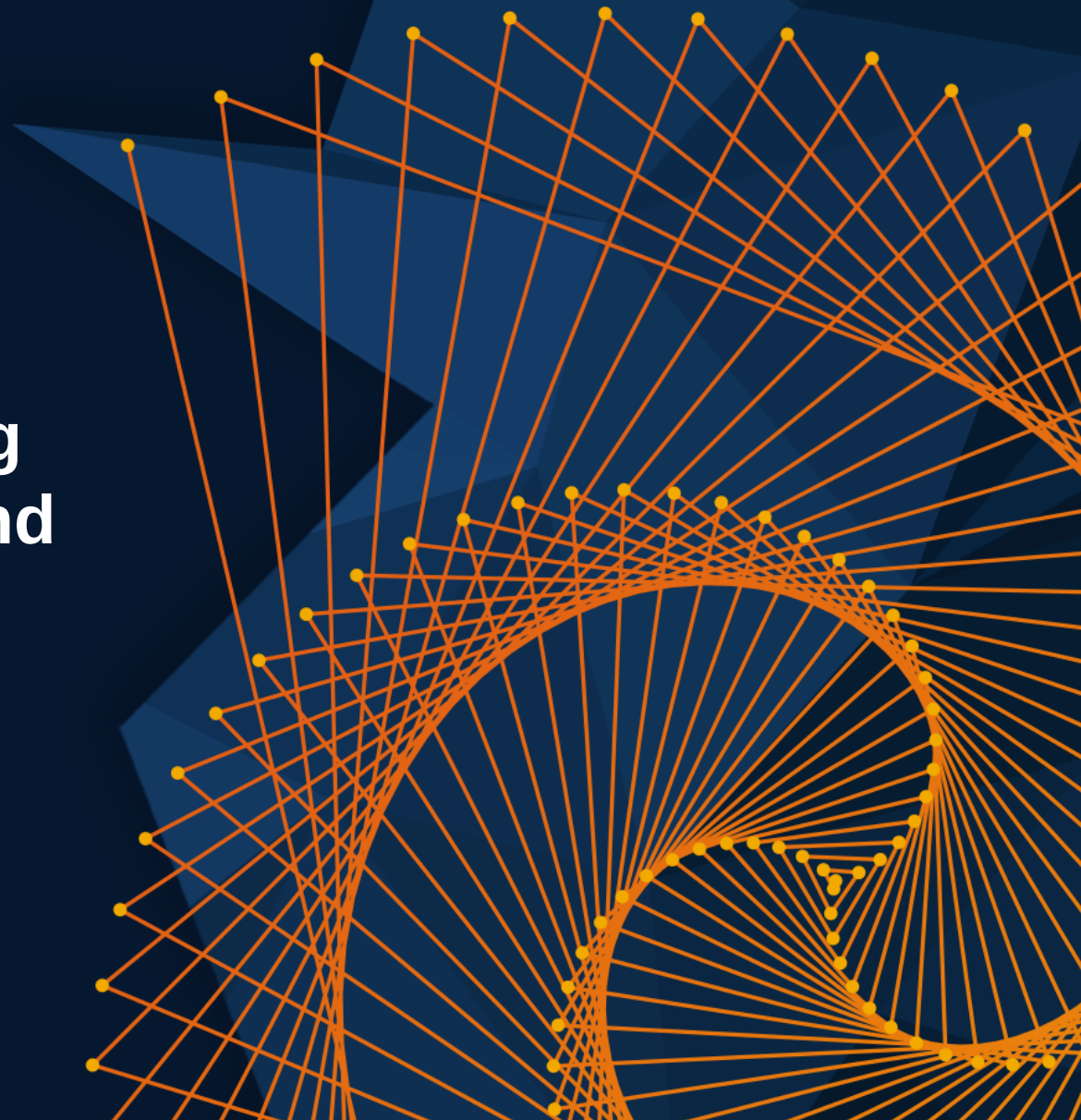
MATLAB EXPO

July 11th, 2024, Bangalore

Addressing Challenges of Meeting Net-Zero Goals with Simulation and Model-Based Design



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MATLAB
EXPO
WELCOME

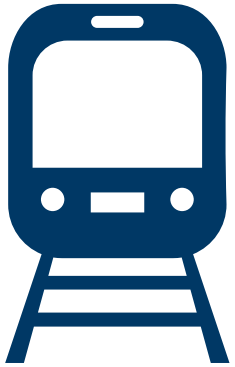
Our Panellist Today

Ramanuja Jagannathan

Abhisek Roy

Ramana Anchuri

Net-Zero Goals for Sustainable Future

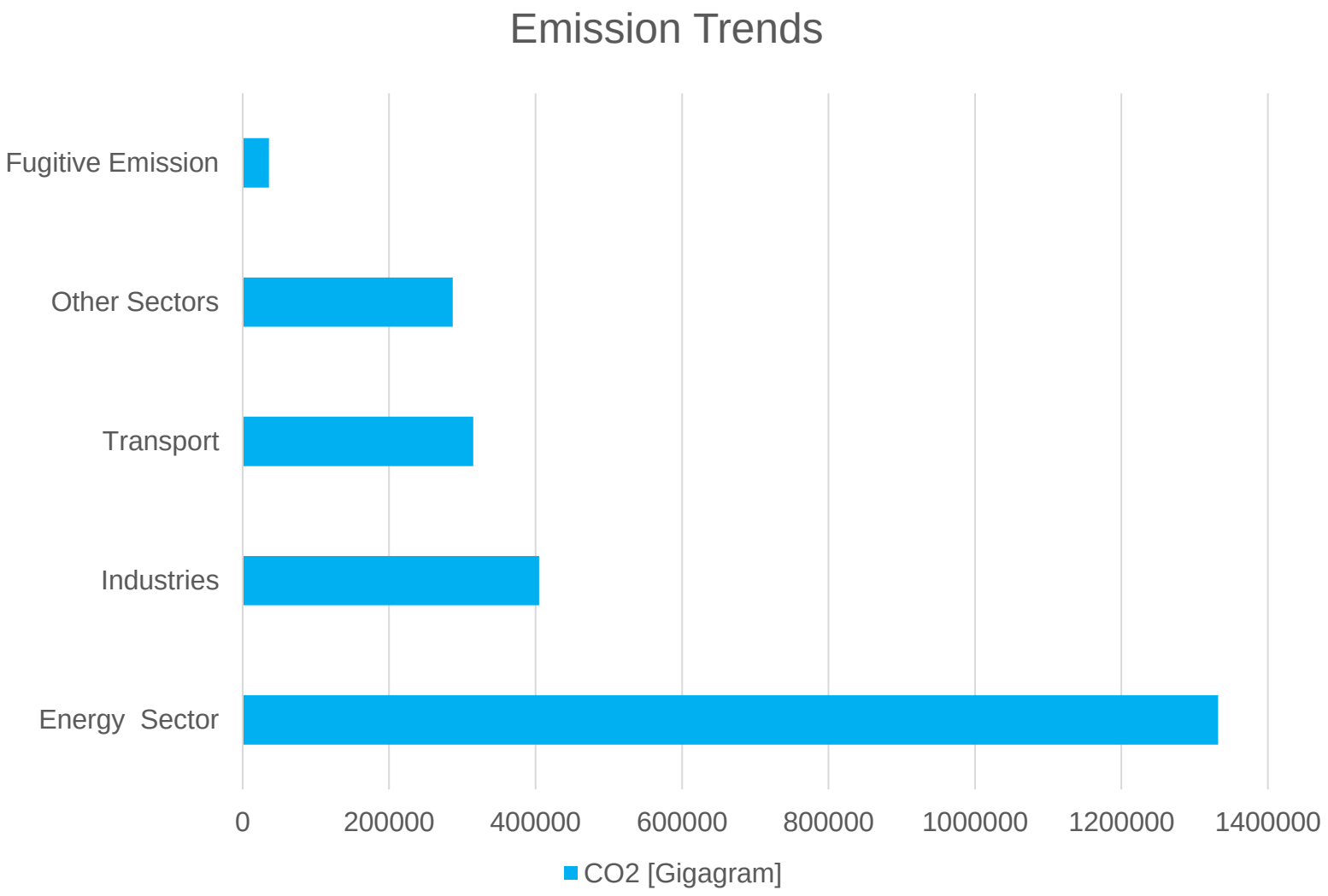


INDIA'S NET-ZERO COMMITMENT

- Net zero by 2070
- Reduce emissions intensity of GDP by 45% by 2030, from the 2005 level
- Achieve 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030
- In the Union Budget 2023-24, nearly $4.3 billion (₹35,740 crore) was allocated for priority capital investments towards energy transition initiatives, net zero objectives, and energy security targets

SOURCE *BT* RESEARCH

Emission Trends in India



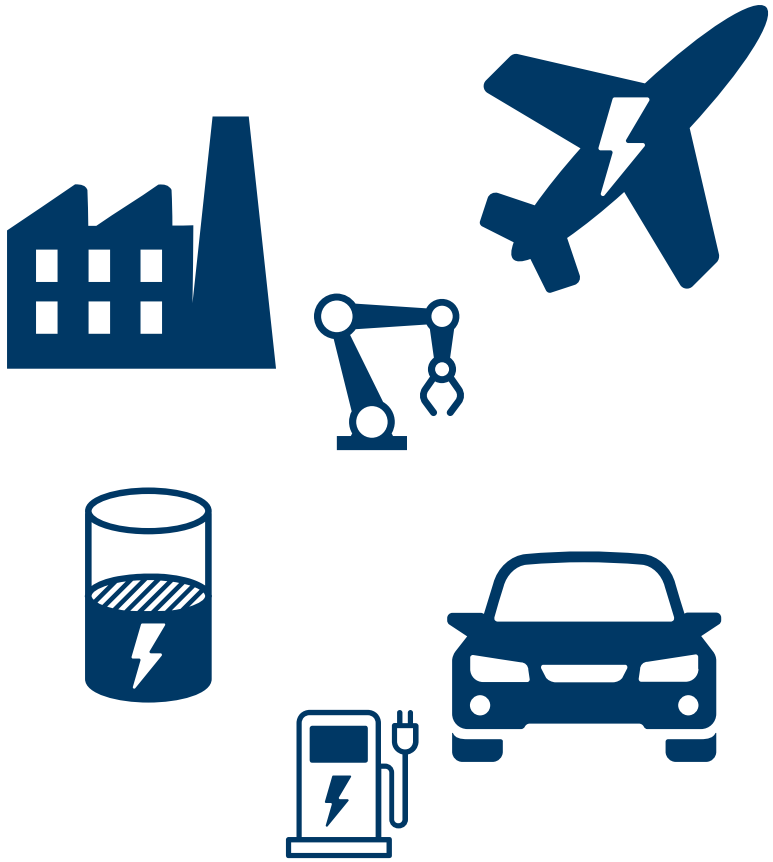
Data source: https://iced.niti.gov.in/climate-and-environment

Electrification Contributing to Net - Zero

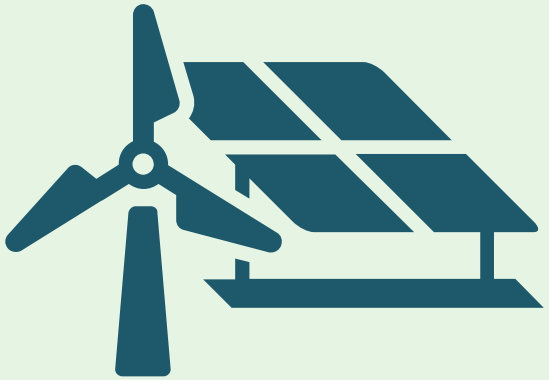
Low-carbon fuels

Energy storage

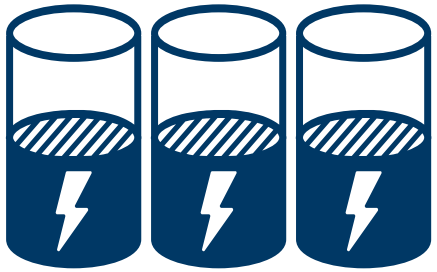
Energy efficiency
Load



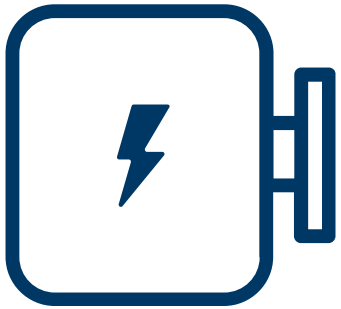
Electrification Contributing to Net - Zero



Renewable Integration



Energy Storage



Load

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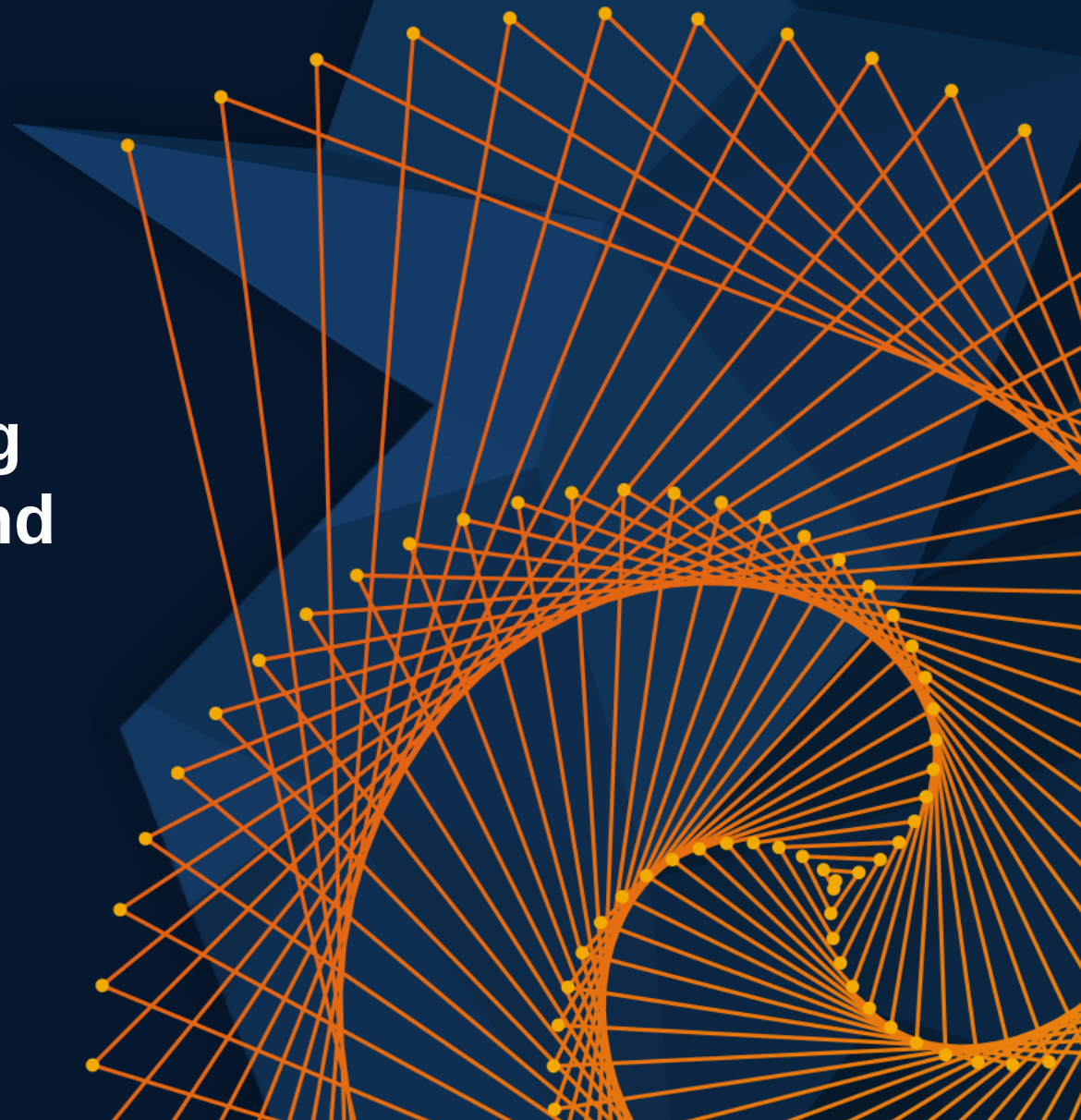

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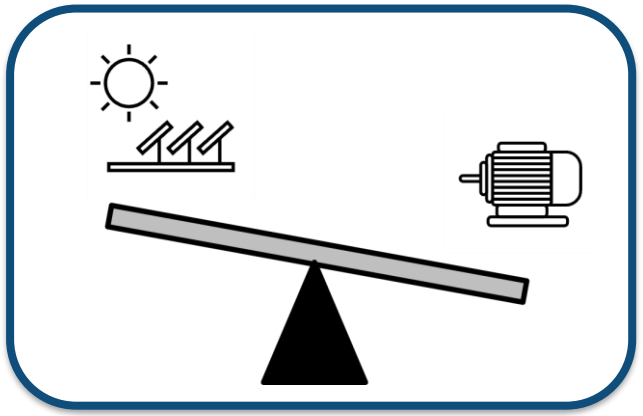
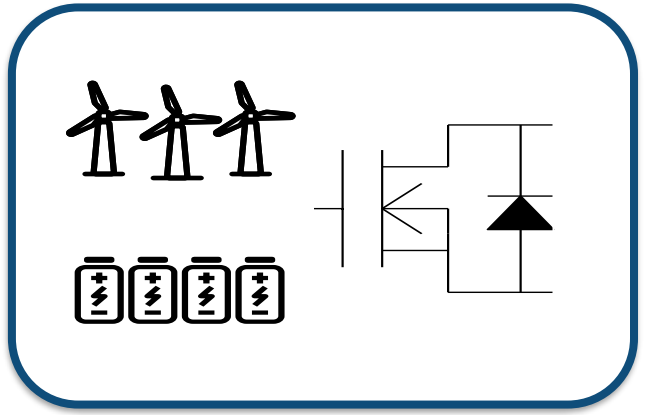
Renewable integration does bring its own challenges

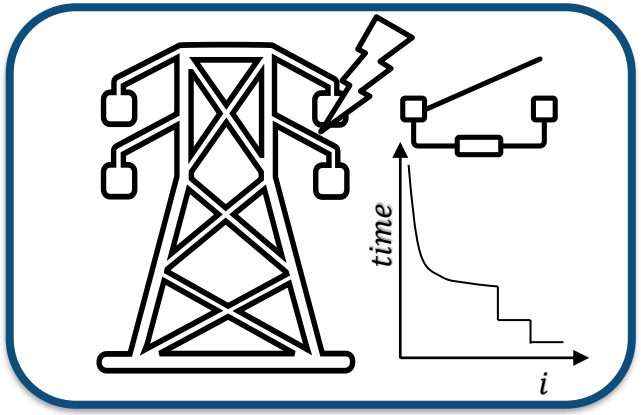
Variability in Renewable Power



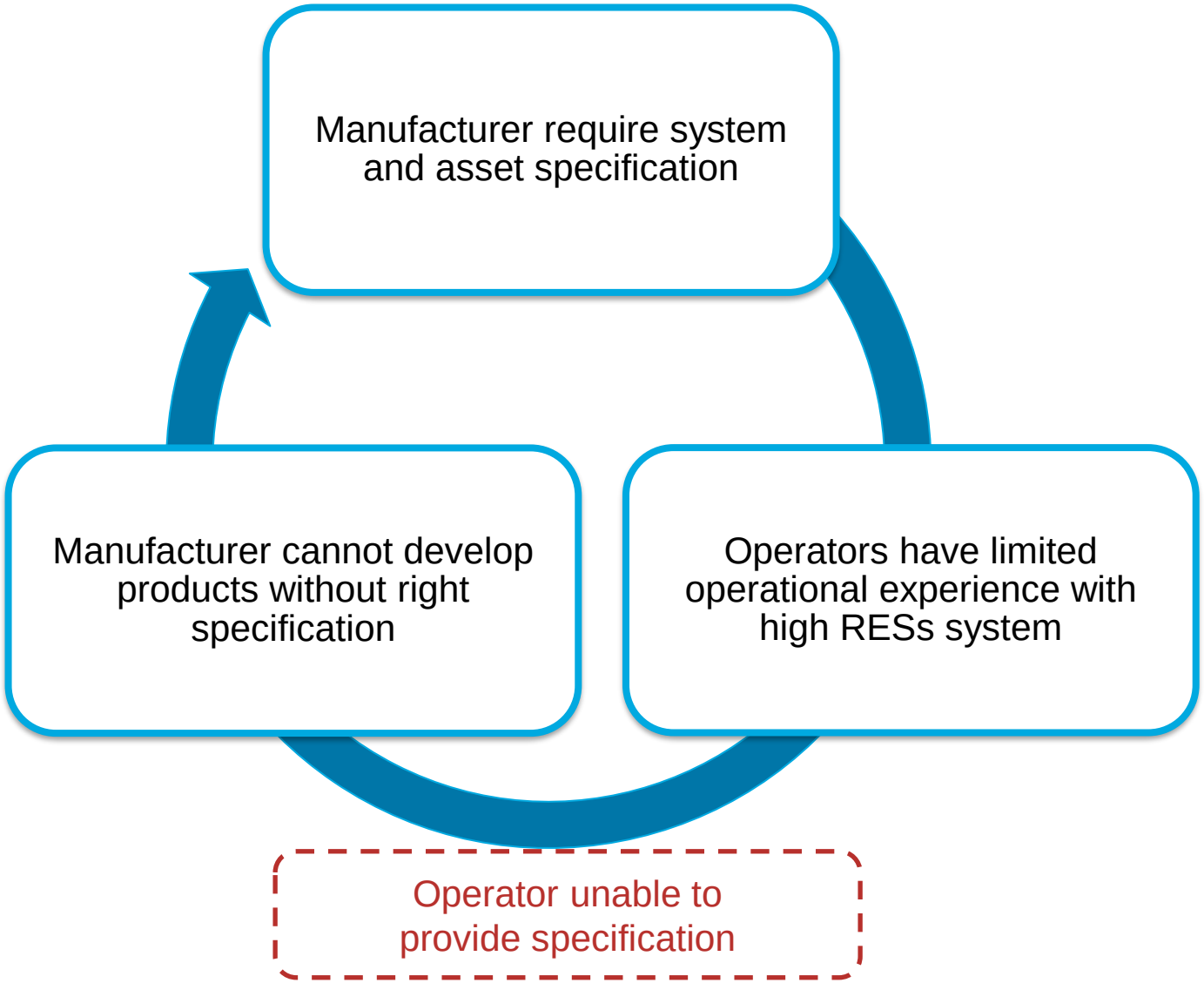
Stability with Inverters



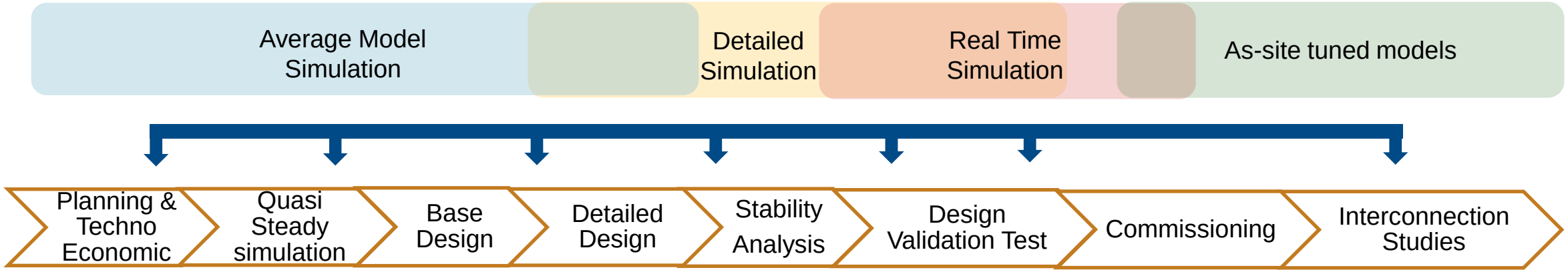
Response to Events



OEM face challenges with increased renewable penetration

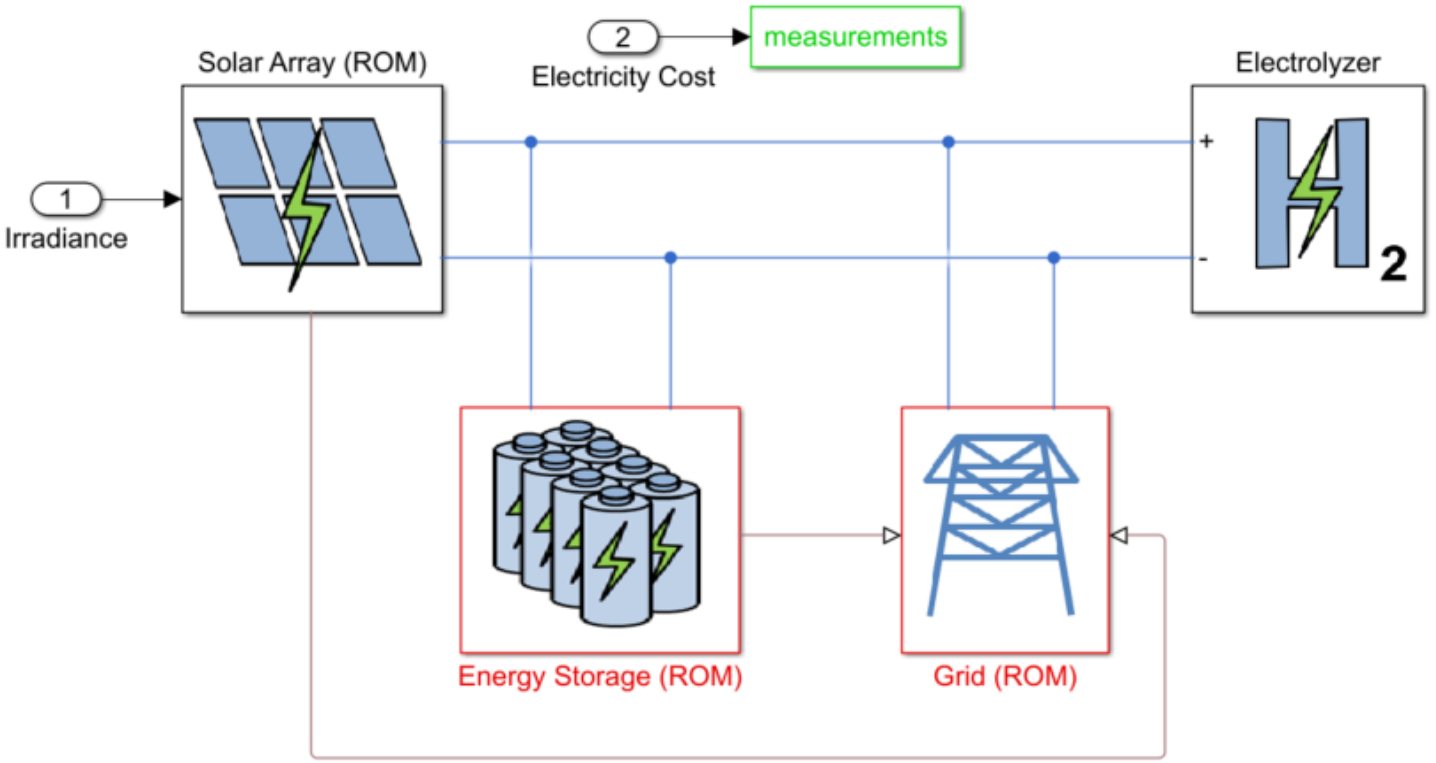


Simulation used as a solution from planning to operations



Reduced order modeling for techno economic analysis

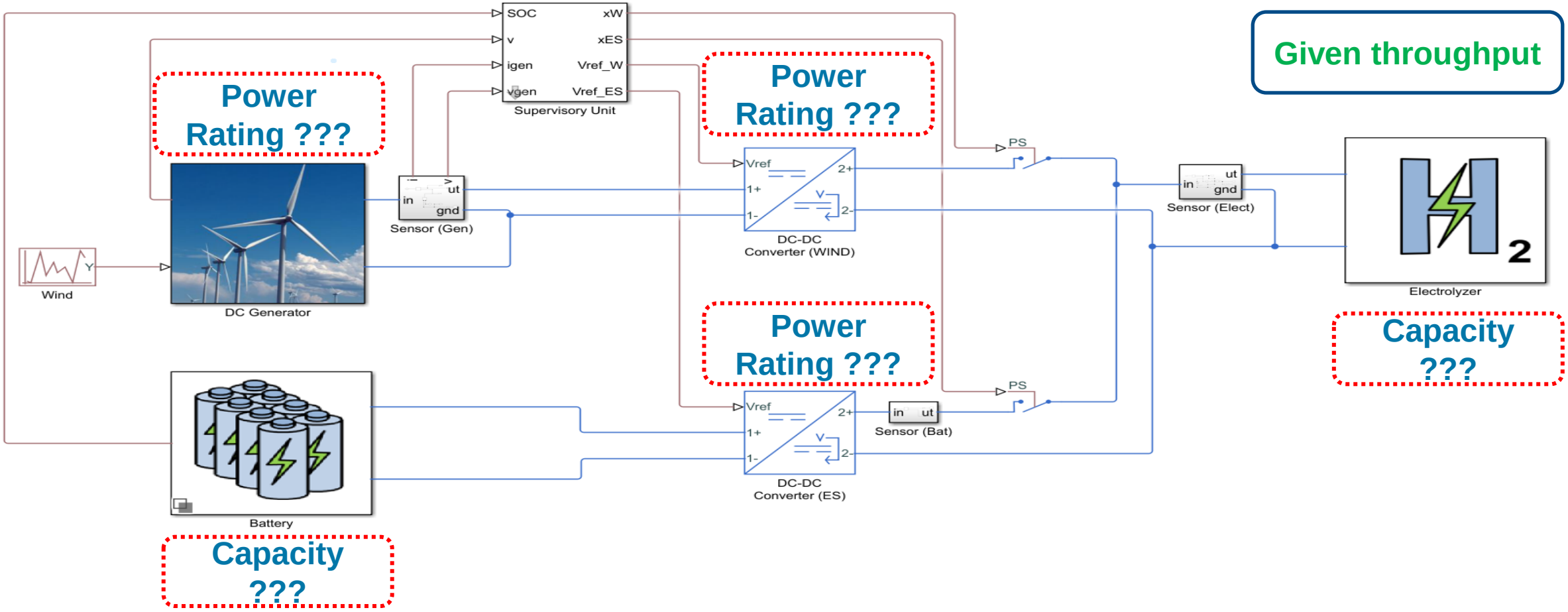
- Objective: Analyze economical aspect of setting up the system
  - Highest and lowest grid cost
  - Highest and lowest solar resources



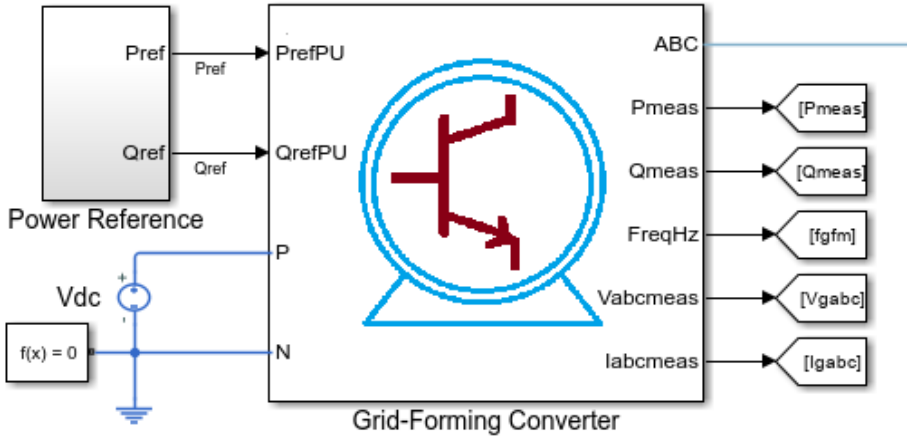
Throughput???

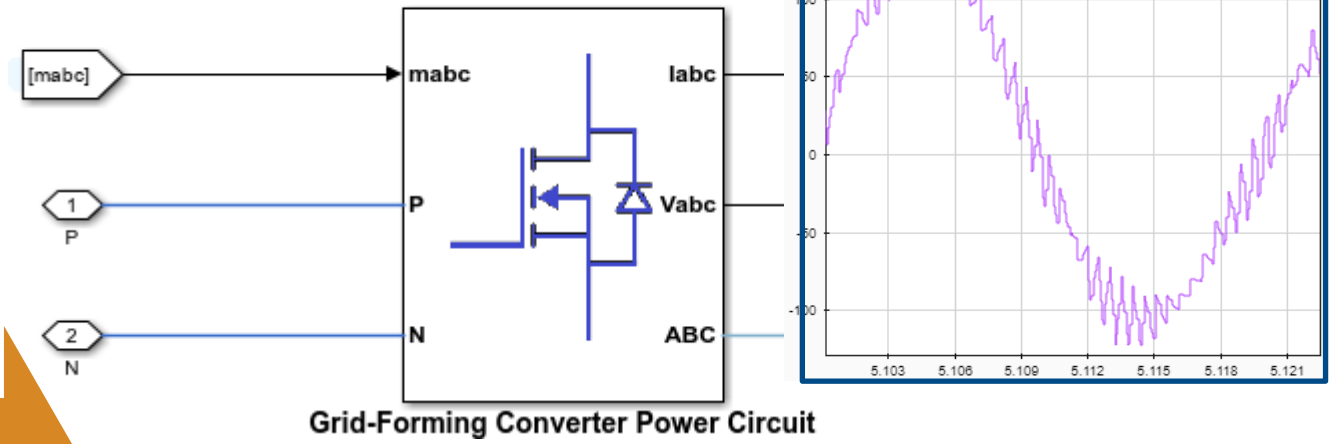
Profit???

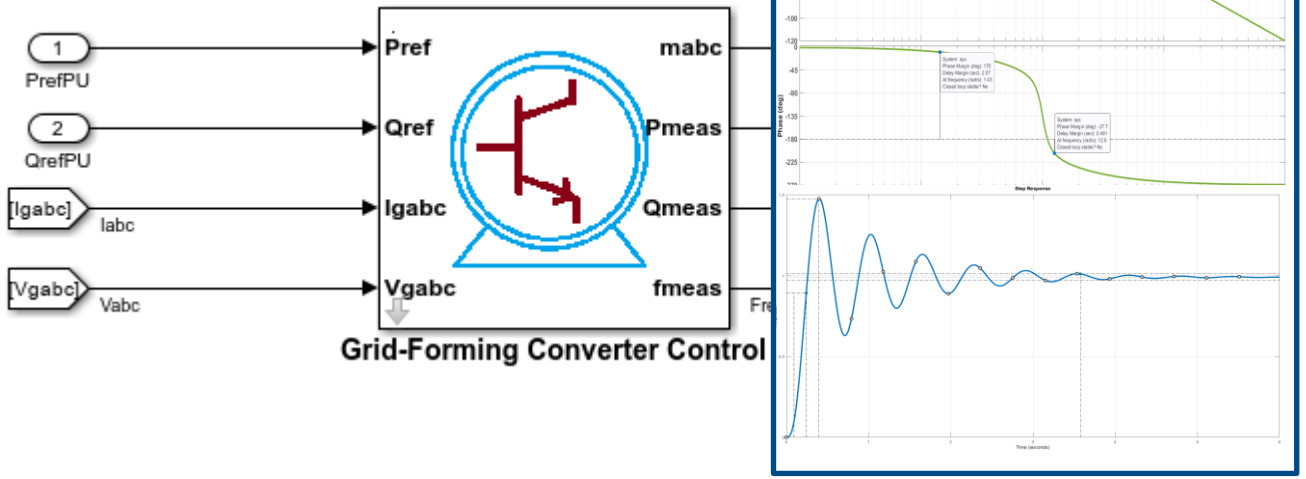
Energy balance model for equipment sizing



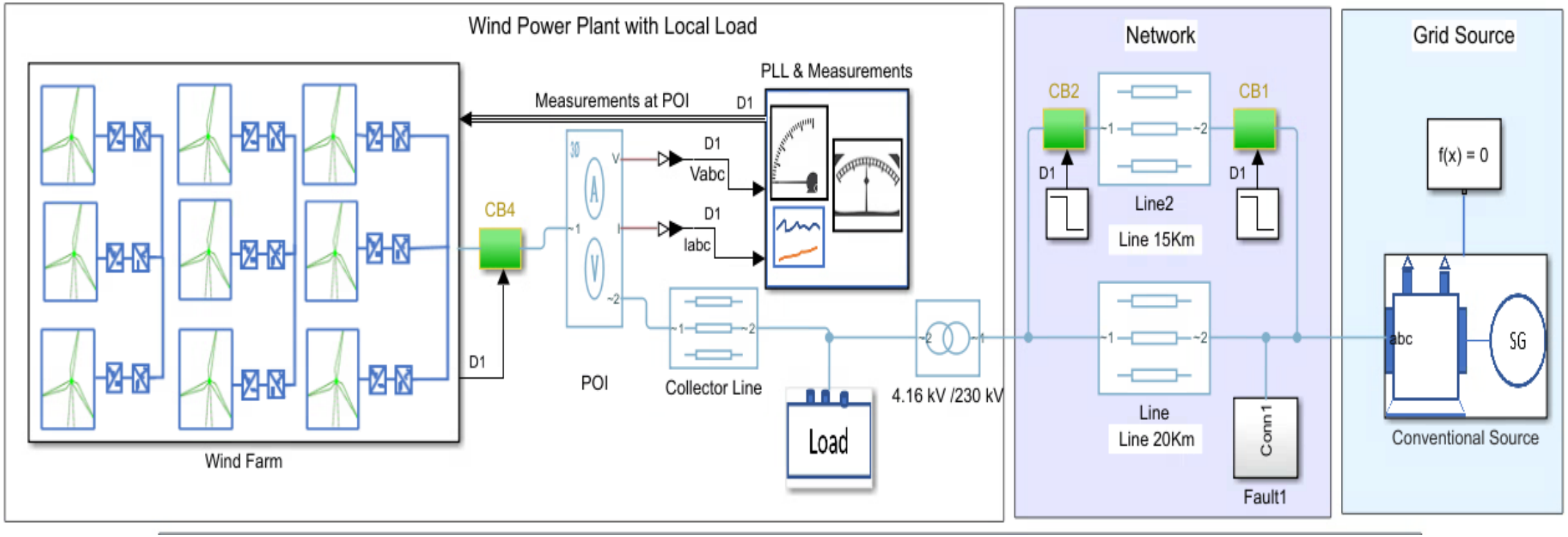
EMT models for stability and power quality analysis







Multi-Domain model for integration studies



Hydro-Québec Models Wind Power Plant Performance

Challenge

Plan the integration of new wind farms into the power system, predict power output, and ensure safe, reliable operation

Solution

Use MathWorks products to simulate individual wind turbines and wind farms and to generate C code for multiprocessor simulation of entire power systems

Results

- Simulation speed increased to real time
- Equipment needs accurately predicted
- Dynamic simulations enabled

Turbines on a wind farm.

"Accurate modeling is essential not only for planning investments but also to detect situations that can cause an outage. With MathWorks tools, we can simulate power electronics, mechanics, and control systems in one environment, and our models respond like the turbines we have in the field."

- Richard Gagnon, Hydro-Québec

Link to user story

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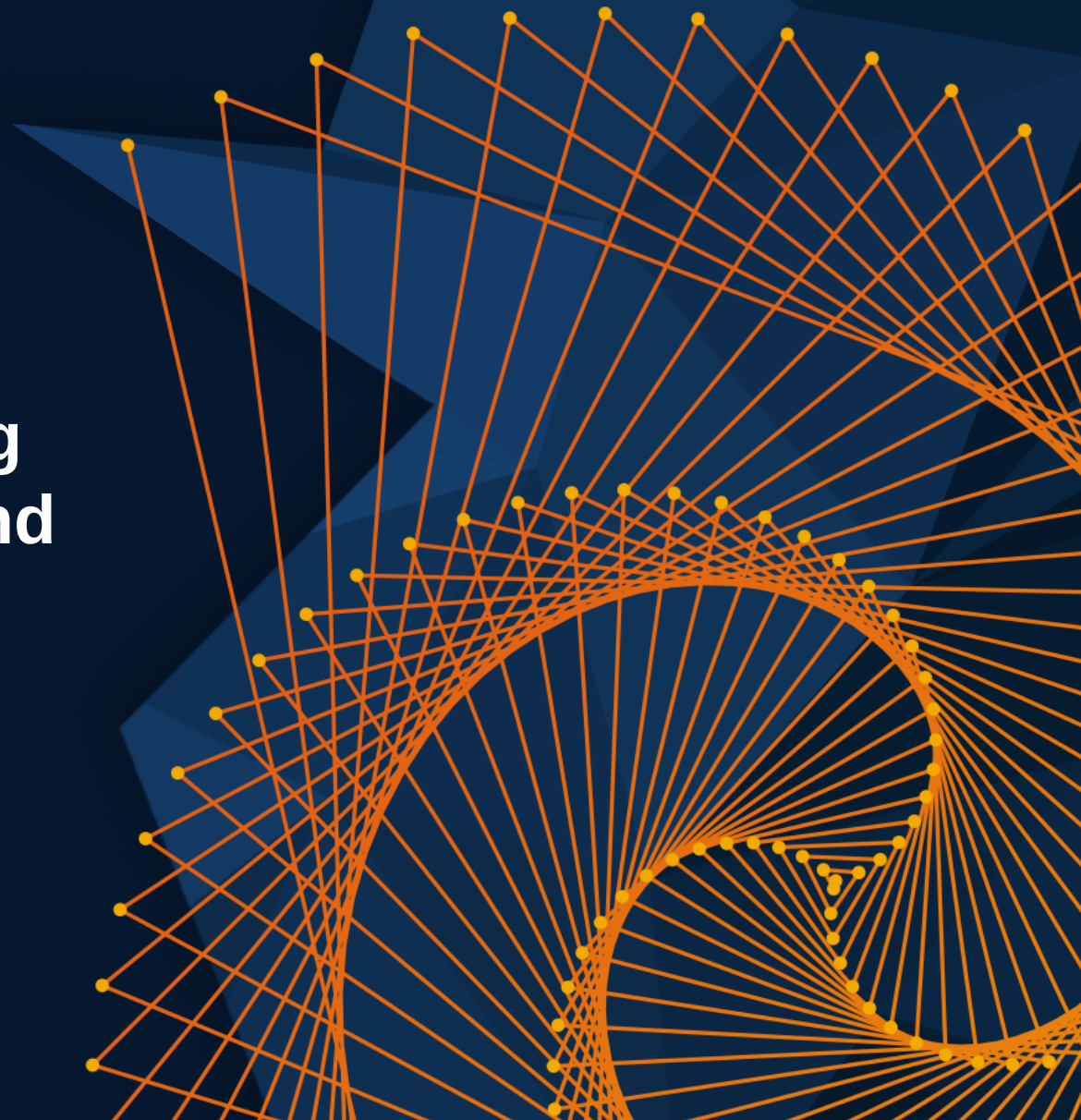

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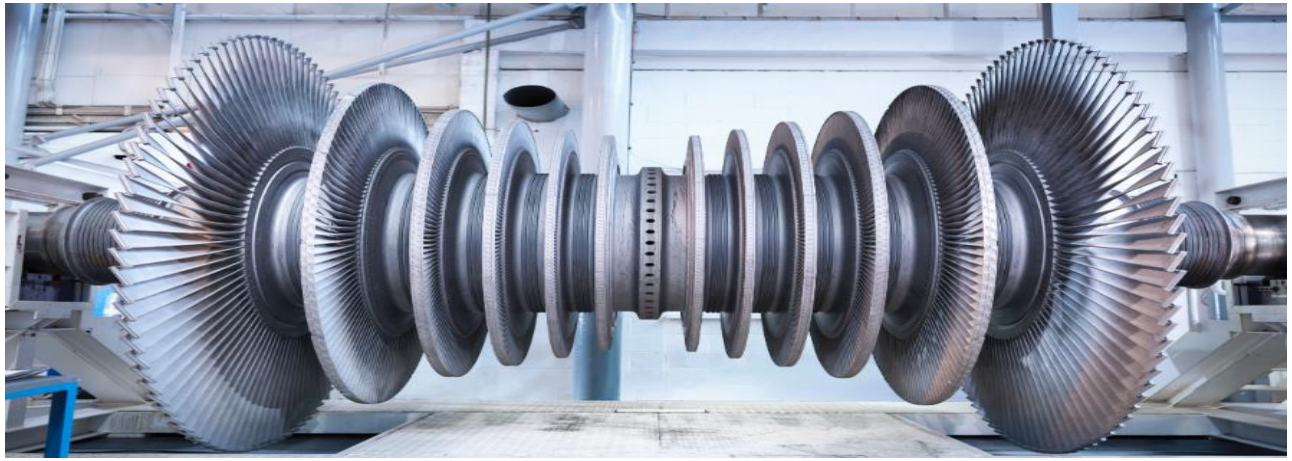
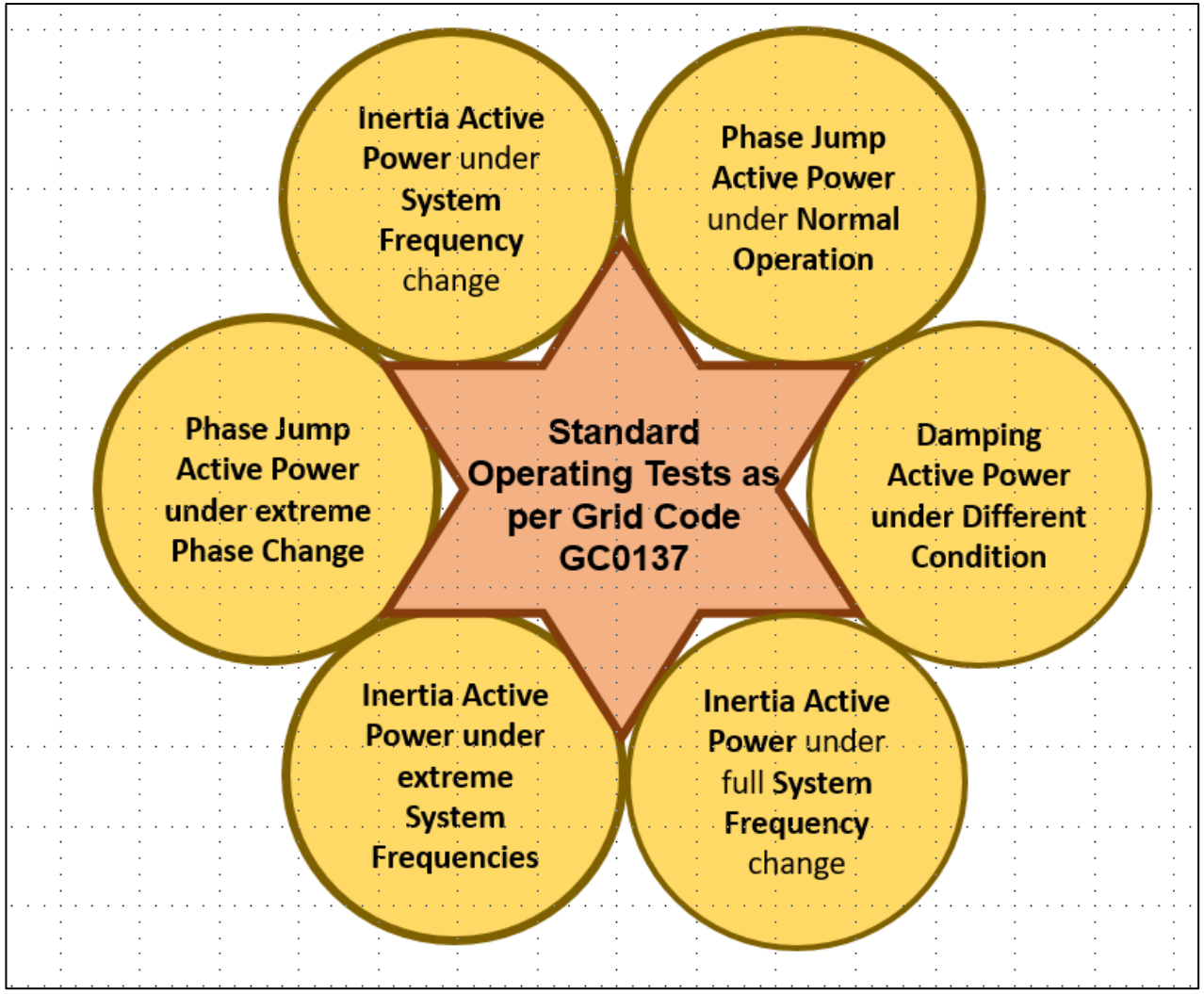
IBR introduces challenges in power grid



- High inertia spinning turbines
- Ability to ride through faults
- Strong grid

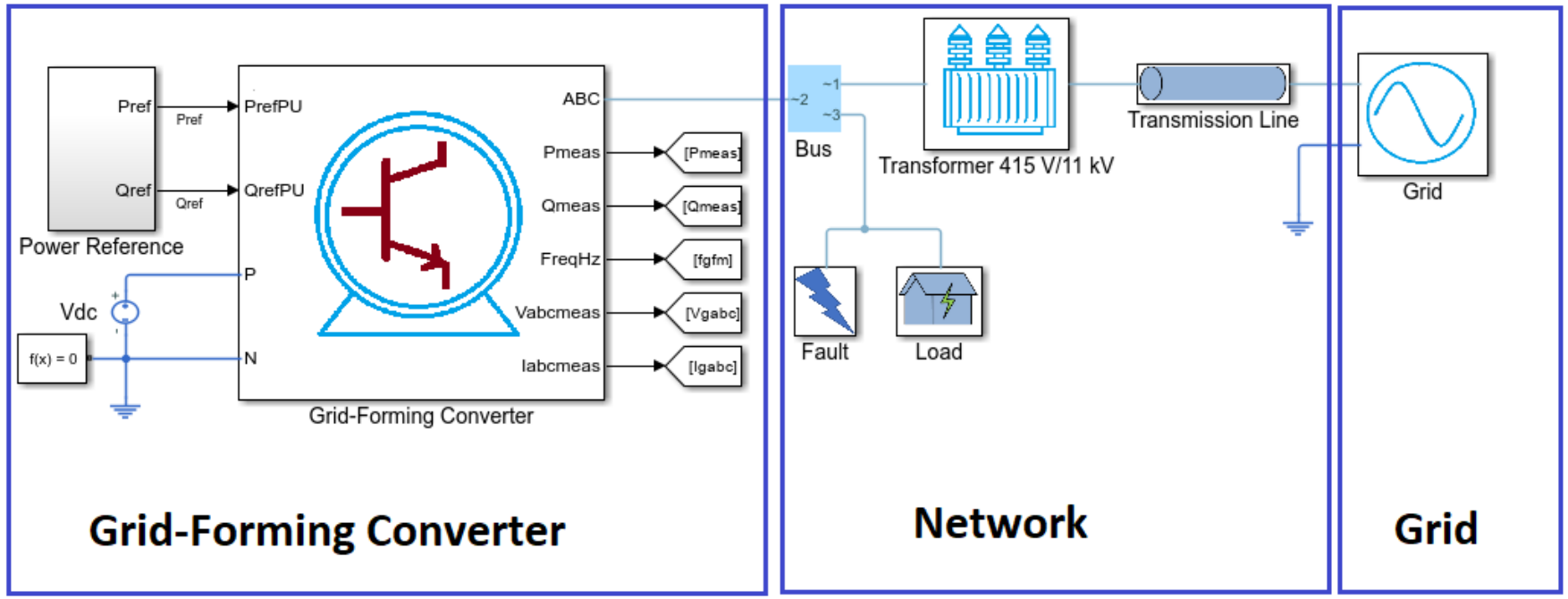
- Low inertia / response to transient
- Control to mimic synchronous machine
- Battery energy storage system (BESS)

Testing as per Grid Code Standard GC0137



Develop testbench models to test GFM compliance

- Grid-forming converter plant
  - Controller
  - Power circuit
- Power network
  - Short circuit ratio
  - X/R ratio
- Grid
  - Voltage
  - Phase
  - Frequency



Test Automation to verify grid code compliance

Testing other requirements

```
methods(Test)
    function testActivePowerTracking(testCase,powerControl) ...

    function testReactivePowerTracking(testCase,powerControl) ...

    function testFrequencyChange(testCase) ...

    function testPhaseJumps(testCase) ...

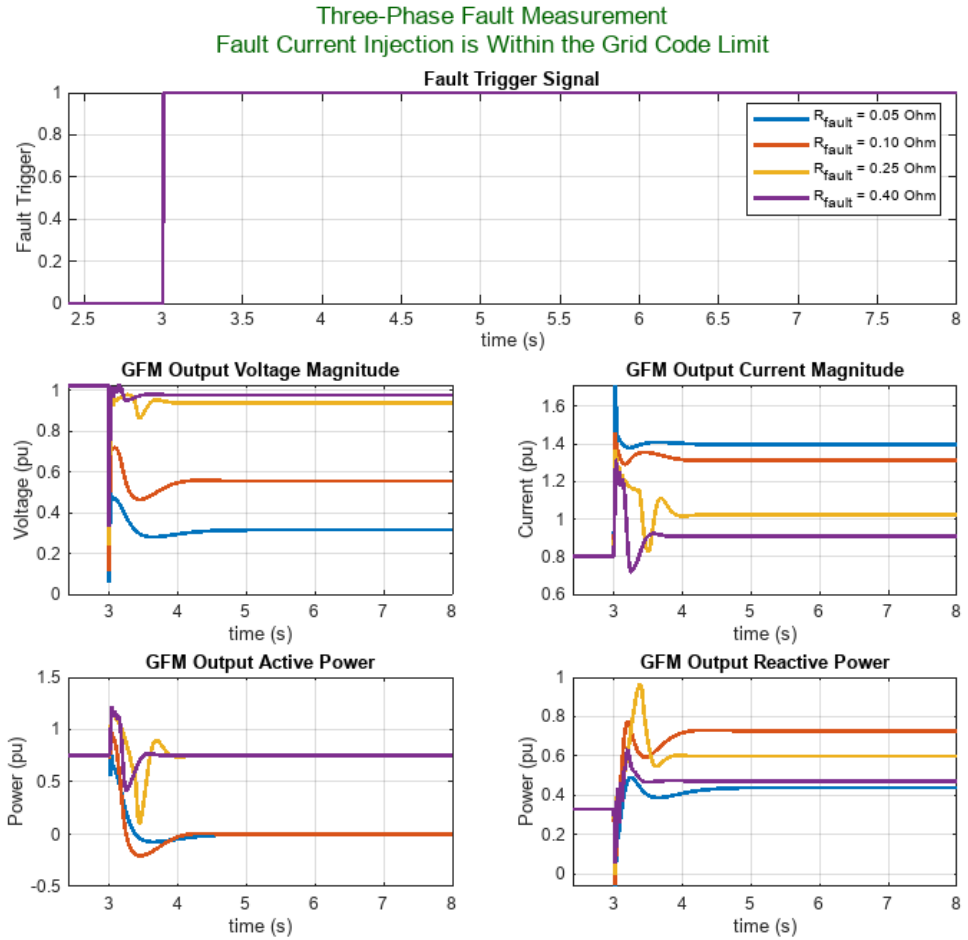
    function testIslanding(testCase) ...

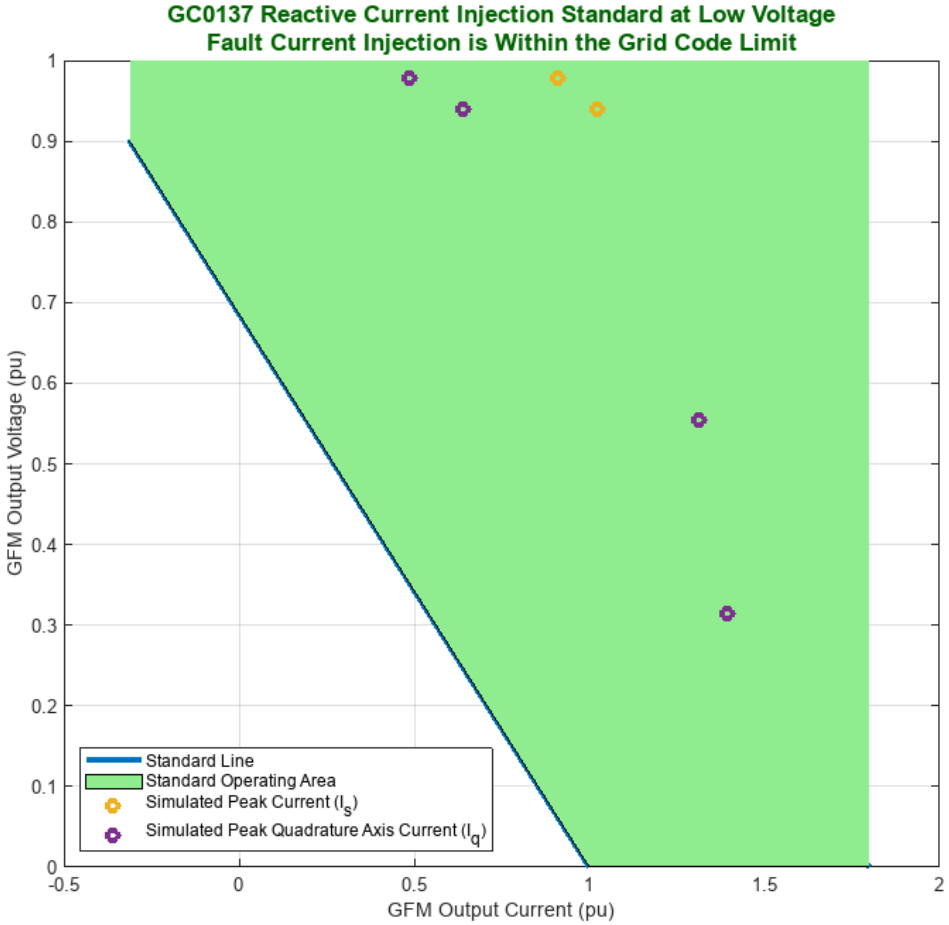
    function testCurrentLimitingVariants(testCase,currentLimit) ...
end

methods
    function verifyStability(testCase,LogsoutGridFormingConverter,timeWindow,limits,condition) ...
end
```

Test Automation to verify grid code compliance

Visualize transient response and compliance to standards





Test Automation to verify grid code compliance

Reporting out test results

```
   Running GridFormingConverterUnit/GFMRunPlotFaultCurrentVoltageEffects
Steady State Grid-Forming Converter Output Measurement in pu
    FaultResistanceInOhm    ActivePower    ReactivePower    Voltage    MinimumStandardCurrent    MeasuredCurrentIs
    ____________________    ___________    _____________    _______    ______________________    _________________

            0.05            -2.8592e-08       0.43993       0.31506          0.54071                1.3945
             0.1             1.2063e-09       0.72879       0.55504          0.19086                1.3124
            0.25                   0.75       0.59973       0.94008         -0.37045                1.0215
             0.4                   0.75       0.47461       0.97762         -0.42517               0.90787
   Done GridFormingConverterUnit/GFMRunPlotFaultCurrentVoltageEffects in 171.1726 seconds
```

```
   Running GridFormingConverterUnit/GFMRunPlotCompareFaultRideThroughMethod
Steady State Grid-Forming Converter Output to Compare Fault Ride-Through Methods
                    TestName                      ActivePower    ReactivePower    Voltage    Current    TestResult
    ______________________________________________    ___________    _____________    _______    _______    __________

    "Virtual Impedance"                           1.1027e-10        0.88326          0.7079    1.2476     "Stable"
    "Current Limiting"                             0.0004716         1.0051         0.56667    1.4002     "Stable"
    "Virtual Impedance and Current Limiting"      1.1563e-10        0.88326          0.7079    1.2476     "Stable"
   Done GridFormingConverterUnit/GFMRunPlotCompareFaultRideThroughMethod in 69.1092 seconds
```

Stem Accelerates Development of Power Electronics Control Systems with Model-Based Design

Challenge

Speed the development and certification of a power electronics control system for a distributed power storage system

Solution

Use Model-Based Design with MATLAB and Simulink to run simulations of power electronics, the electrical grid, and controller; generate production microcontroller code; and achieve certification

Results

- Six months of development time saved
- Thousands of dollars in board spin costs saved
- System fully operational days after hardware becomes available

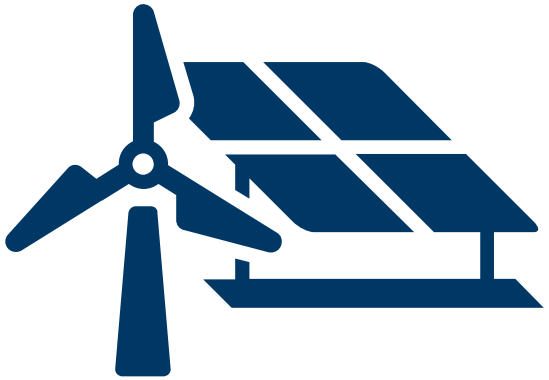
A commercial installation of Stem's PowerStore energy system.

"With Model-Based Design we saw exactly how our controller would work with the hardware even while the hardware was being developed. After we had the hardware, refinements were easy because the simulations matched what we saw on the scope, and that gave us tremendous confidence in the design."

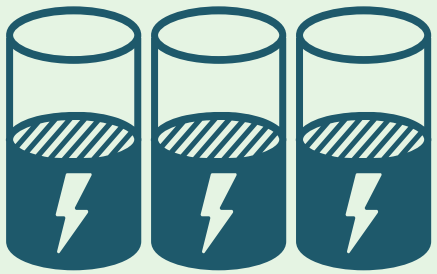
- David Erhart, Stem

Link to user story

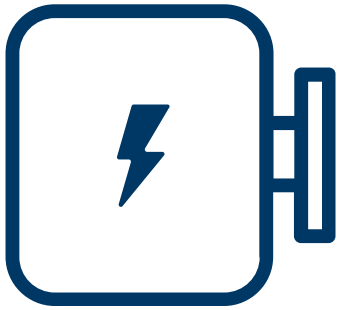
To be decided



Renewable Integration



Energy Storage



Load

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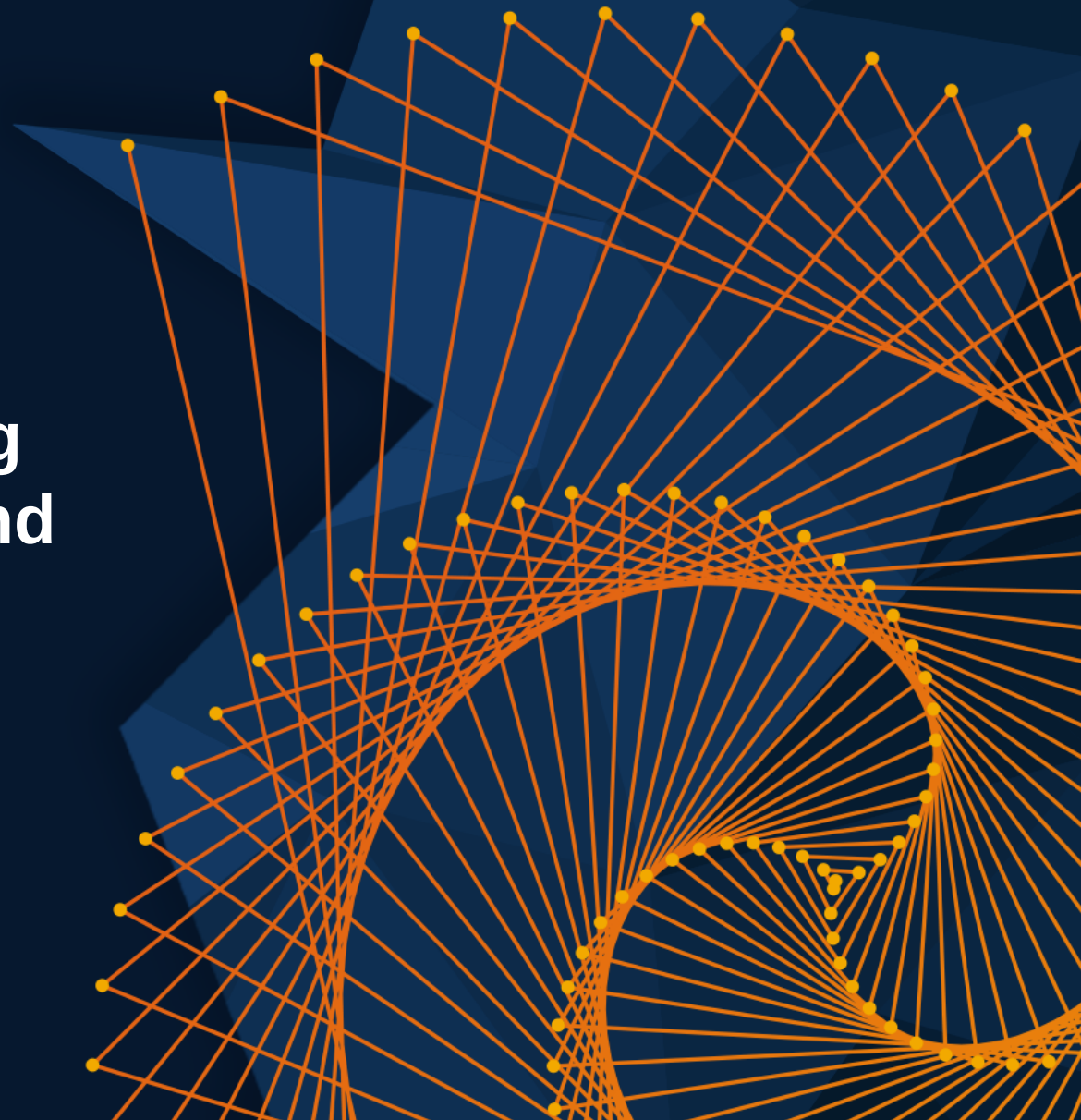
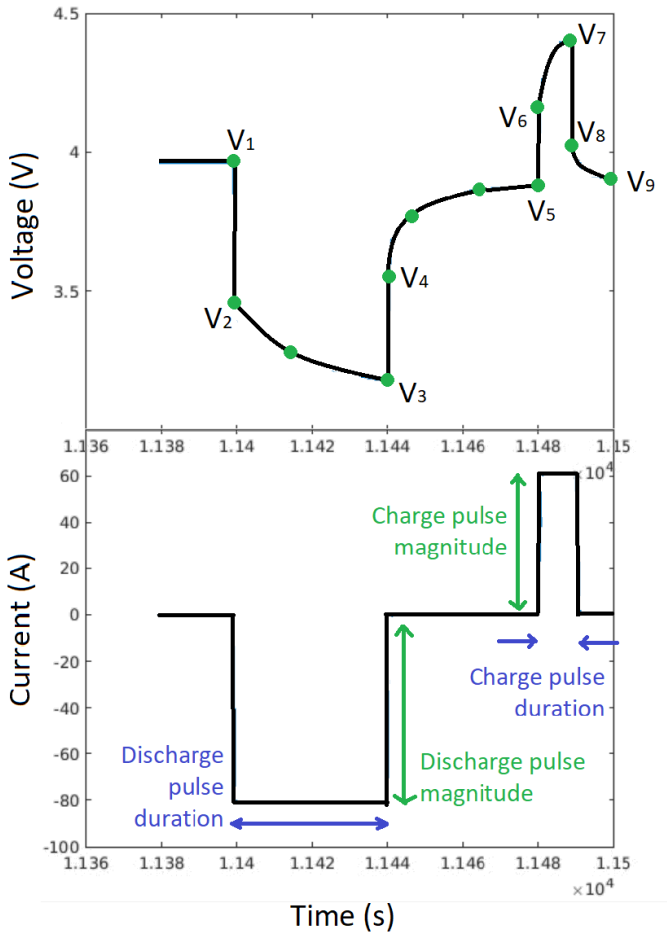
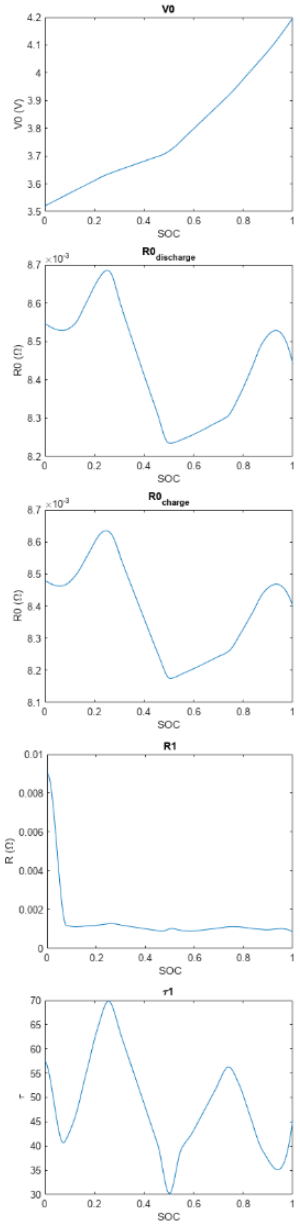


MathWorks

Start from the Cell Parameters

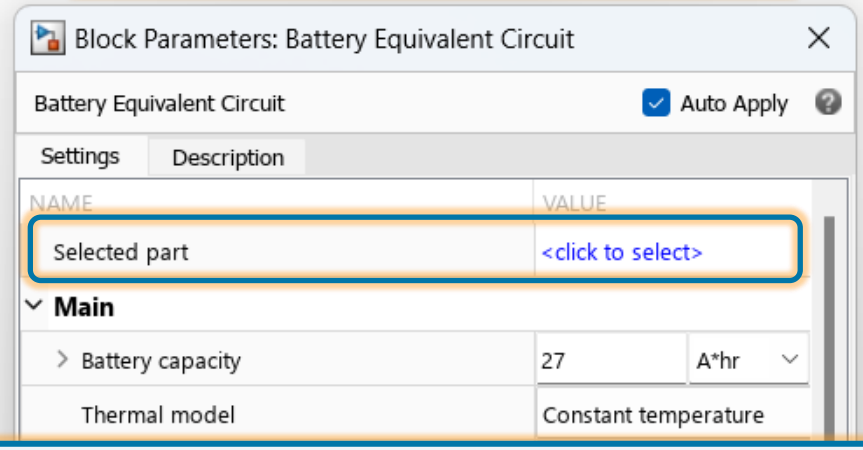
Fit from Data

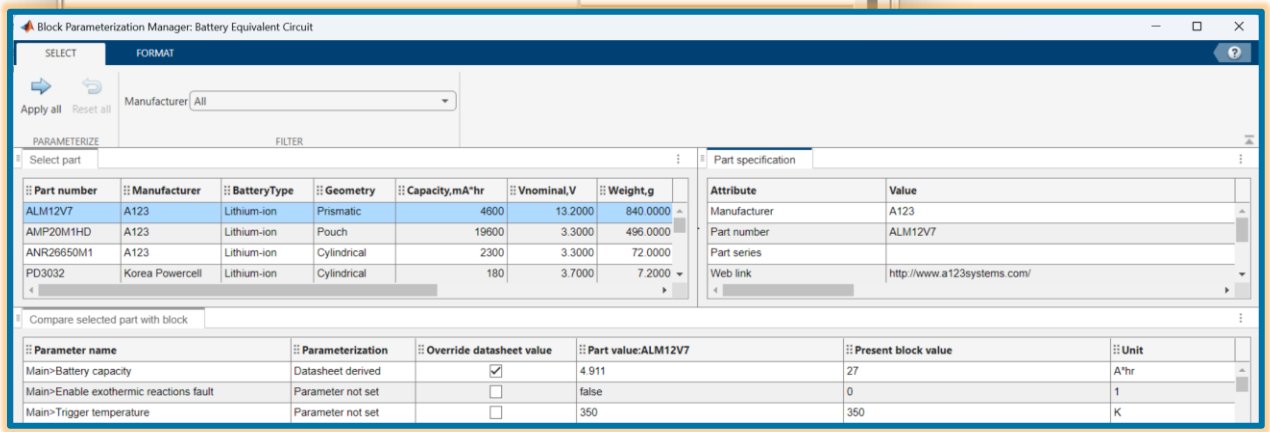




Pre-parametrized parts

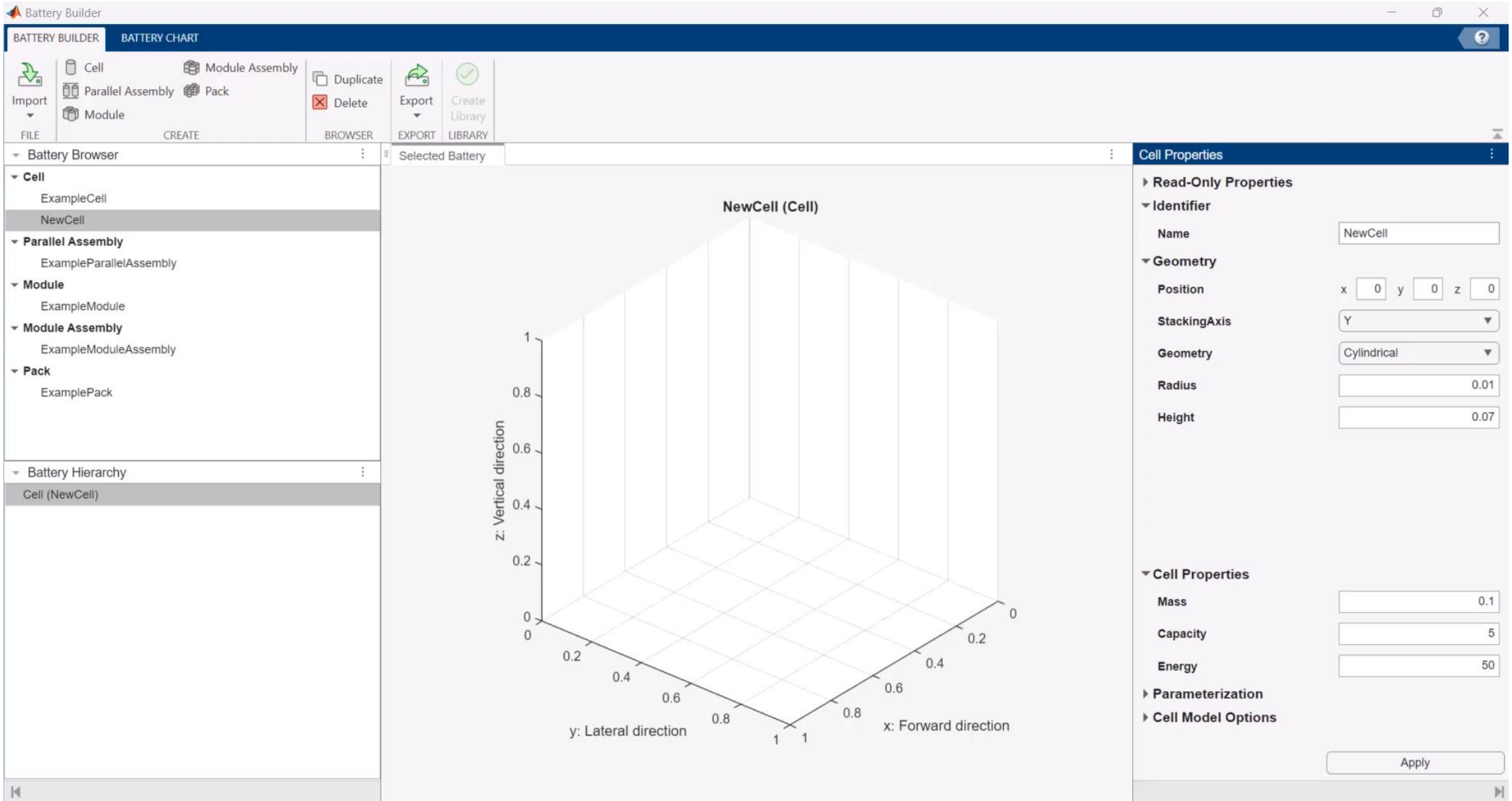
Battery Equivalent Circuit





[Characterize Battery Cell for Electric Vehicles]

Assemble the cells to create the battery pack



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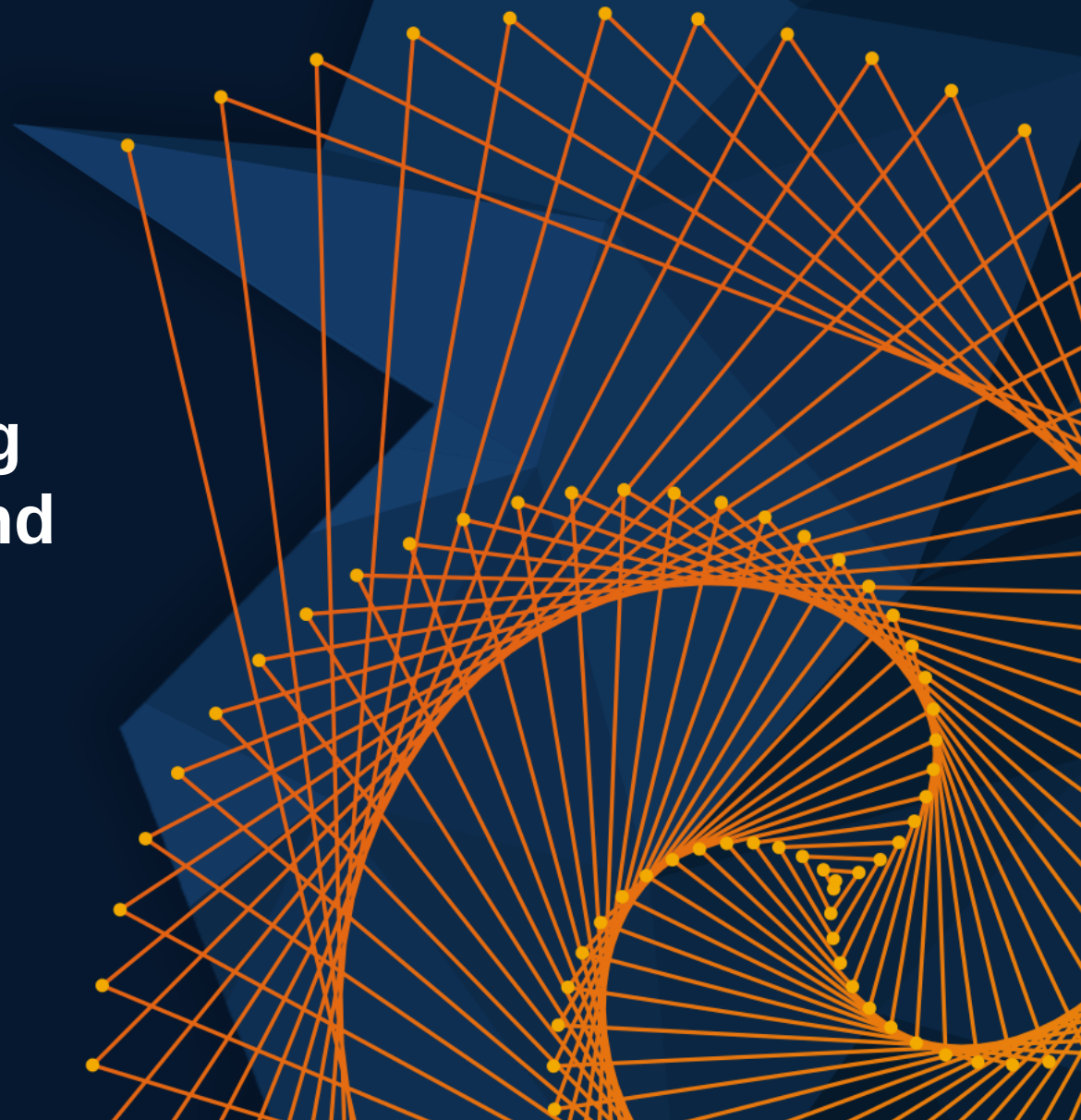
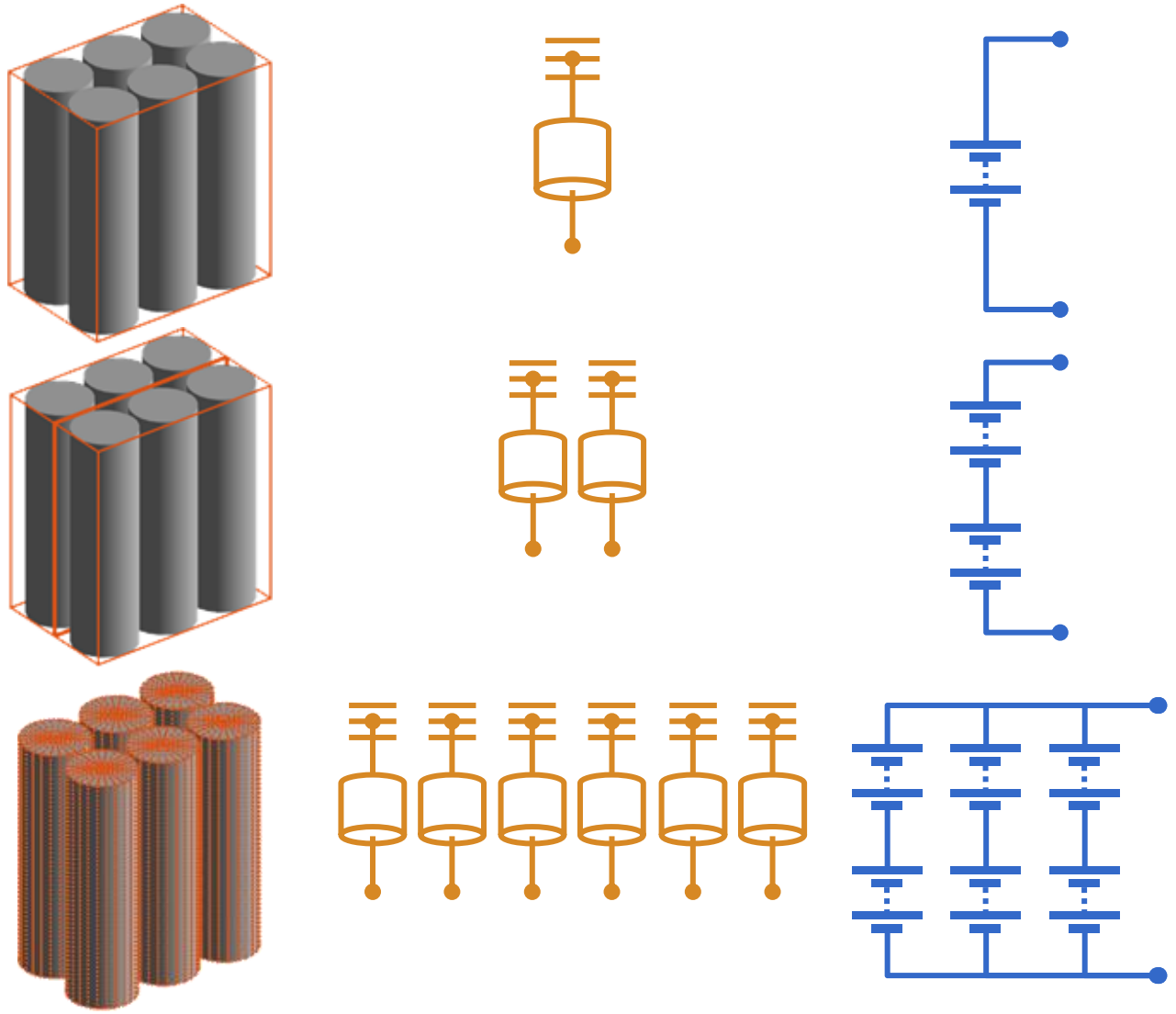


MathWorks

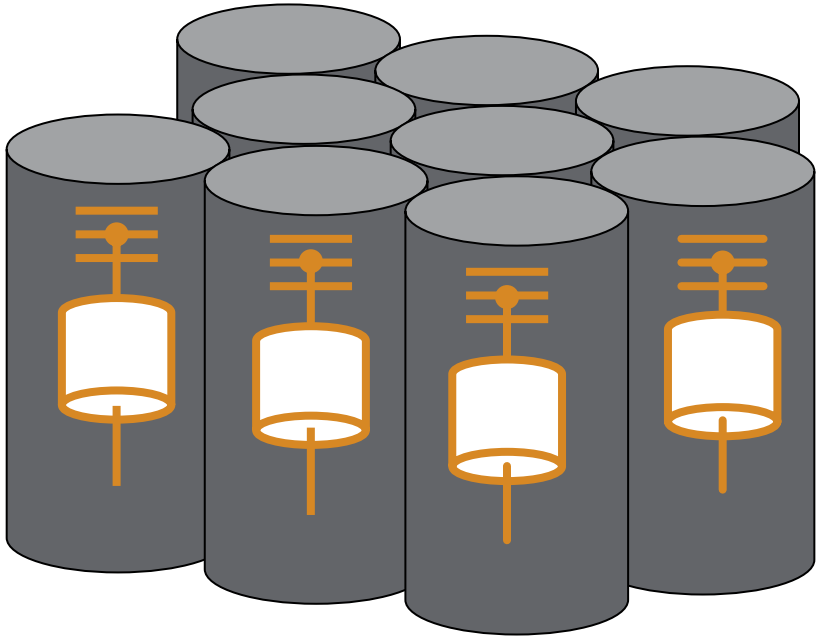
Battery Pack Model Fidelity

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



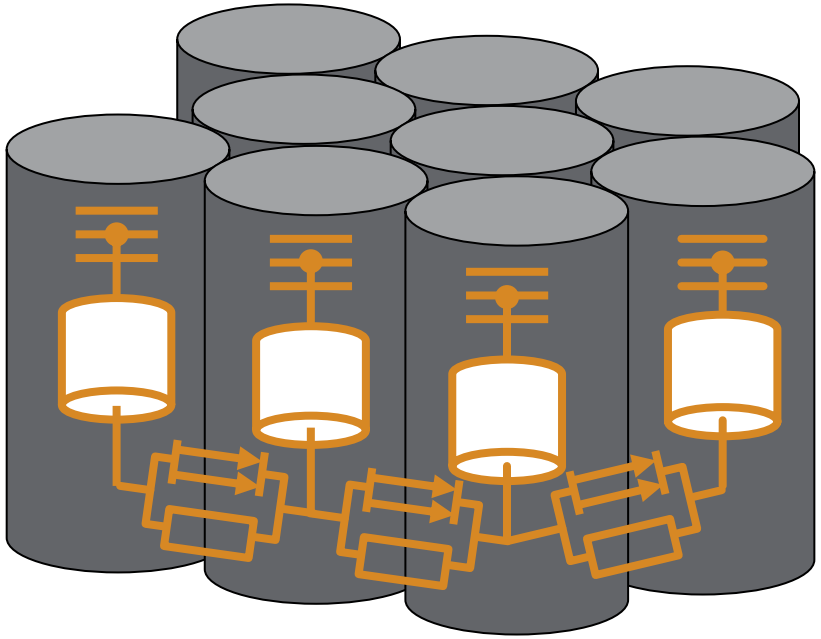
More to Model Resolution

How are the Thermal Connections set up?



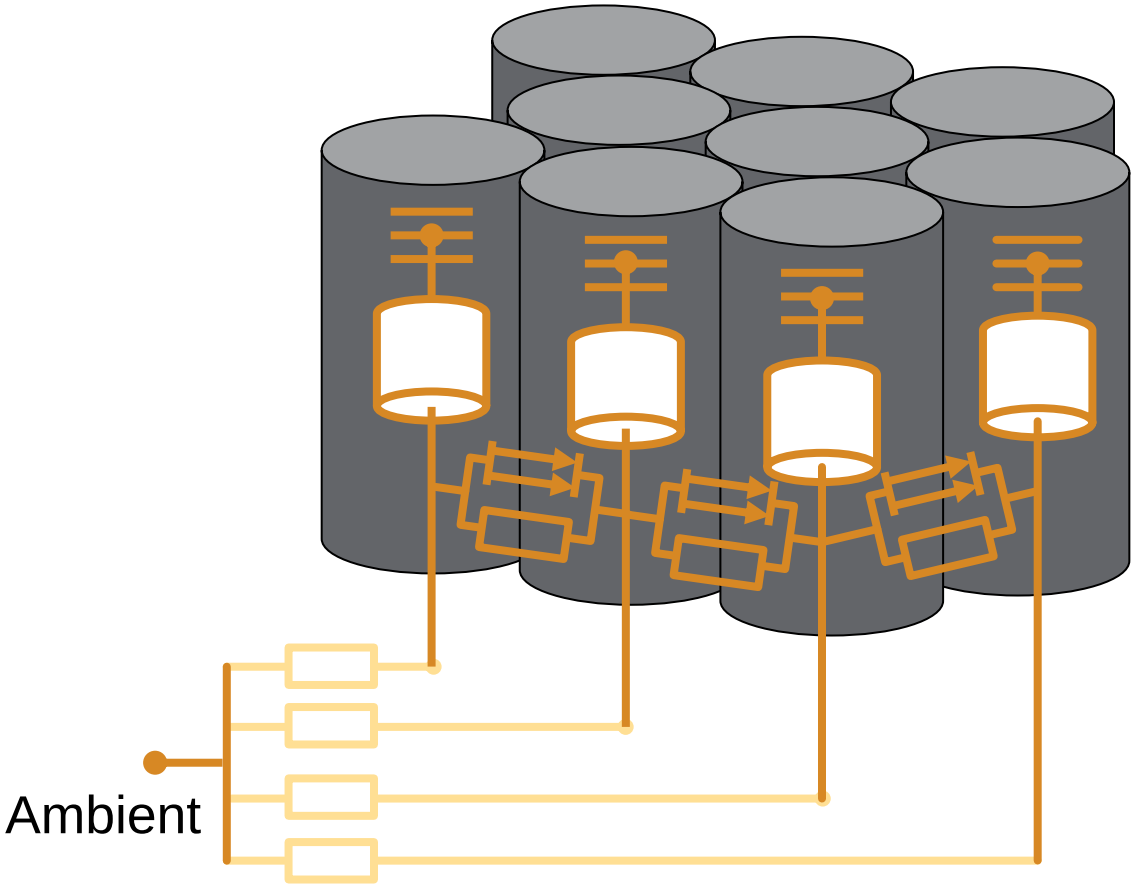
```
batteryModule = simscape.battery.builder.Module(...
    ParallelAssembly = pAssembly,...
    NumSeriesAssemblies = 3,...
    ModelResolution = "Detailed");
```

How are the Thermal Connections set up?



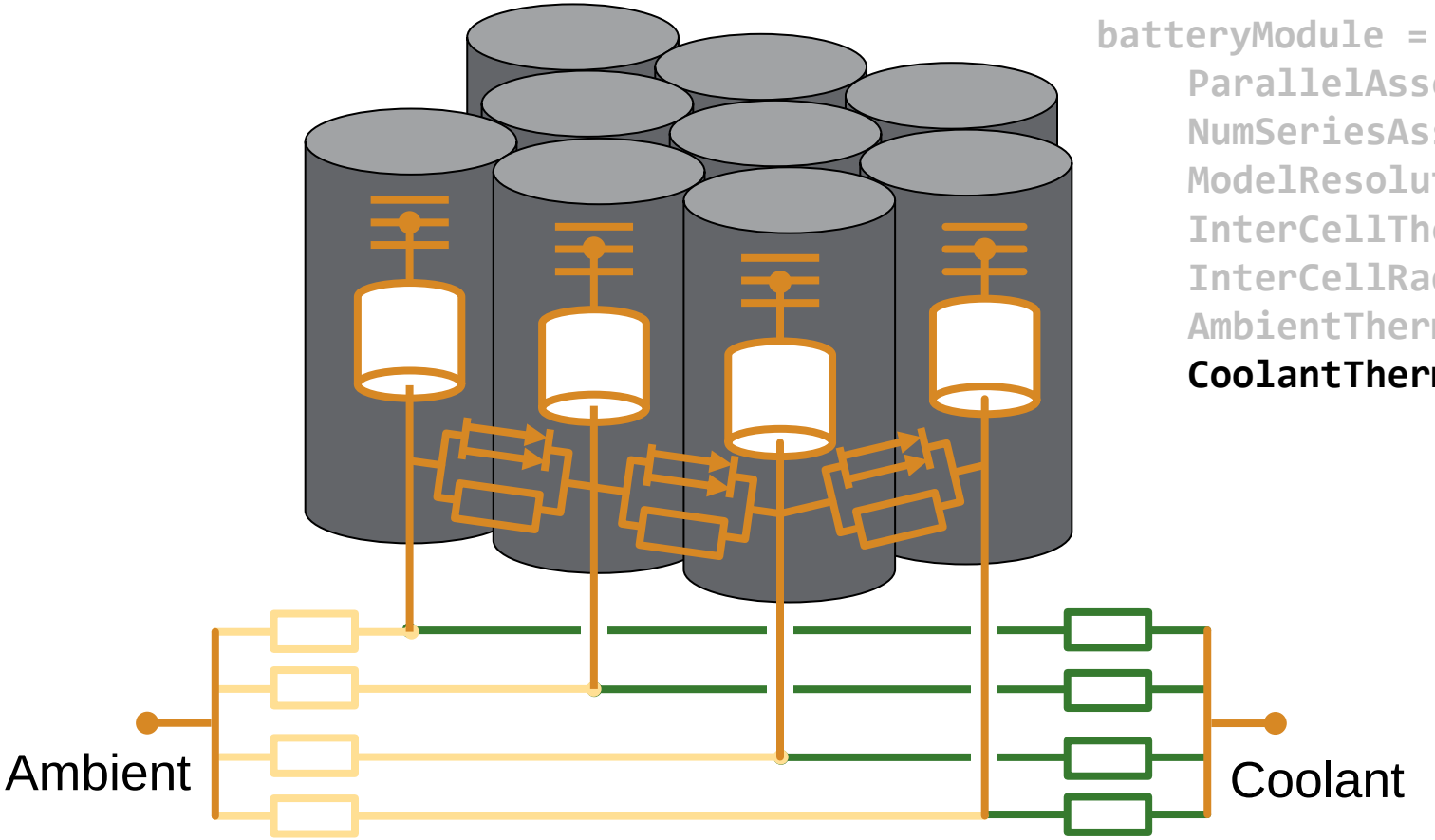
```
batteryModule = simscape.battery.builder.Module(...
    ParallelAssembly = pAssembly,...
    NumSeriesAssemblies = 3,...
    ModelResolution = "Detailed",...
    InterCellThermalPath = "on",...
    InterCellRadiativeThermalPath = "on");
```

How are the Thermal Connections set up?



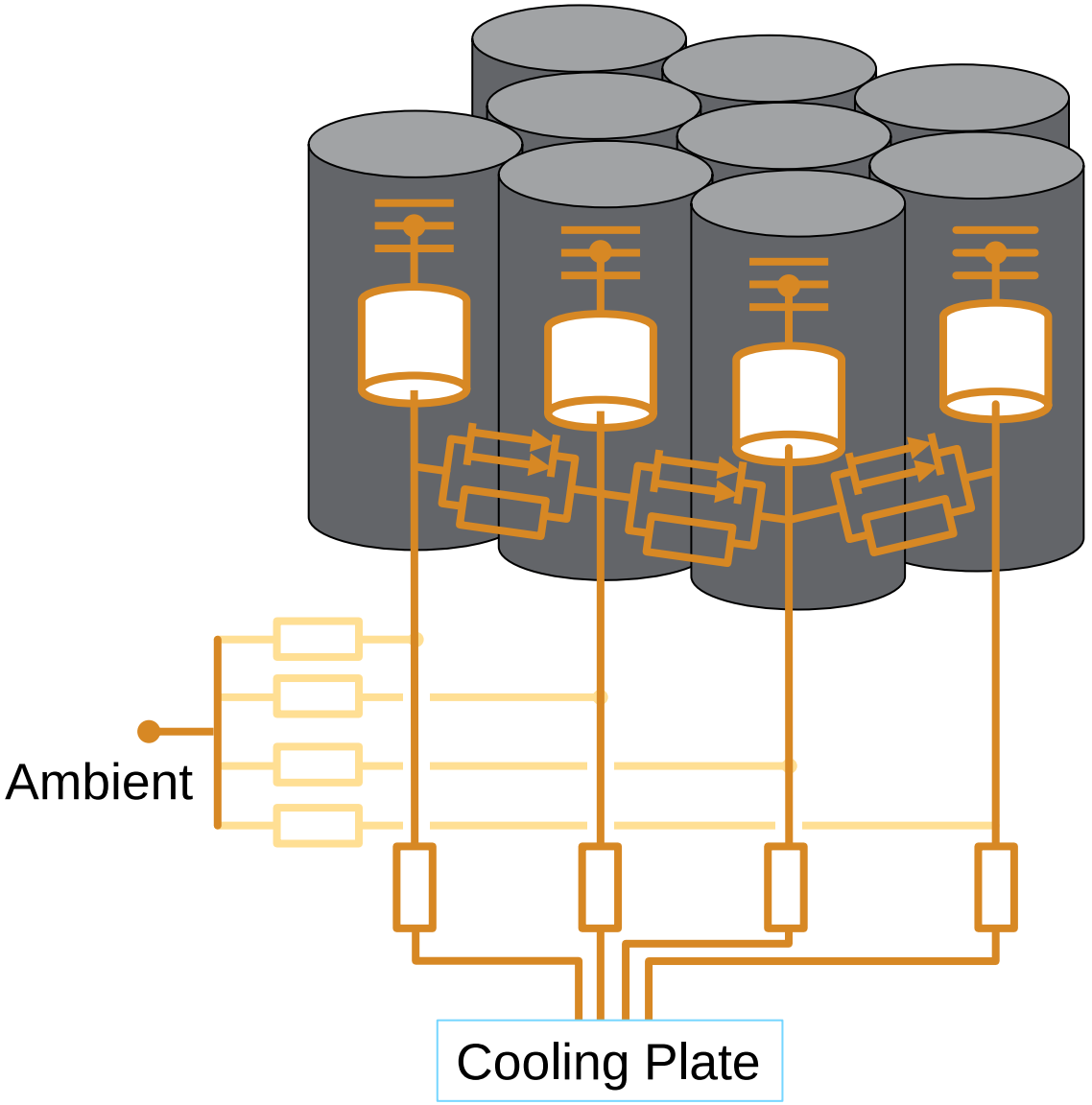

```
batteryModule = simscape.battery.builder.Module(...
    ParallelAssembly = pAssembly,...
    NumSeriesAssemblies = 3,...
    ModelResolution = "Detailed",...
    InterCellThermalPath = "on",...
    InterCellRadiativeThermalPath = "on",...
    AmbientThermalPath = "CellBasedThermalResistance");
```

How are the Thermal Connections set up?




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

And the Cooling Plates?

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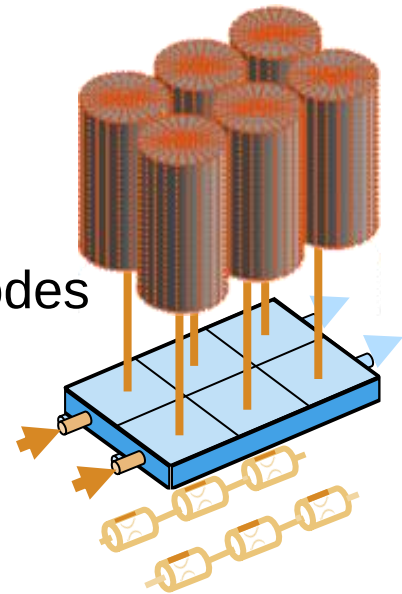
batteryModule = simscape.battery.builder.Module(...
    ParallelAssembly = pAssembly,...
    NumSeriesAssemblies = 3,...
    ModelResolution = "Detailed",...
    InterCellThermalPath = "on",...
    InterCellRadiativeThermalPath = "on",...
    AmbientThermalPath = "CellBasedThermalResistance",...
   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

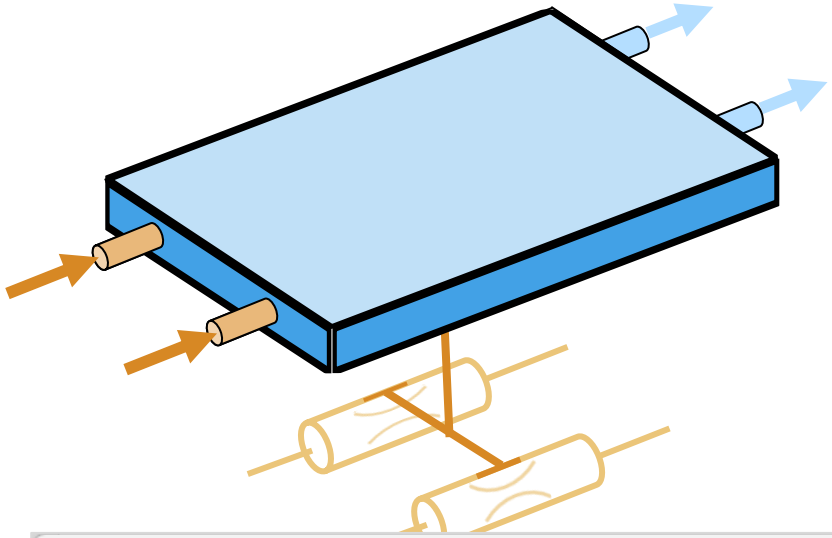
Array of thermal nodes

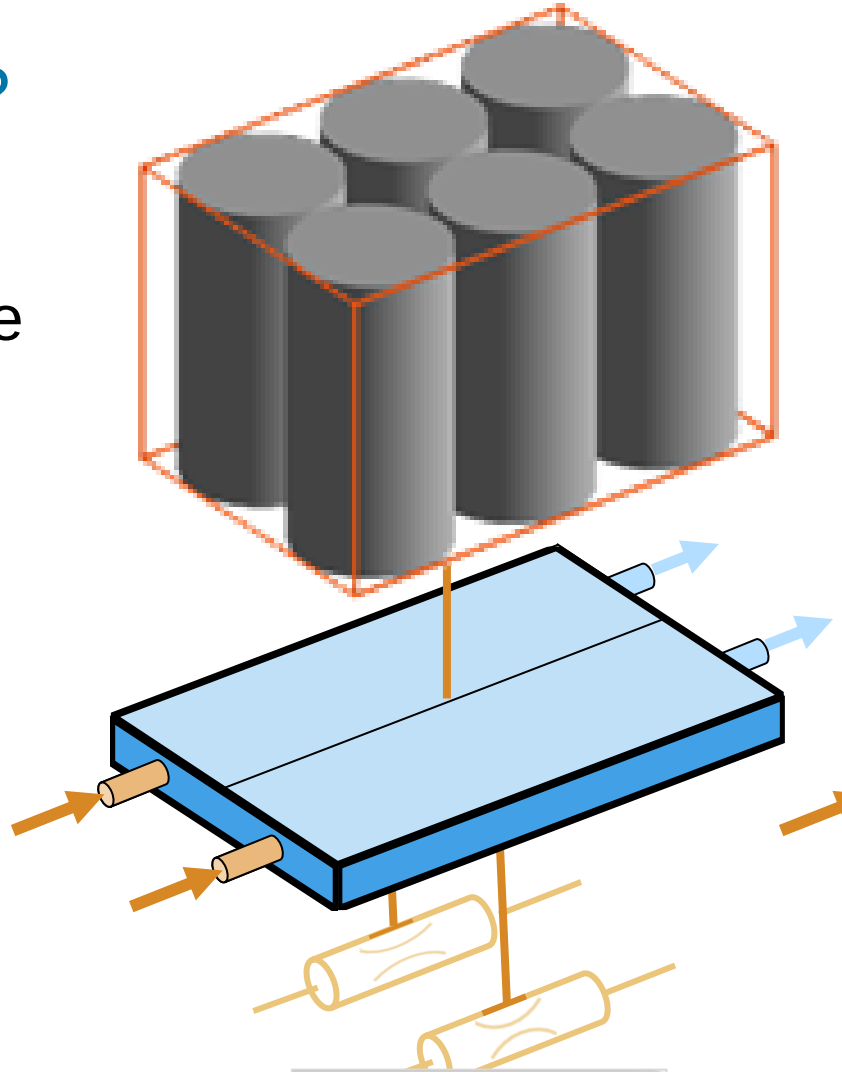


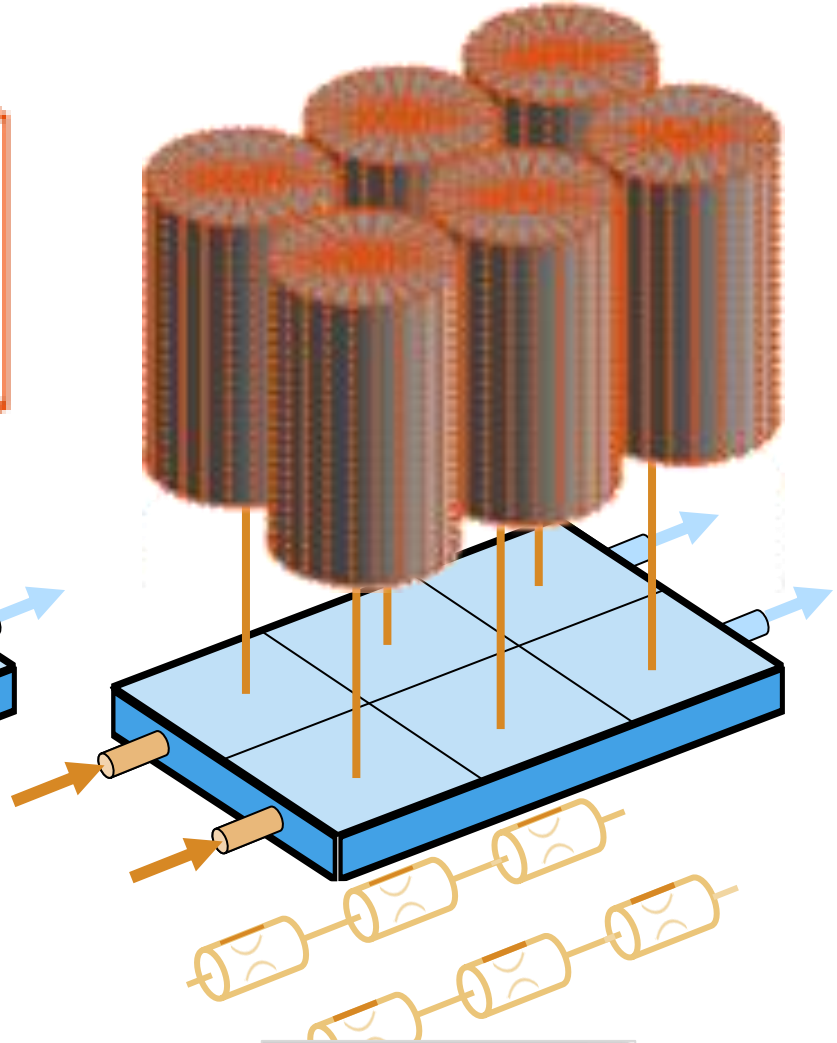
Discretized plate and cooling channels

And the Cooling Plates?

- 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]

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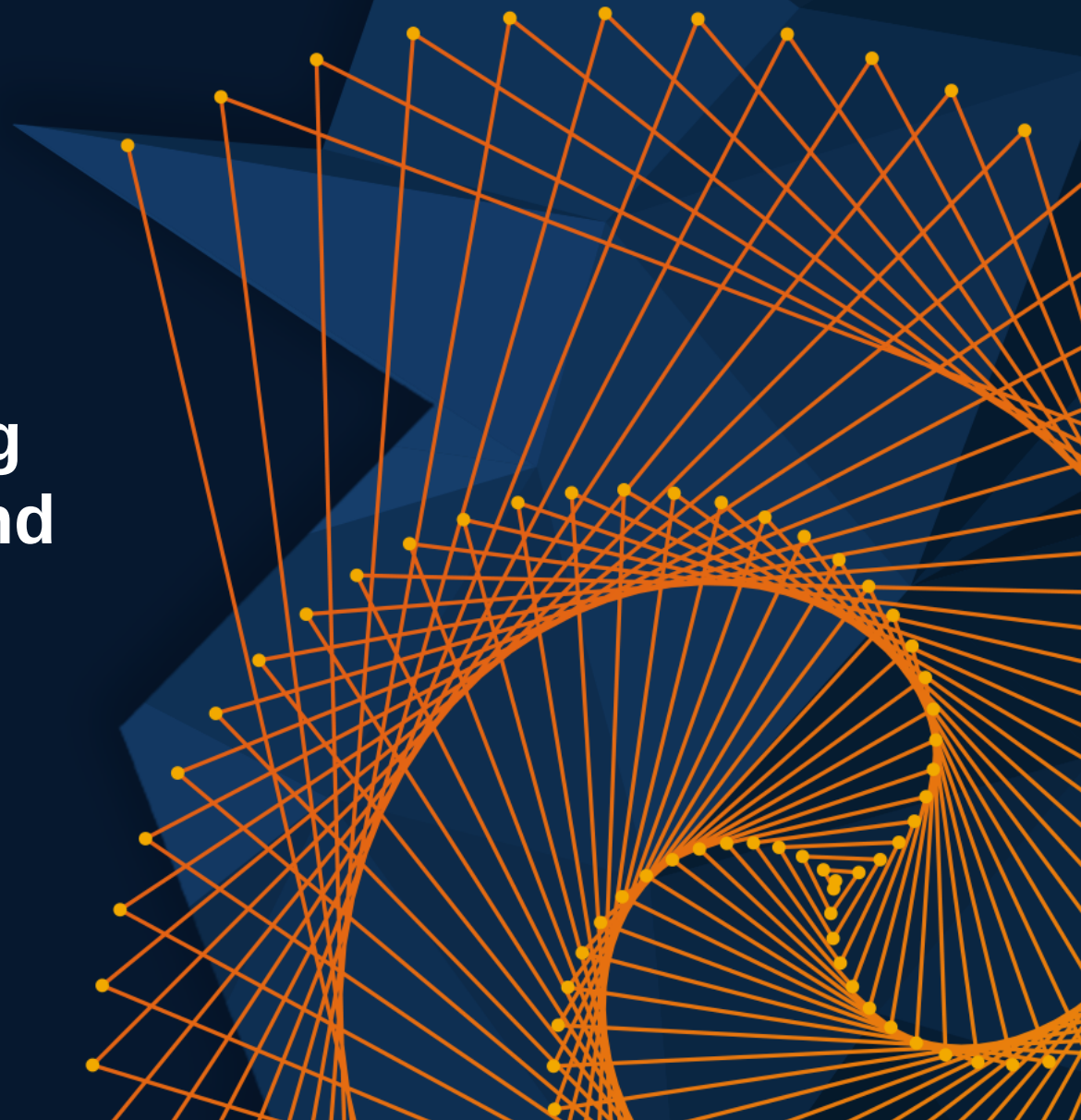
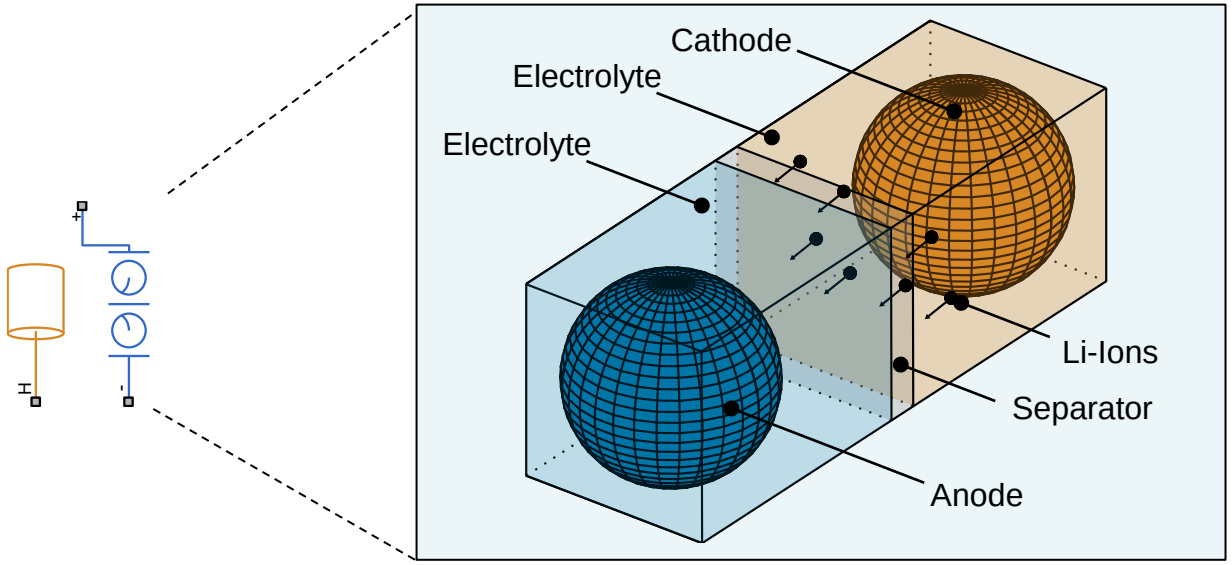


MathWorks

Electrochemical Cell Model for higher accuracy

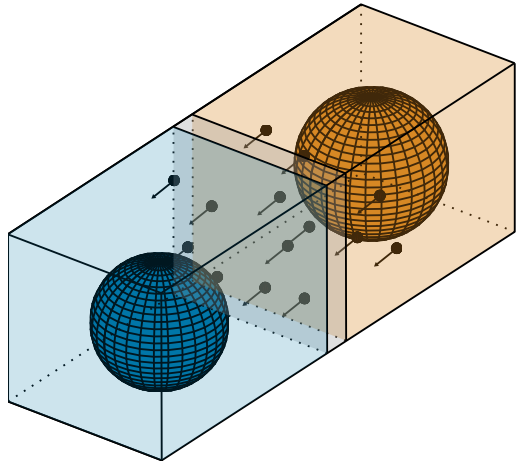
Electrochemical Model

- Single Particle Model (SPM)
- Improved accuracy & balanced complexity
- Requires detailed parameters



Understanding the Electrochemical Model (SPM)

Charging procedure (from 0% to 80% SOC)



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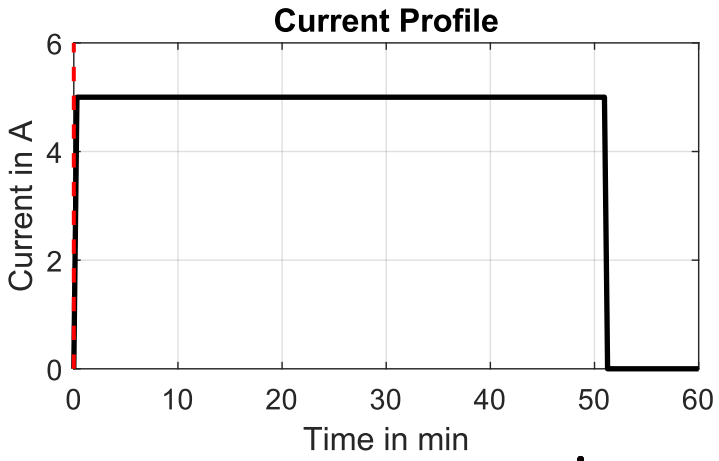

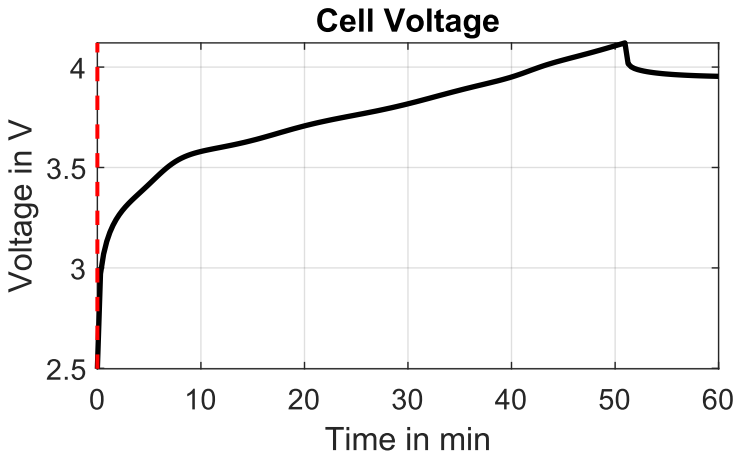

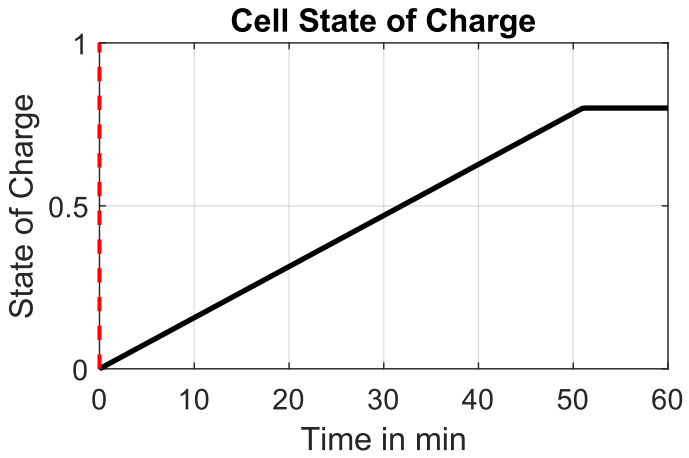

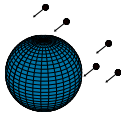

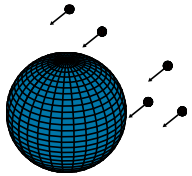

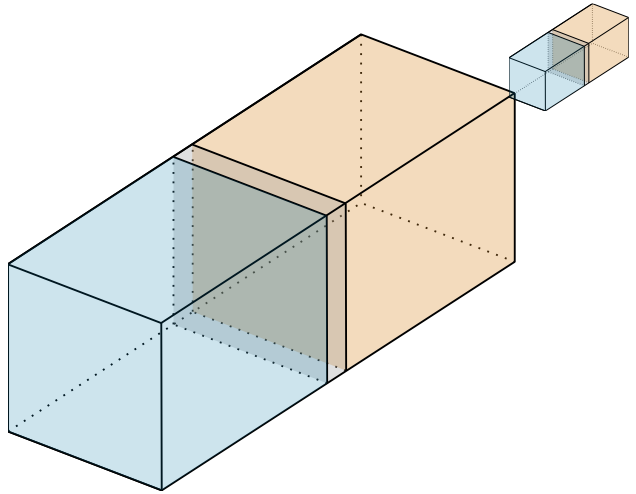

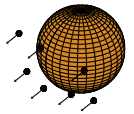

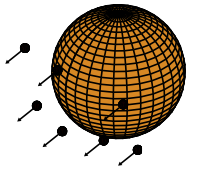

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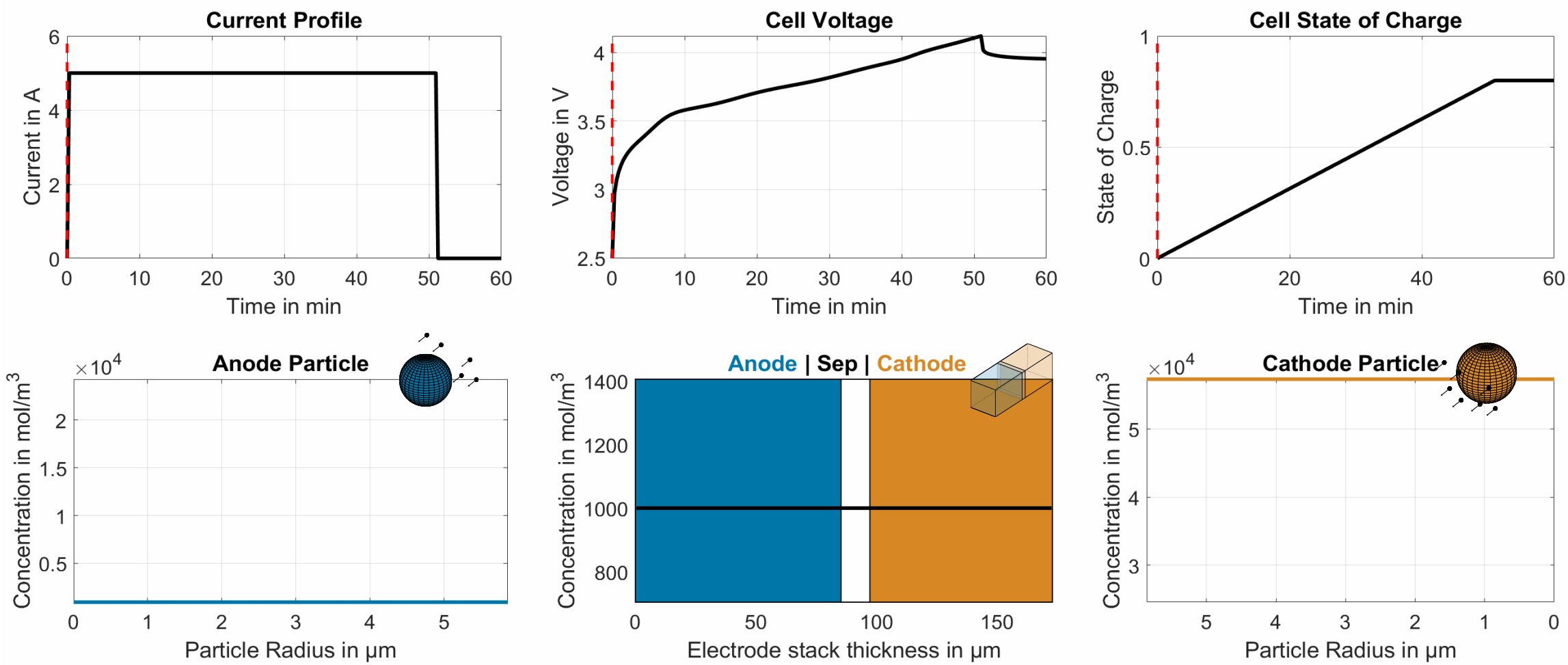
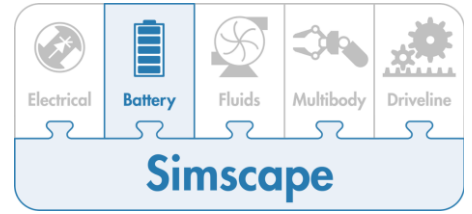
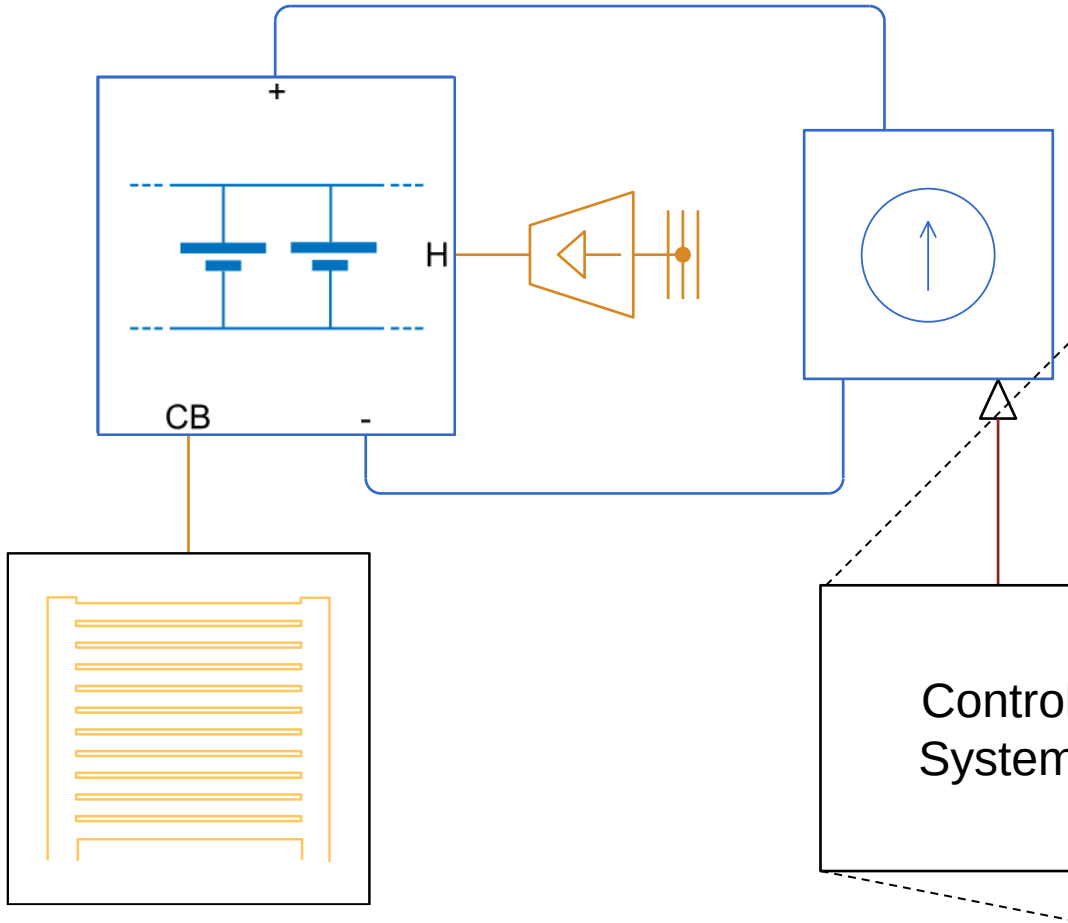


Use SPM model to identify safe operating range

Parallel assembly fast charge

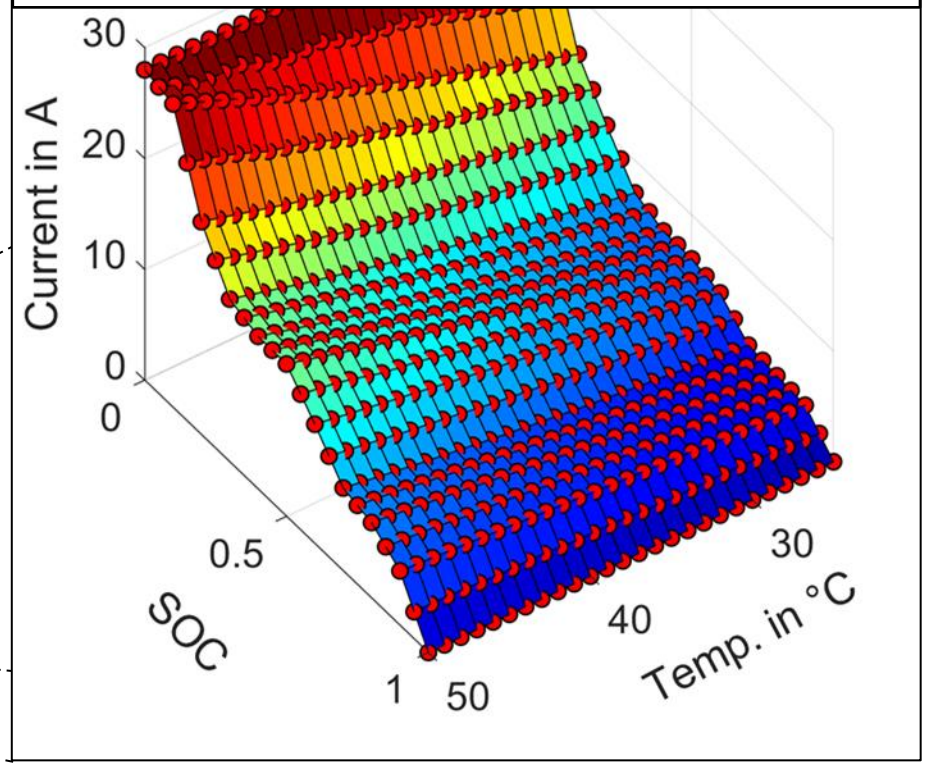




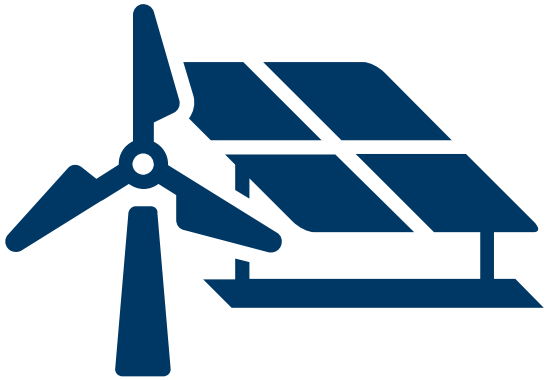
Control System

Parallel Assembly Monitoring

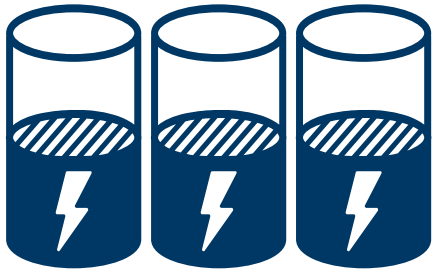
Select the charging current based on the lowest temperature and the highest SOC



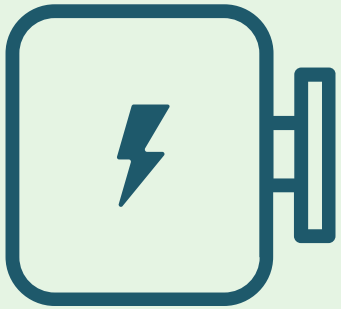
To be decided



Renewable Integration



Energy Storage



Load

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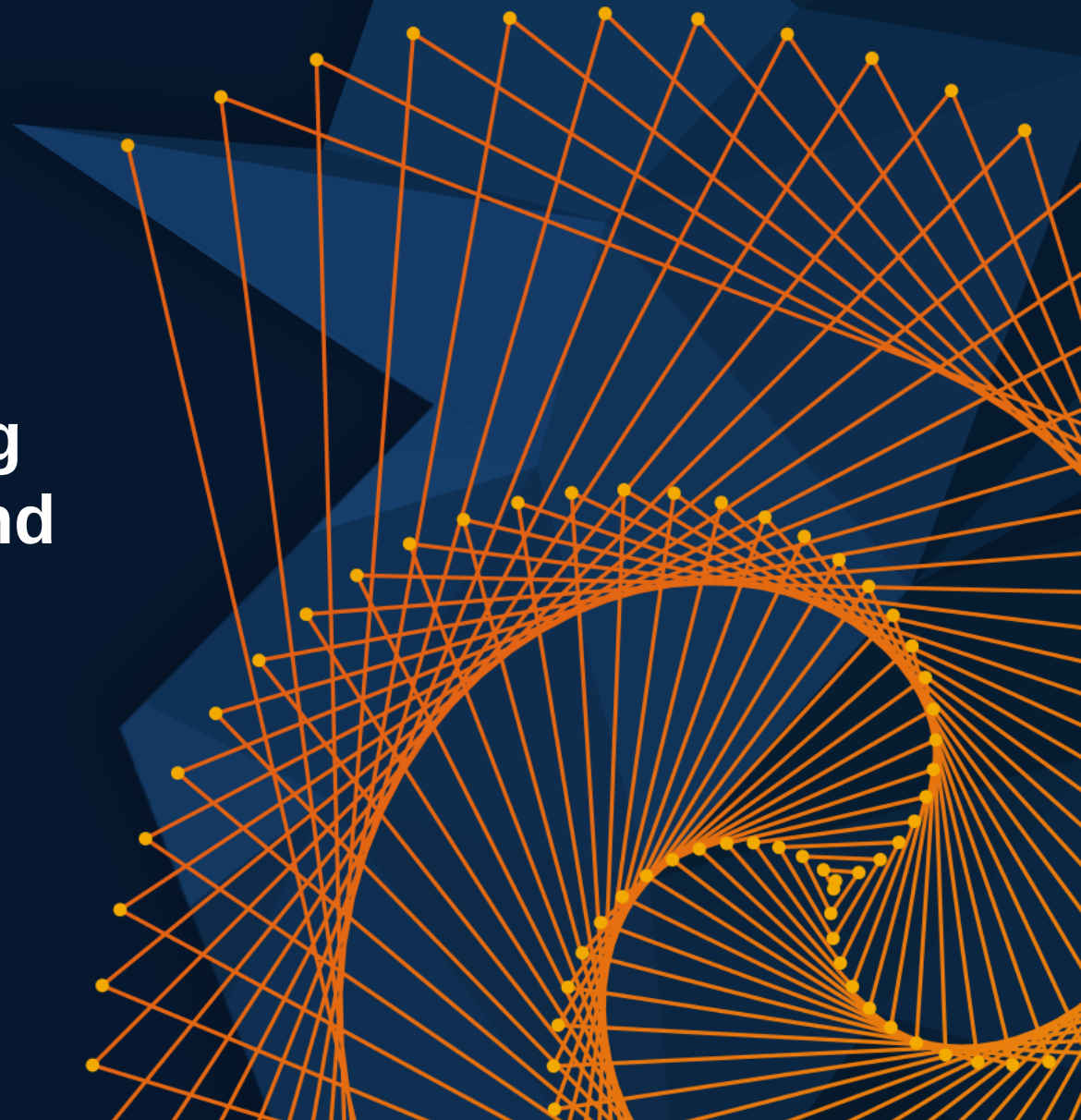
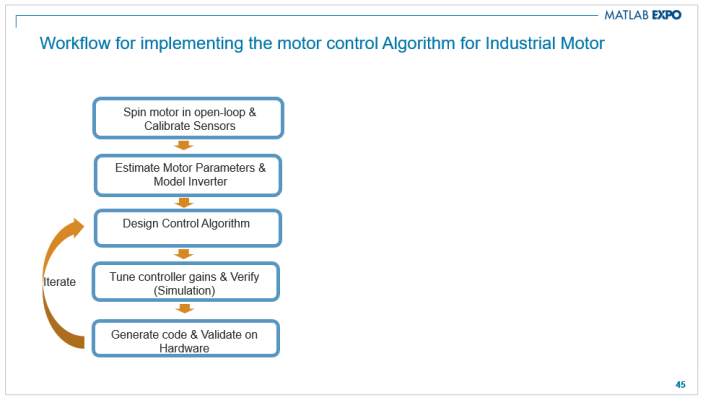


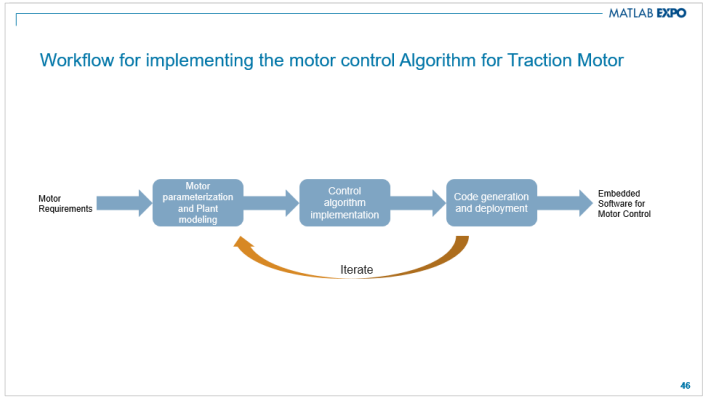
MathWorks

Two major workflows for motor control implementation

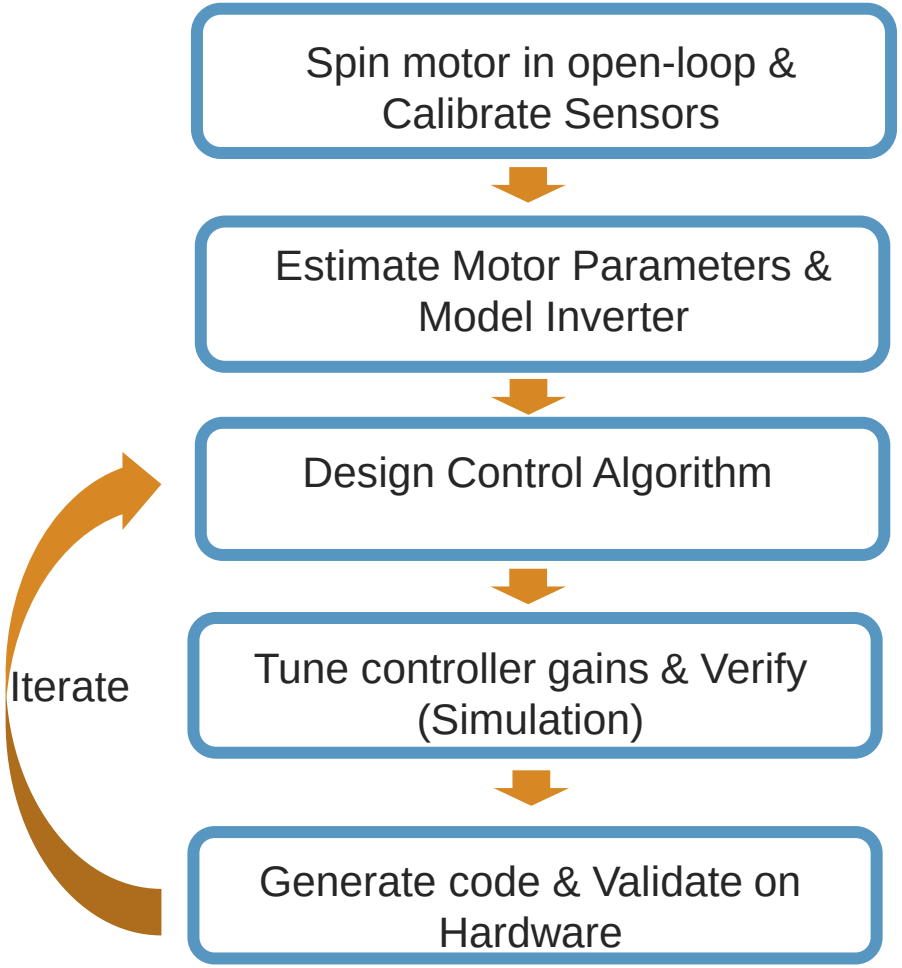
Workflow for motor control (Industrial Automation)



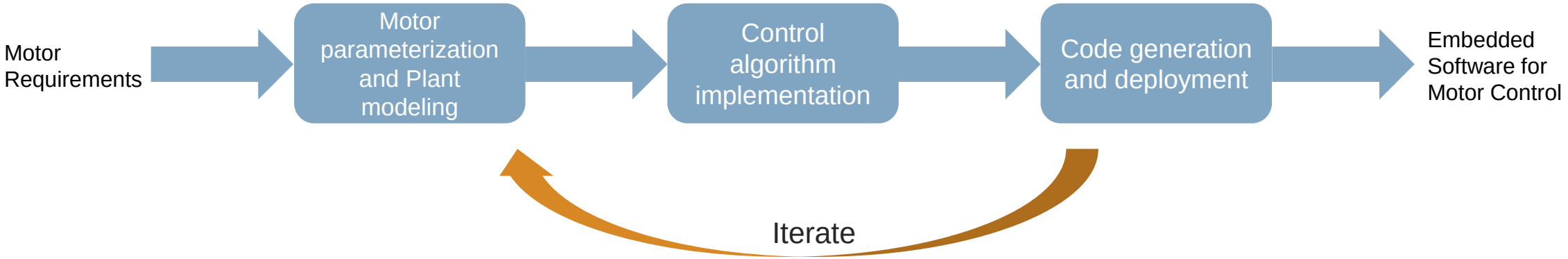
Workflow for non-linear motor control (Automotive)



Workflow for implementing the motor control Algorithm for Industrial Motor



Workflow for implementing the motor control Algorithm for Traction Motor



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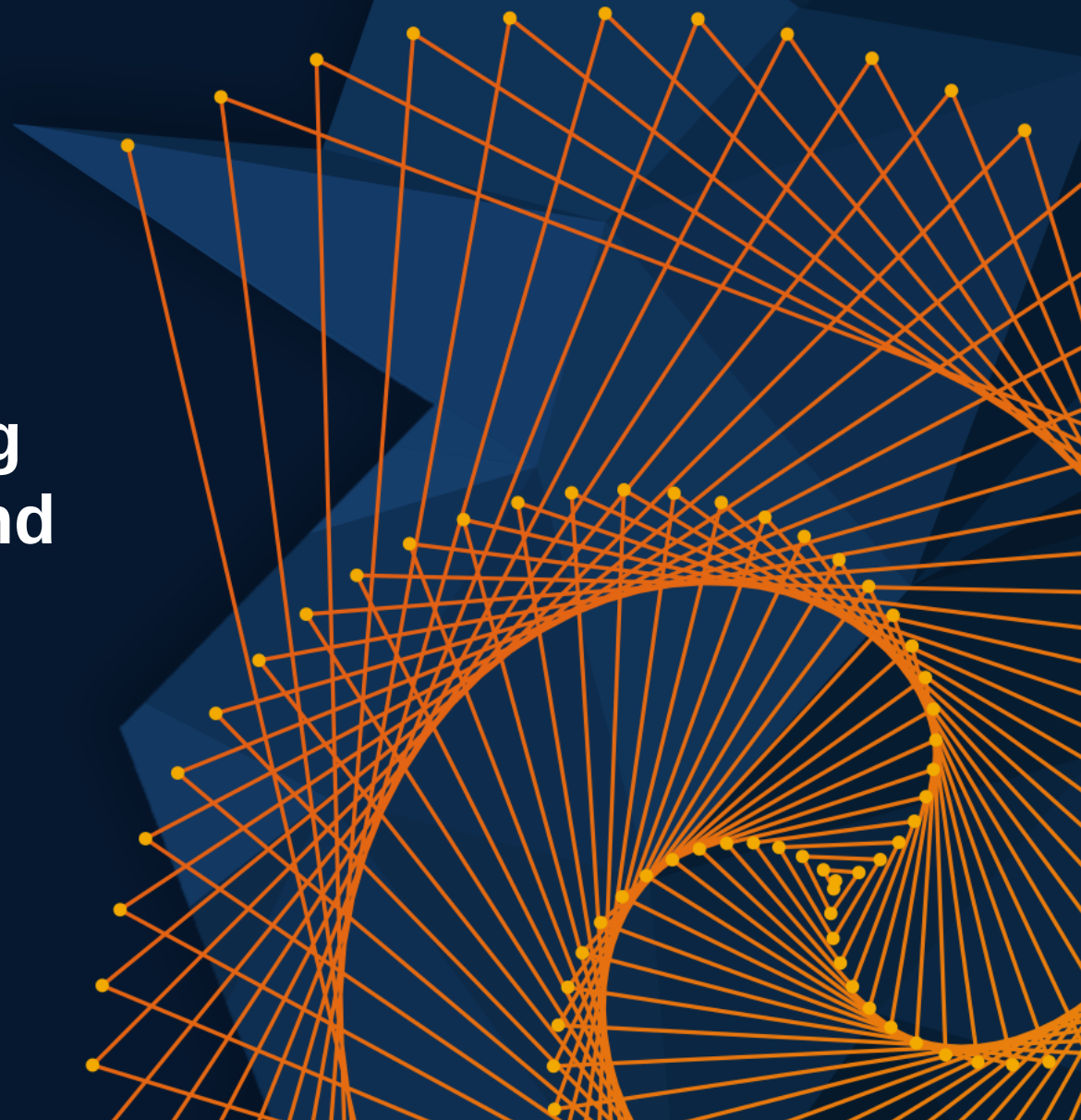
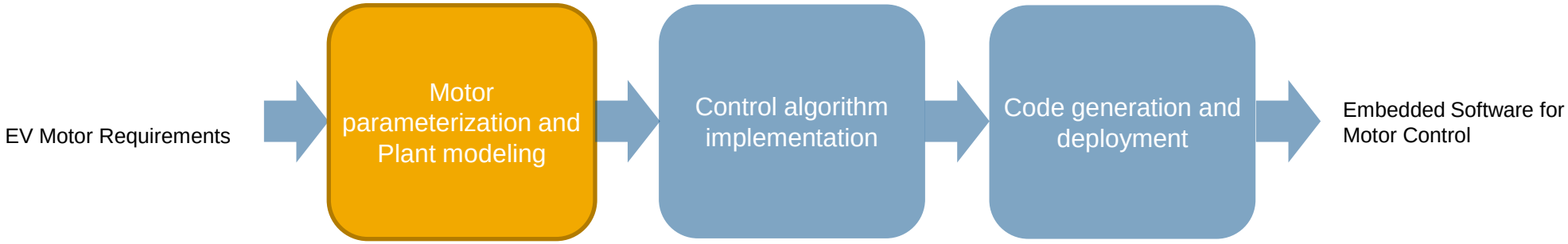
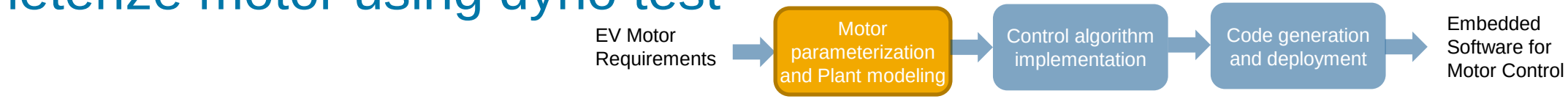


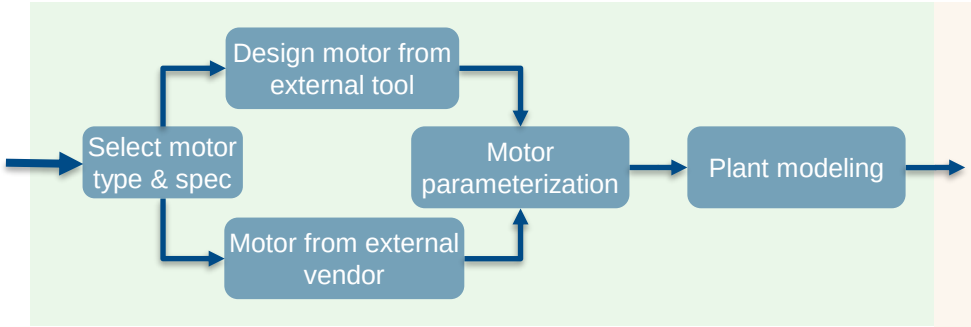
MathWorks

Parameterize IPMSM (non-linear motor model) using dyno test



Parameterize motor using dyno test

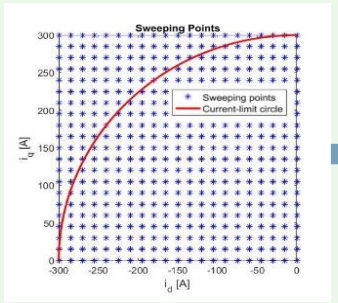




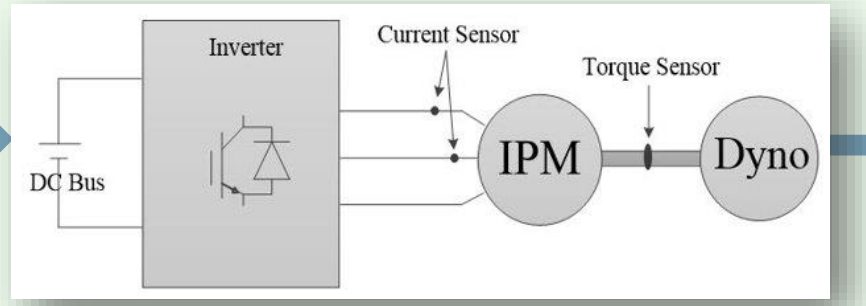
Motor parameterization and Plant modeling

Control algorithm implementation

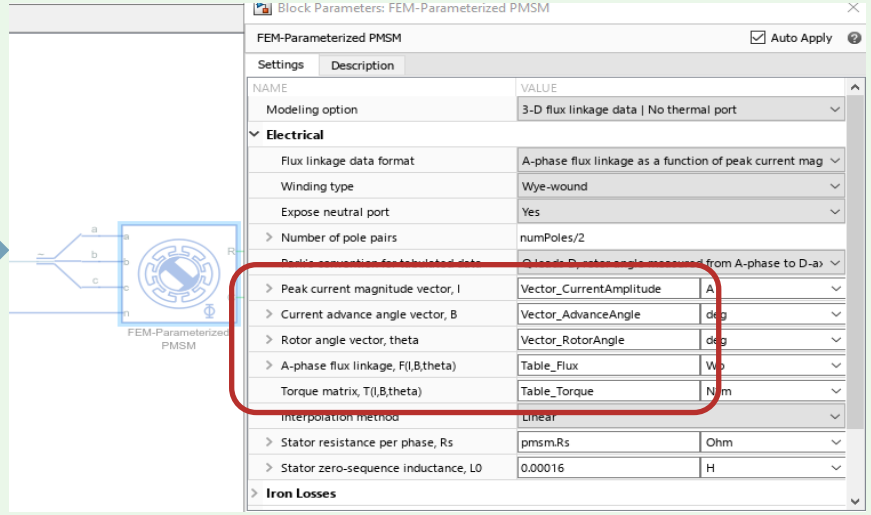
Code gen and deployment



Sweep Idq ref



Motor load setup (Dyno)



Update measured value in motor model

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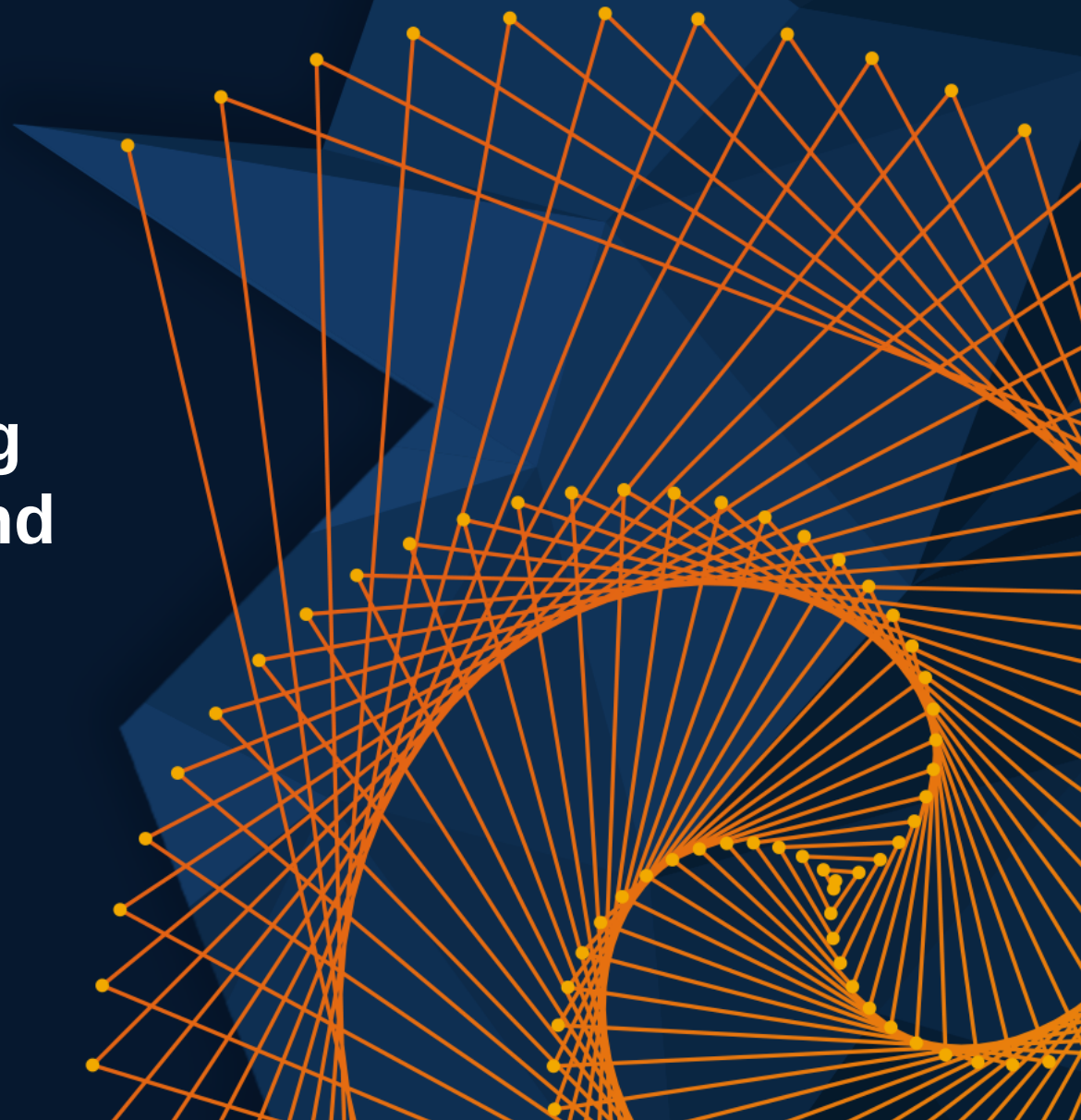
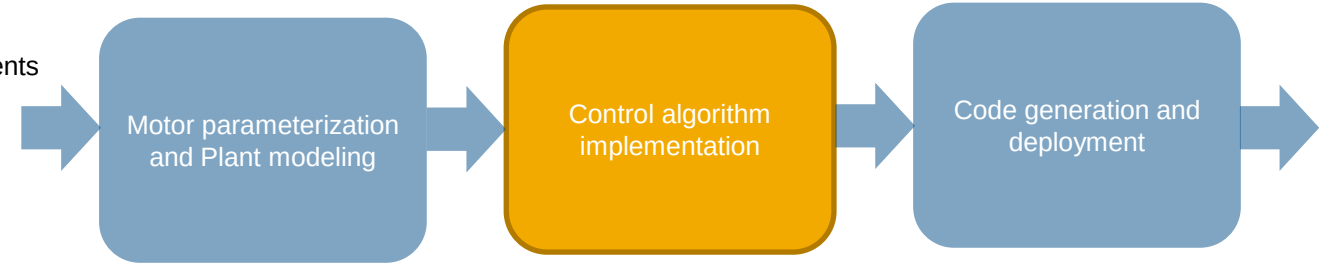


MathWorks

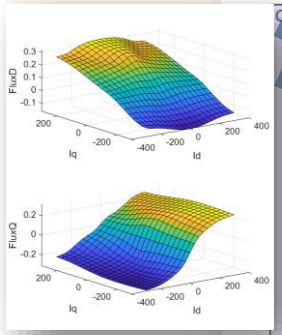
Compute reference current to achieve MTPA, field-weakening control and MTPV

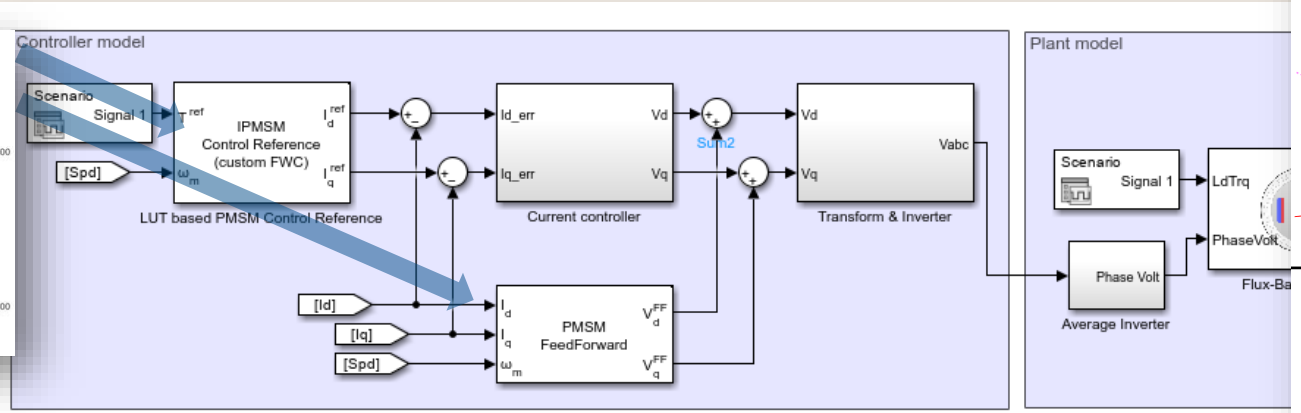
Embedded Software for Motor Control

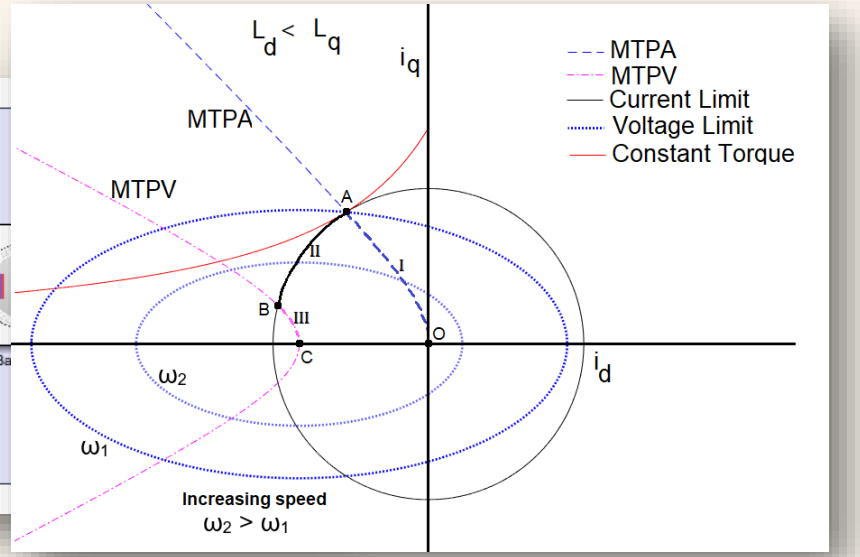
EV Motor Requirements



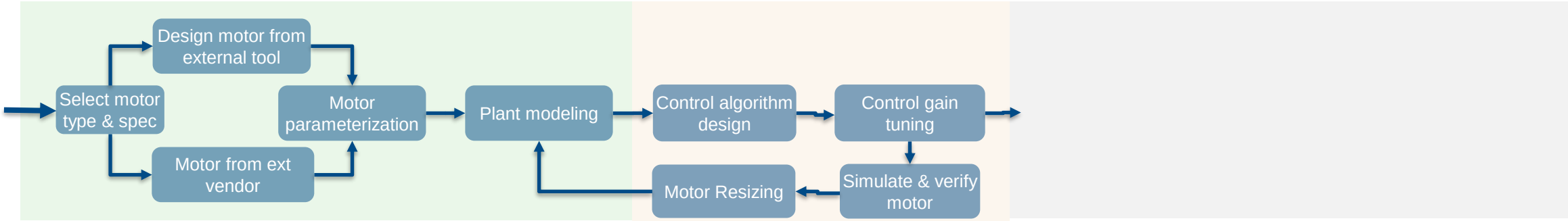
Test data from motor load test

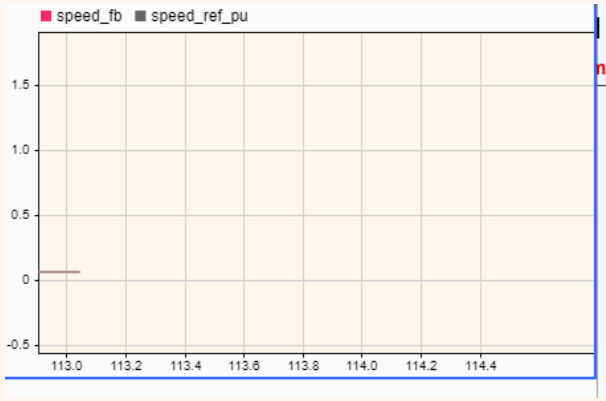


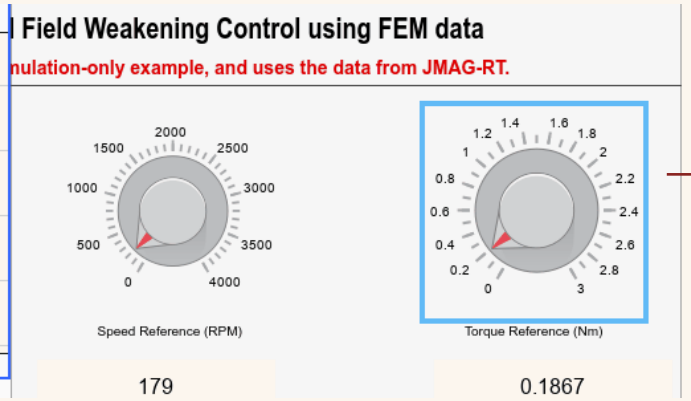


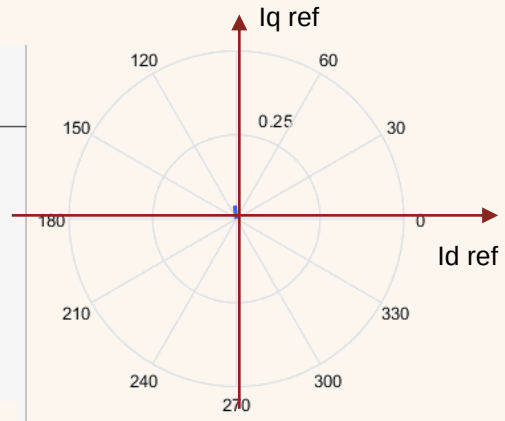


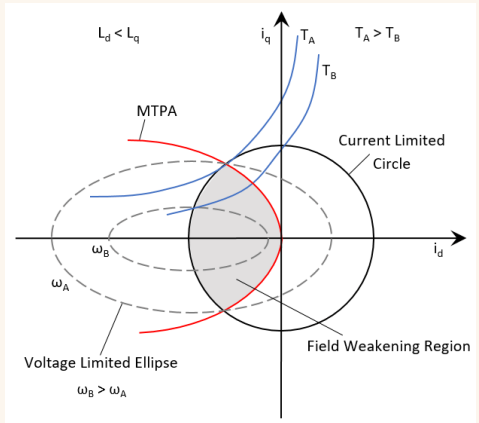
Simulate field-weakening control and validate motor sizing requirement











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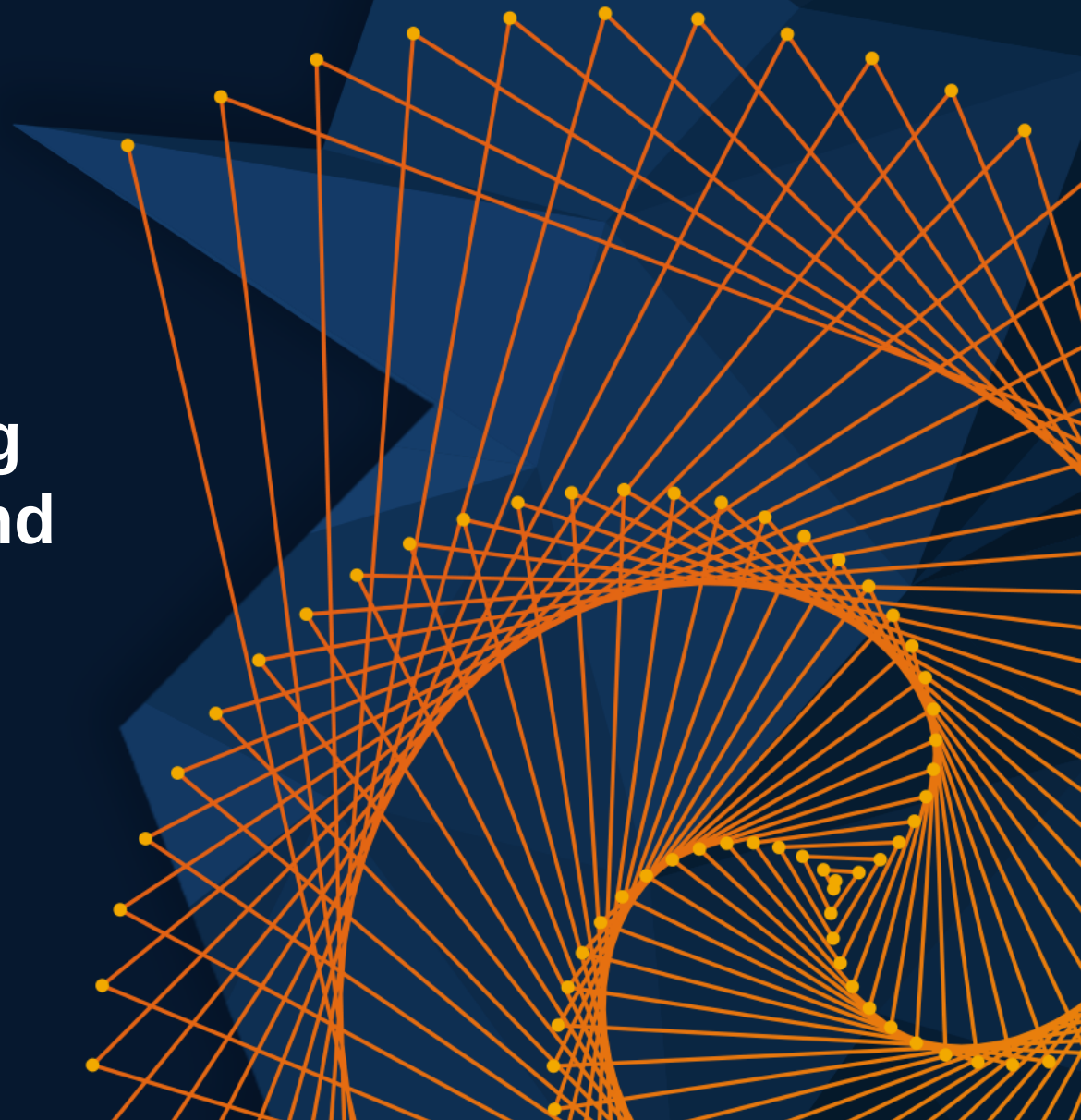


MathWorks

Increasing use of electric vehicles requires addressing many questions to ensure infrastructure is ready

Will the grid support the additional load from increasing EVs?

Where should new charging stations be placed?

Primary concerns:
Reducing risk, building confidence

How to adapt for renewable energy sources?

What size storage and solar units do we need?

Techno-economic analysis and optimization are needed to address these challenges

Technical + Economic

Example Considerations

- Storage sizing
- Equipment degradation
- Contingency planning
- Safety limits
- System efficiency

Example Considerations

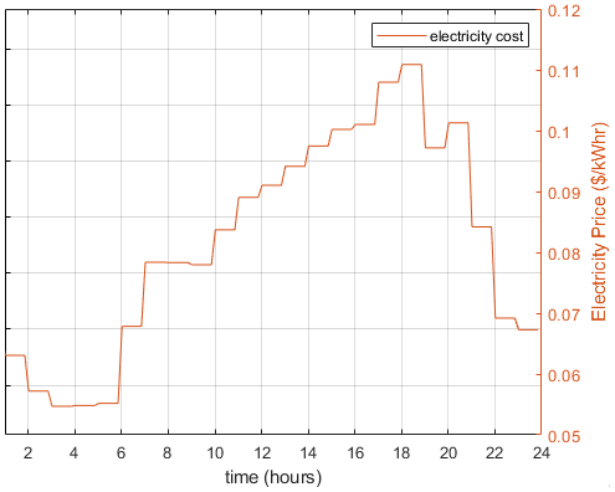
- Energy prices
- Equipment costs
- Maintenance costs
- Business commitments
- Energy trading

Benefits

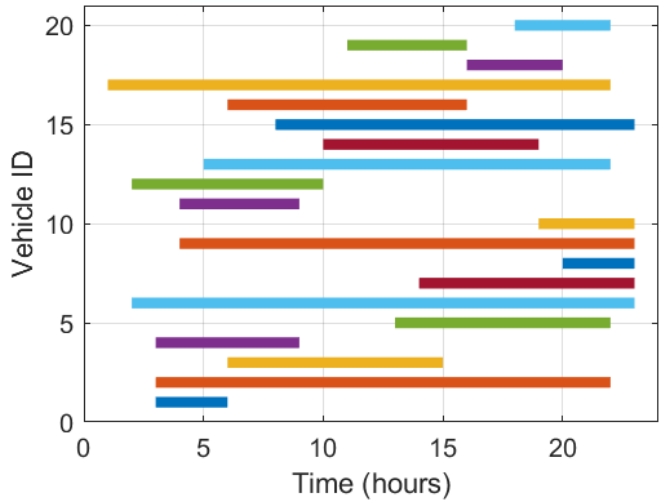
- Reduce risk, increase profitability, build confidence
- Understand system performance over time
- Identify problematic factors and optimize design and operation
- Automate decision-making and design for complex scenarios

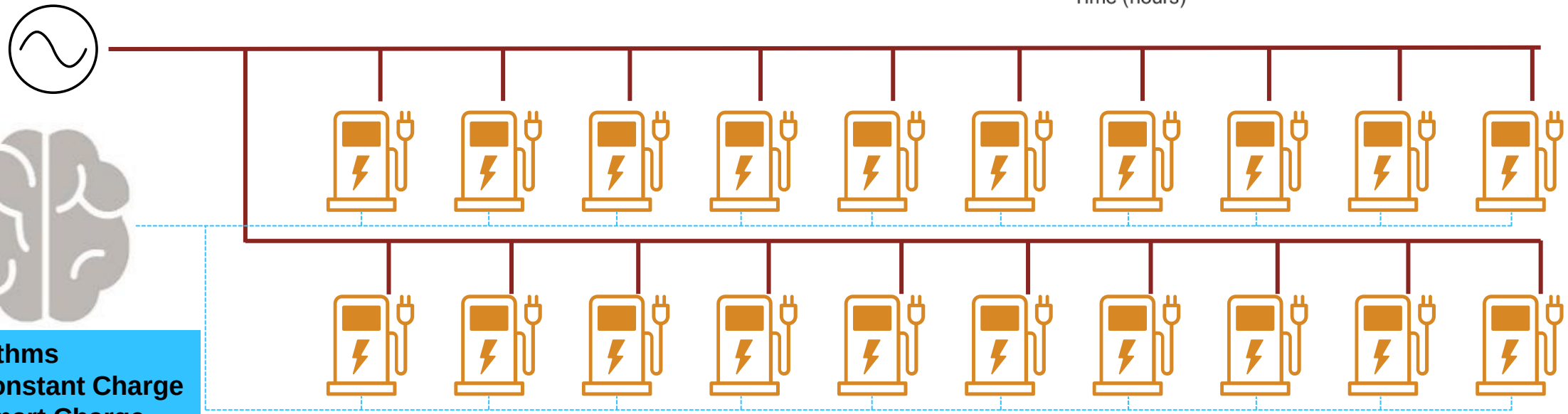
Minimize total cost of electricity in an EV charging hub

Grid Cost



Plug- In Time





Algorithms
1. **Constant Charge**
2. **Smart Charge**

Describe the components of the optimization problem

Input Data:
1. Grid Cost
2. Plug-in time

Design Variables:
1. Power flow
2. Power cost / revenue

Optimization Objective
Minimize total cost of electricity

Constraints:
1. $min \leq gridPower \leq max$
2. $\sum storagePower + loadPower = gridPower$
3. $min \leq SOC \leq max$
4. $SOC_{final} = 1$

Implement the optimization problem

- Variable example:

```
gridPower = optimvar("gridPower",no_steps,1,"LowerBound",-0.2*no_units,"UpperBound",2*no_units);
```

- Constraint example:

```
prob.Constraints.powerBalance = sum(storagePower,2) + loadPower' == gridPower;
```

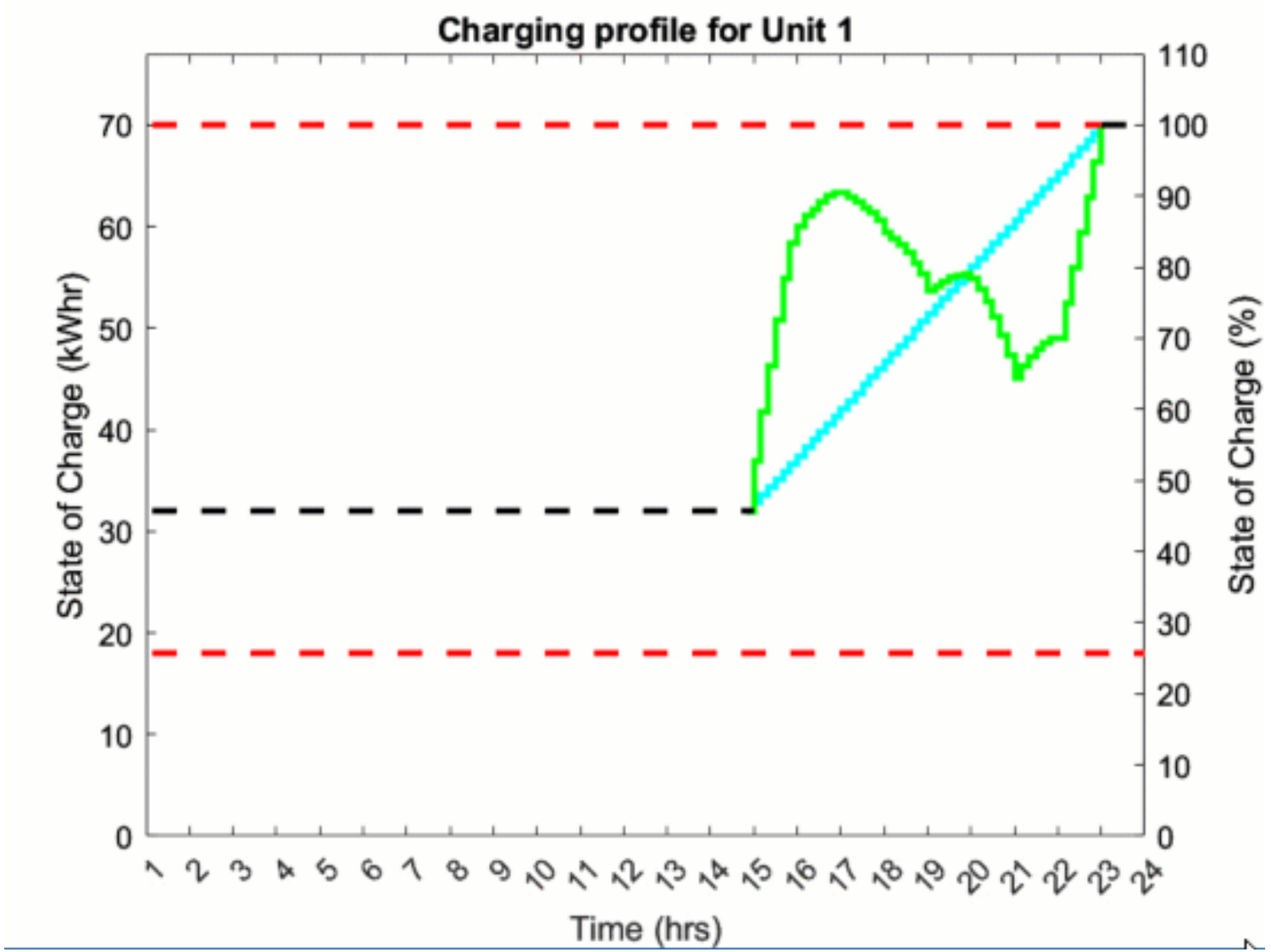
- Objective example:

```
prob.Objective = gridPower'*price;
```

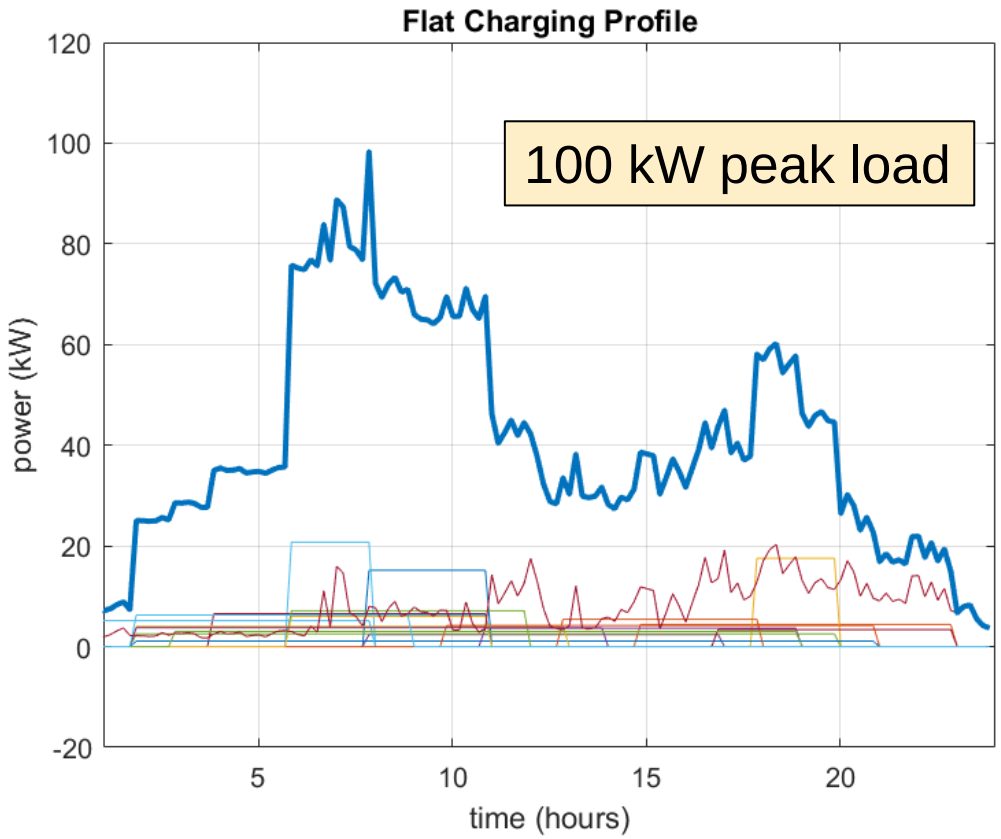
- Solve problem

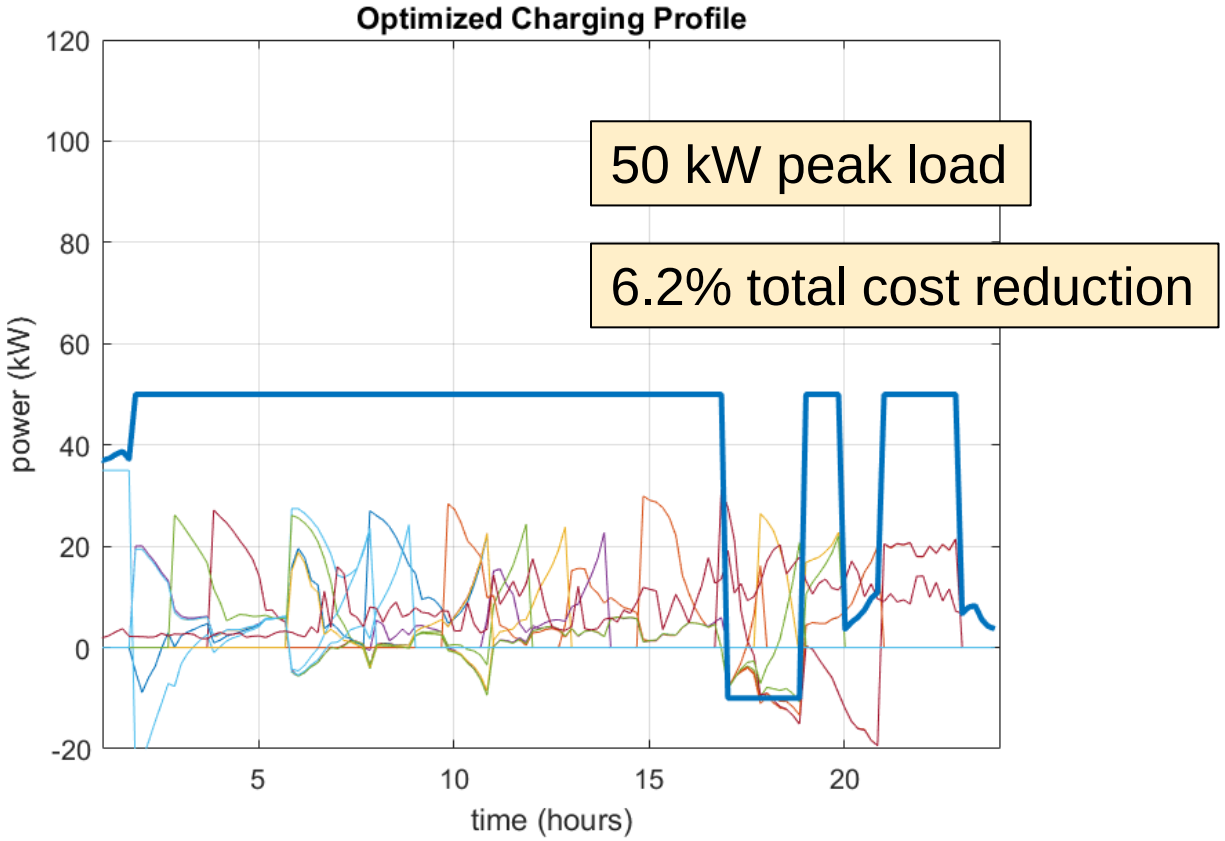
```
[sol,fval,exitflag,output] = solve(prob,"Options",optlin)
```

Optimized charging profile developed for each charger unit

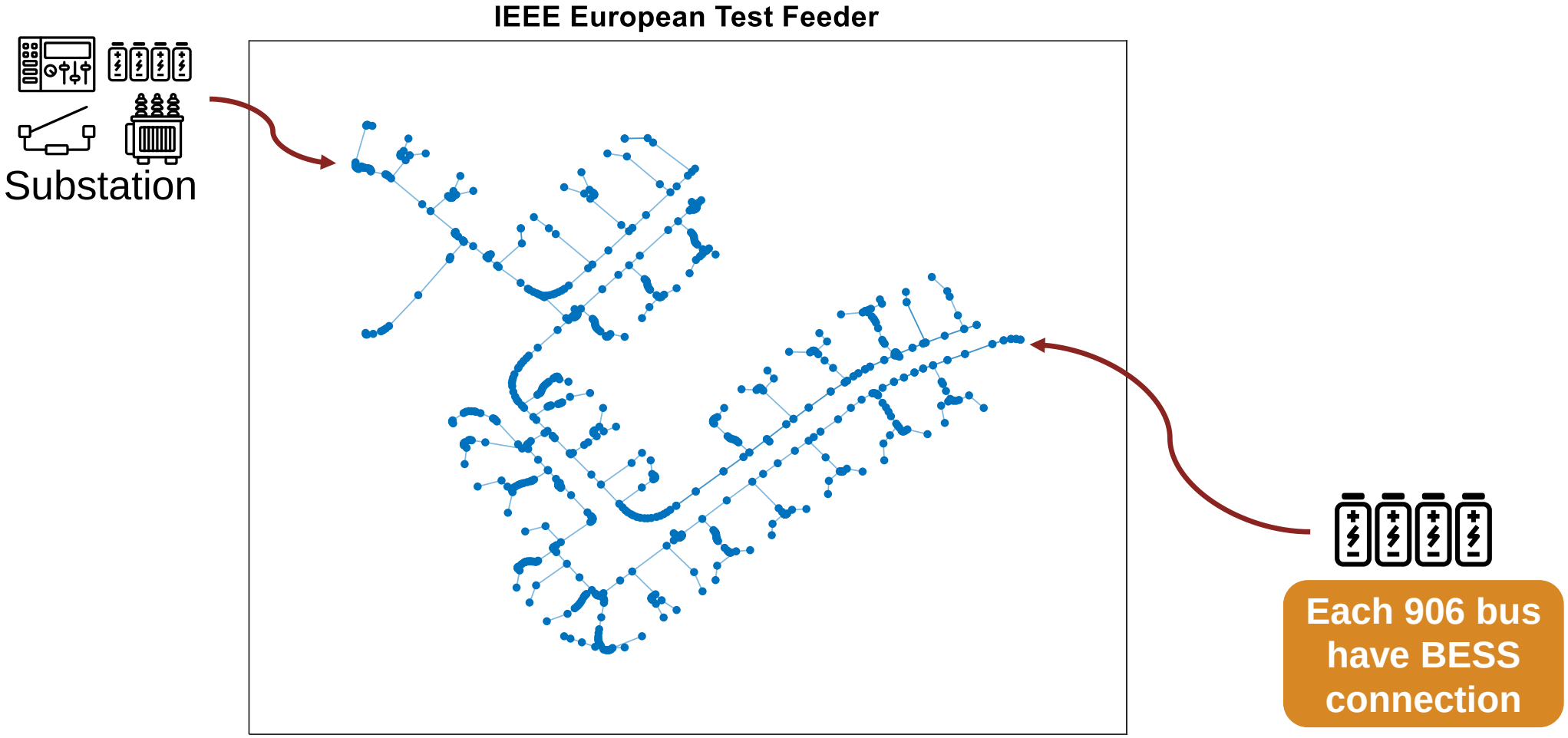


Optimized charging profile minimizes overall cost and limits peak load





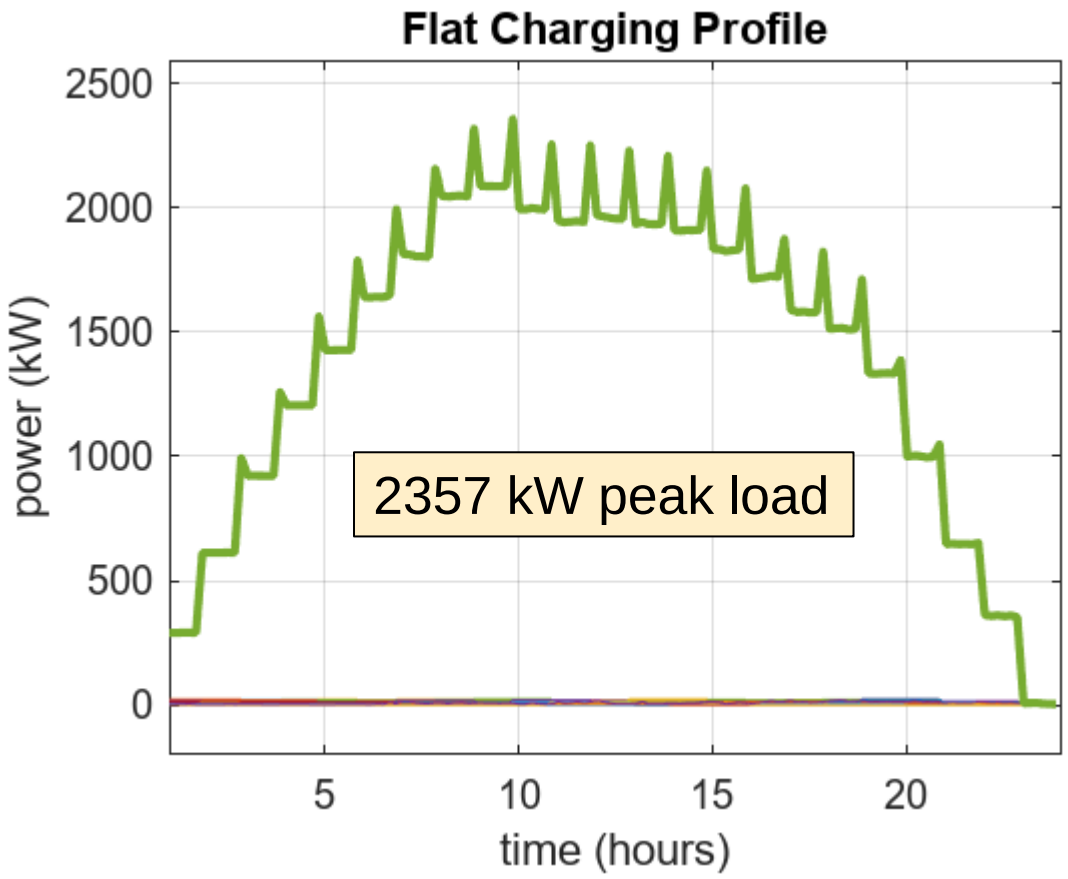
Evaluate the charging profiles on the IEEE European Test Feeder

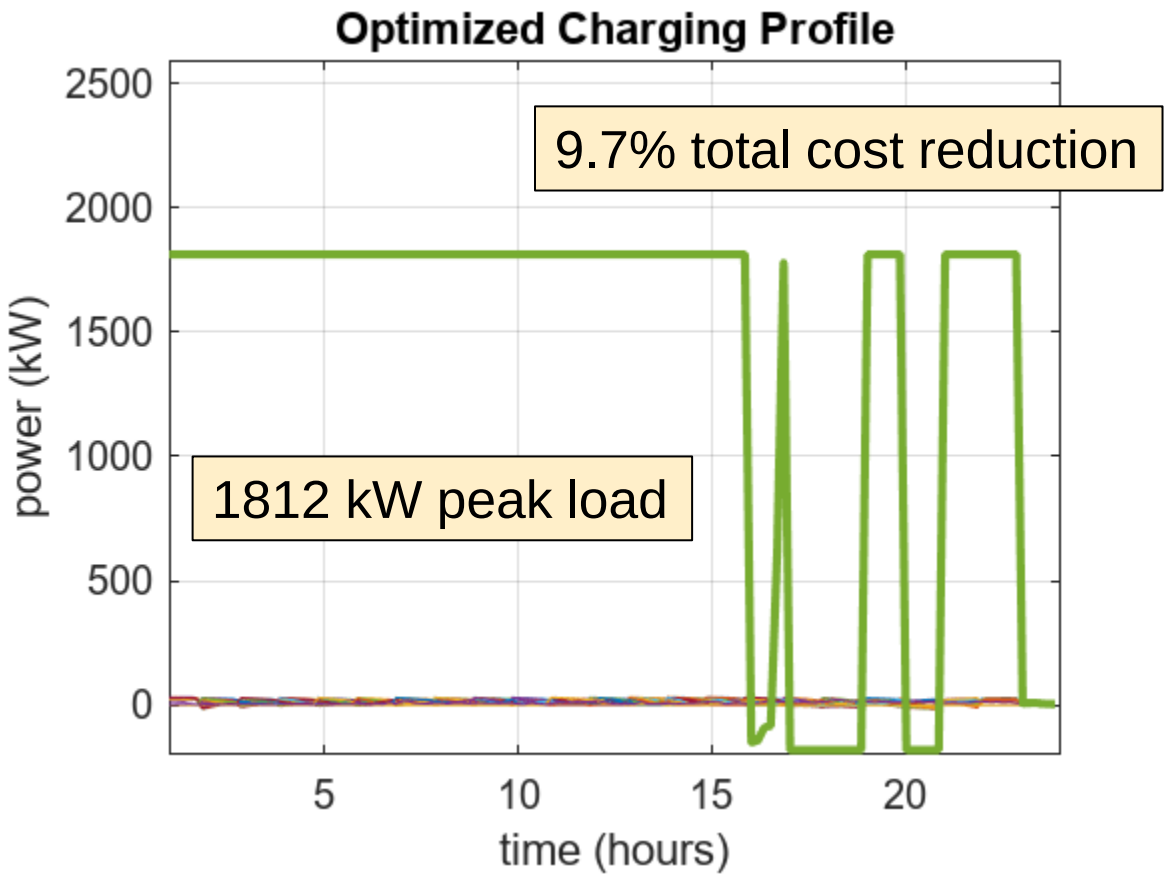


906 bus three-phase distribution system published by the IEEE AMPS Distribution System Analysis Subcommittee

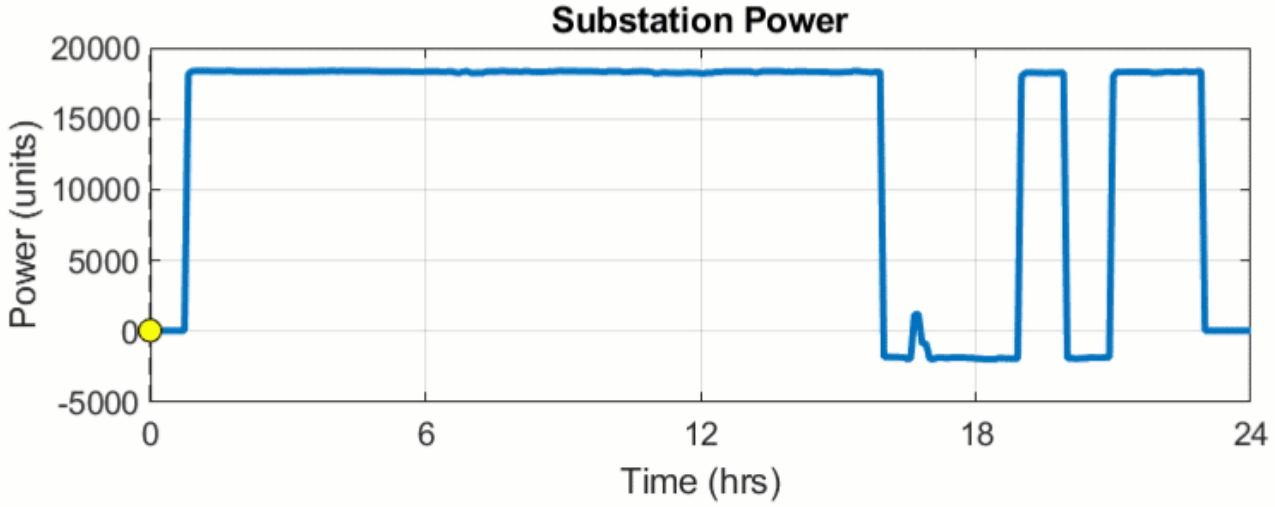
https://cmte.ieee.org/pes-testfeeders/wp-content/uploads/sites/167/2017/08/European_LV_Test_Feeder_v2.zip

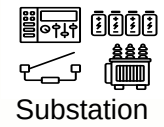
Scaled up study (906 units) continues to show cost and peak load benefits

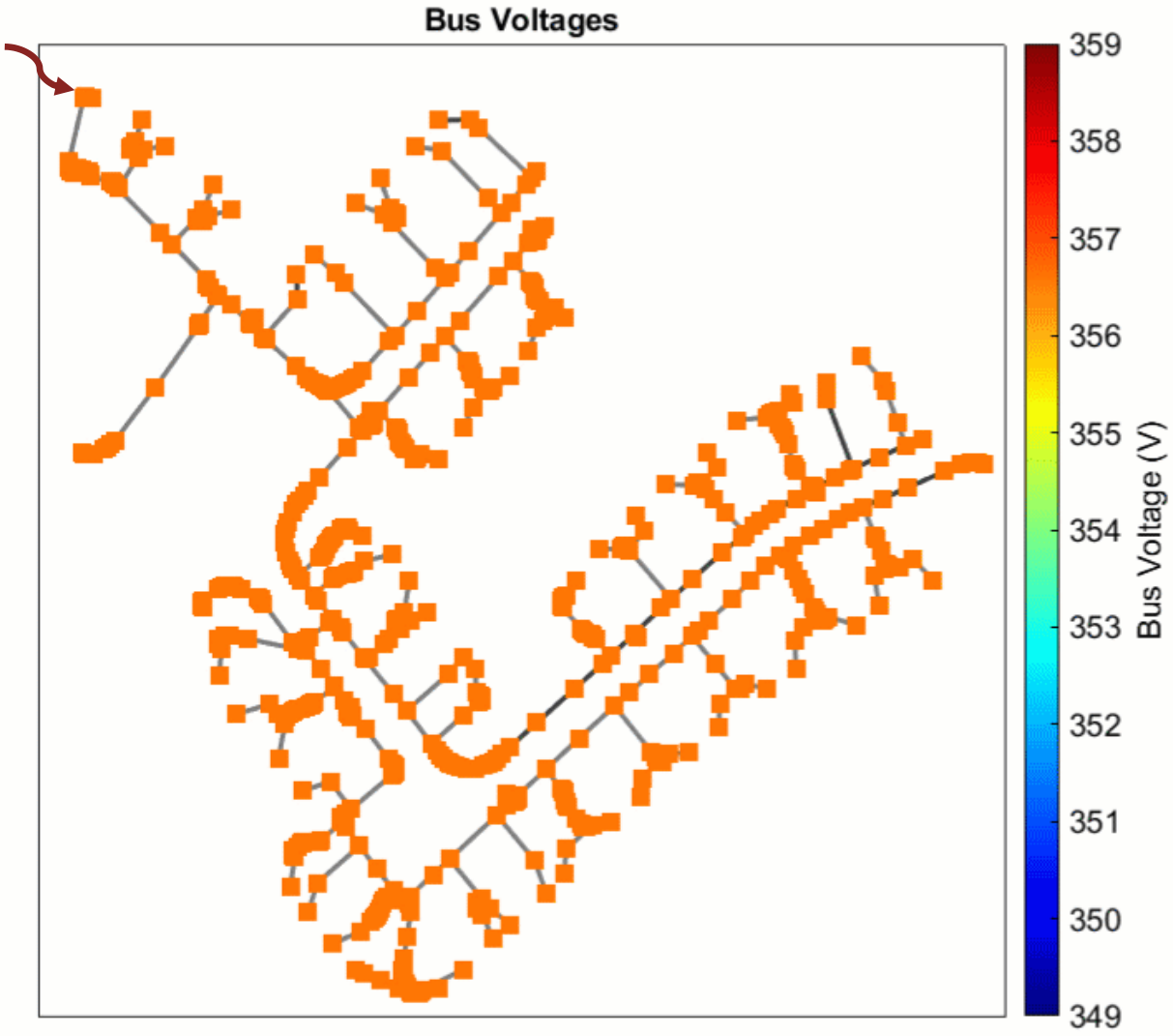




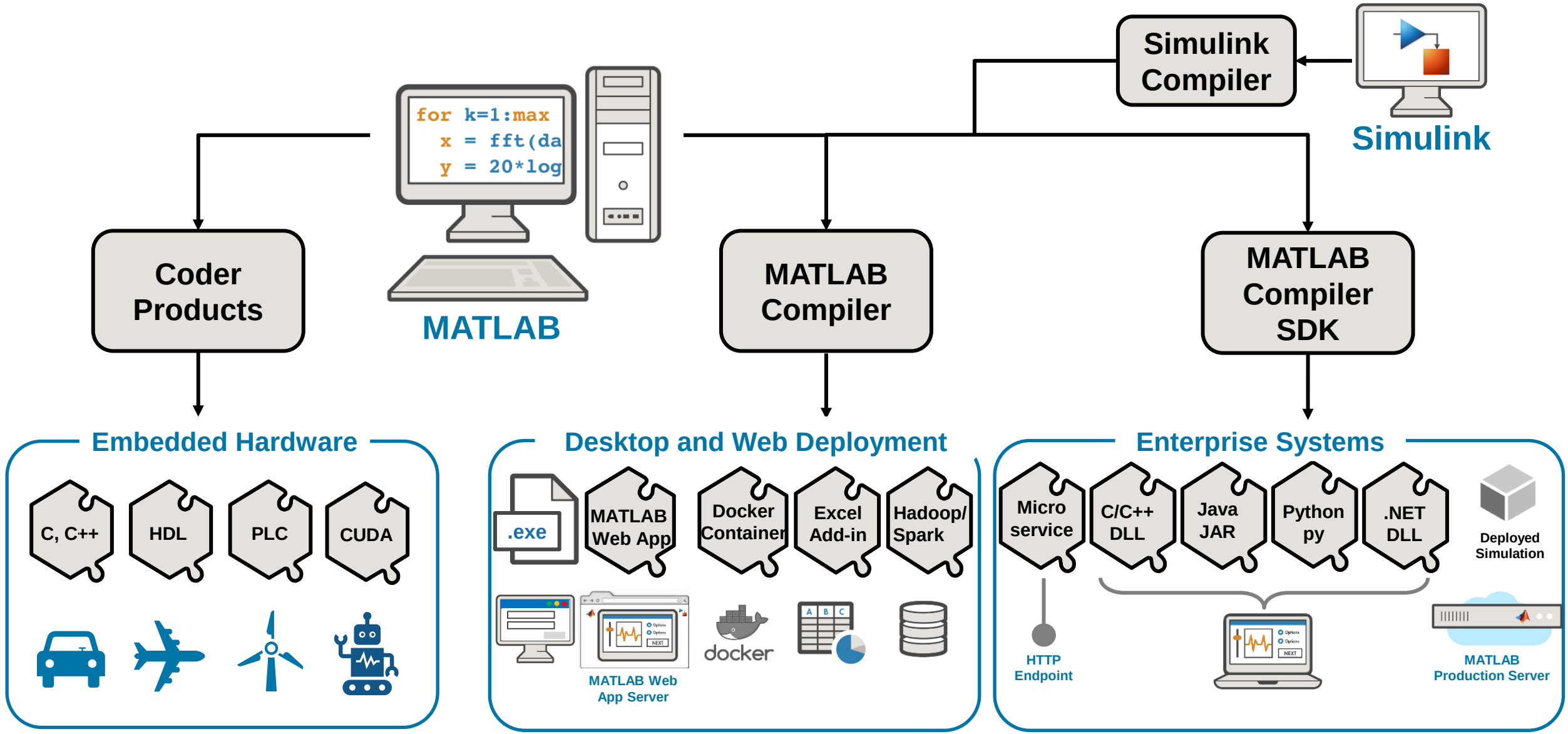
Enhanced visualization - voltage levels across 24 hours







Flexible deployment options to choose the right production target



TIWAG-Tiroler Wasserkraft AG Meets Stringent Environmental Regulations with MATLAB

Working with MathWorks Consulting Services, TIWAG developed an optimization solution for its power plant network while simultaneously complying with strict environmental regulations.

Key Outcomes

- Using MATLAB enables TIWAG to solve a scheduling optimization problem and incorporate it into its existing SCADA system, ensuring regulatory compliance
- The customized optimization solution helps TIWAG respond to frequently varying river water flow conditions in real time
- A centralized workflow through one platform enables the integration and processing of data from multiple sources

The recently constructed dam of the new Gemeinschaftskraftwerk Inn (GKI) power plant, situated on the Upper Inn River in the border region between Austria and Switzerland. The GKI must comply with strict environmental regulations.

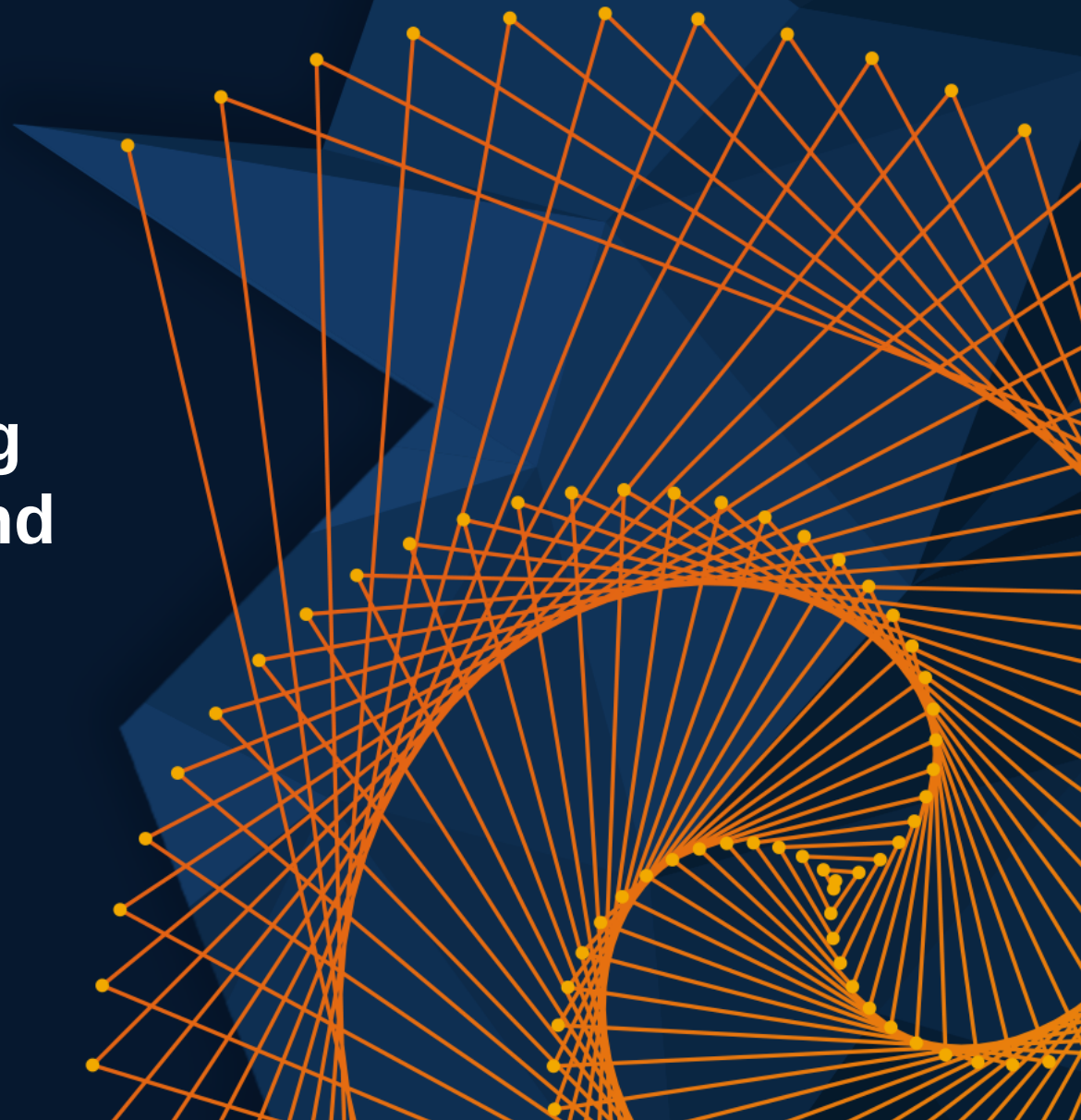
The test phase has already shown that our optimization solution has significant economic potential thanks to its predictive control.

Link to user story

MATLAB EXPO

July 11th, 2024, Bangalore

Addressing Challenges of Meeting Net-Zero Goals with Simulation and Model-Based Design



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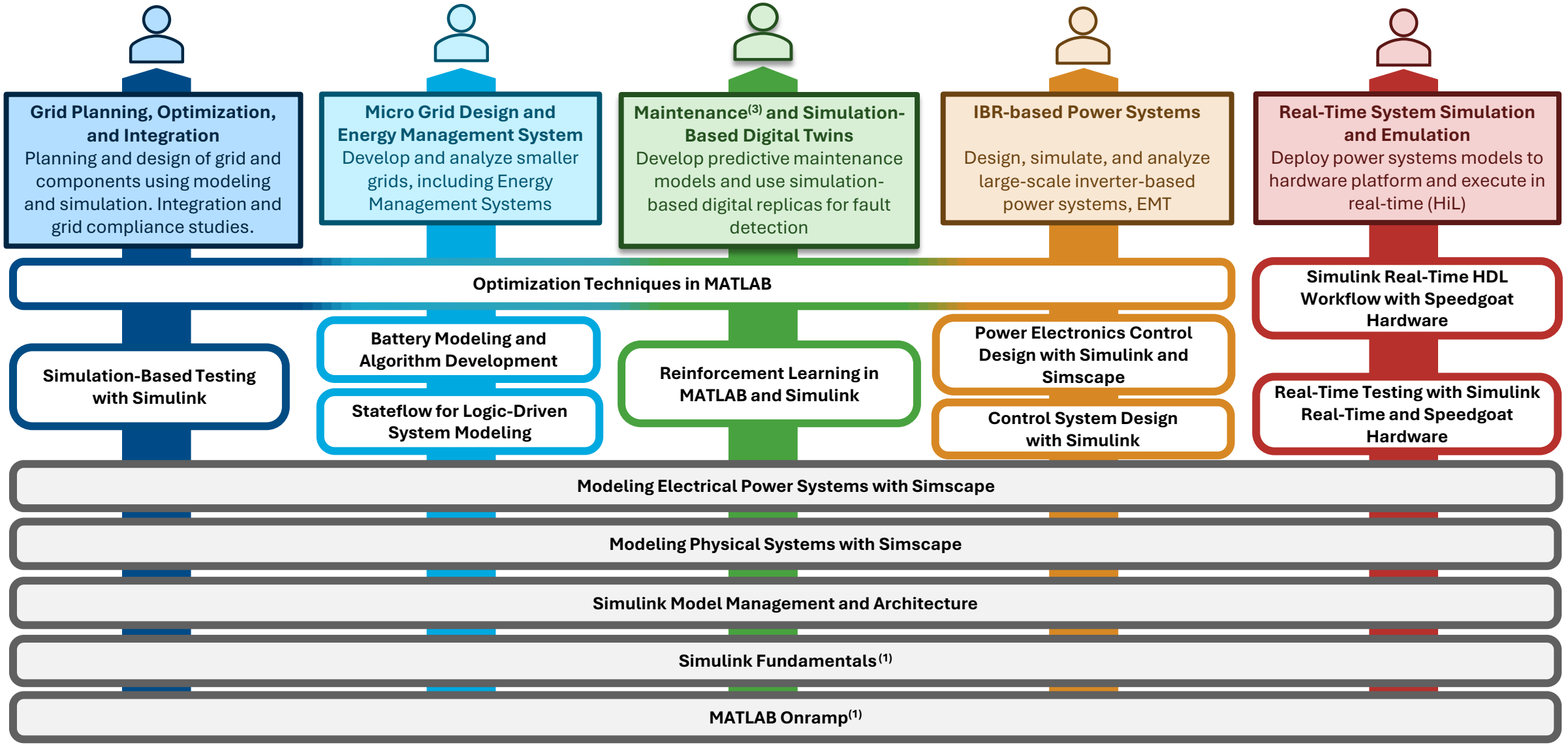
Curriculum Path - Production, Transmission, Distribution, Renewable



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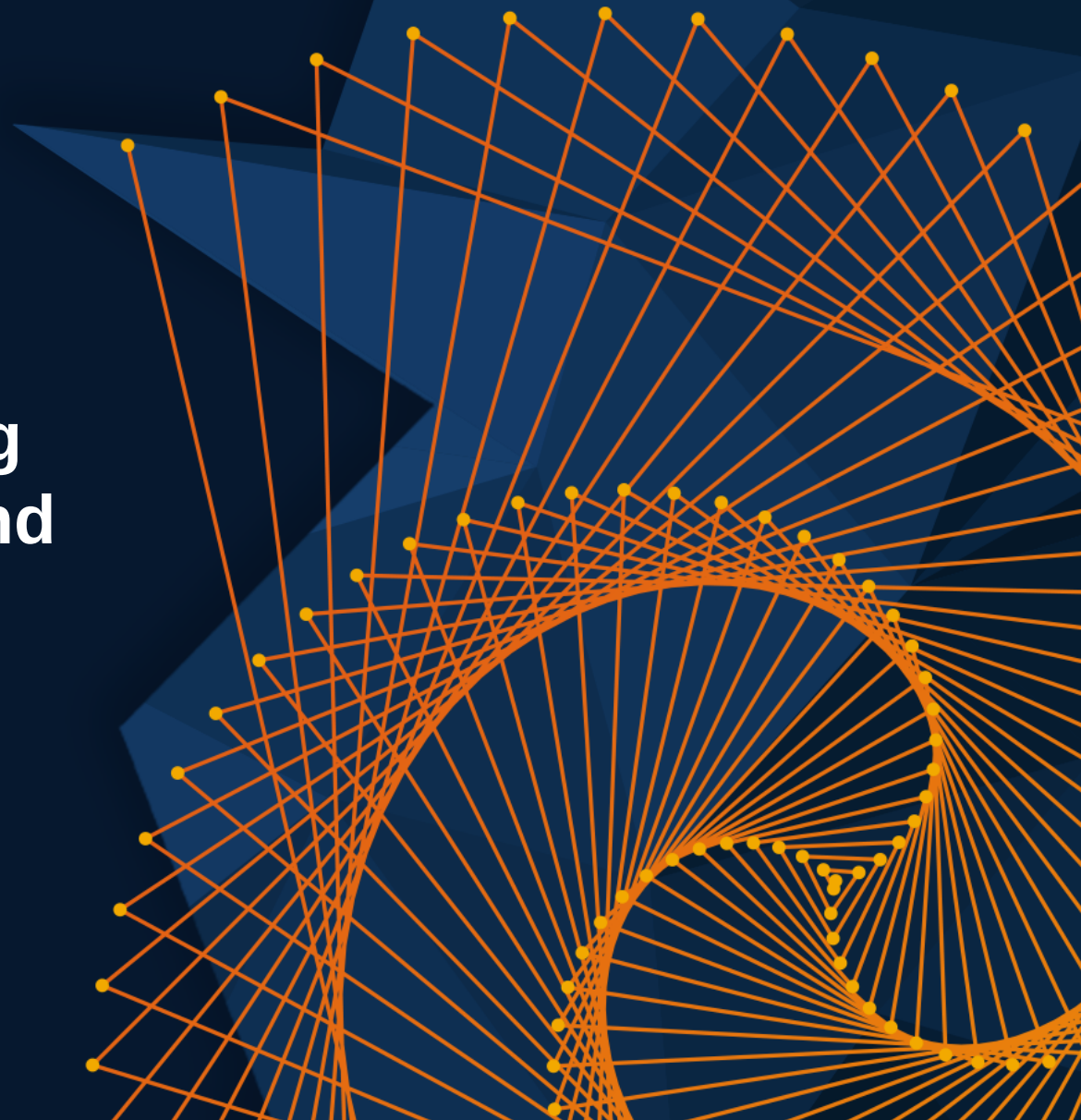

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EV Curriculum for Educators

Module-1	Module-2	Module-3	Module-4	Module-5
Overview of EV Course	Introduction to Model-Based Design	Power Electronics Simulation	Battery Modelling	Vehicle Dynamics Simulation
Introduction to Programming	Solving ODEs using Block-Diagrams	Hardware Integration & Code Generation	Battery Management Systems	System-Level Electric Vehicle Design
Solving ODEs using Numerical Methods	Multi-domain Physical Modelling	BLDC Motor Simulation & Control	Thermal Modeling of Vehicle Components	Design Project: Electric Vehicle System Configuration
Simplified Vehicle Model	Control System Design (PID)	Field-Oriented Control (FOC) for PMSM Motor	Vehicle Powertrain Simulation	
Hands-On Practice	Hands-On Practice	Hands-On Practice	Hands-On Practice	Hands-On Practice

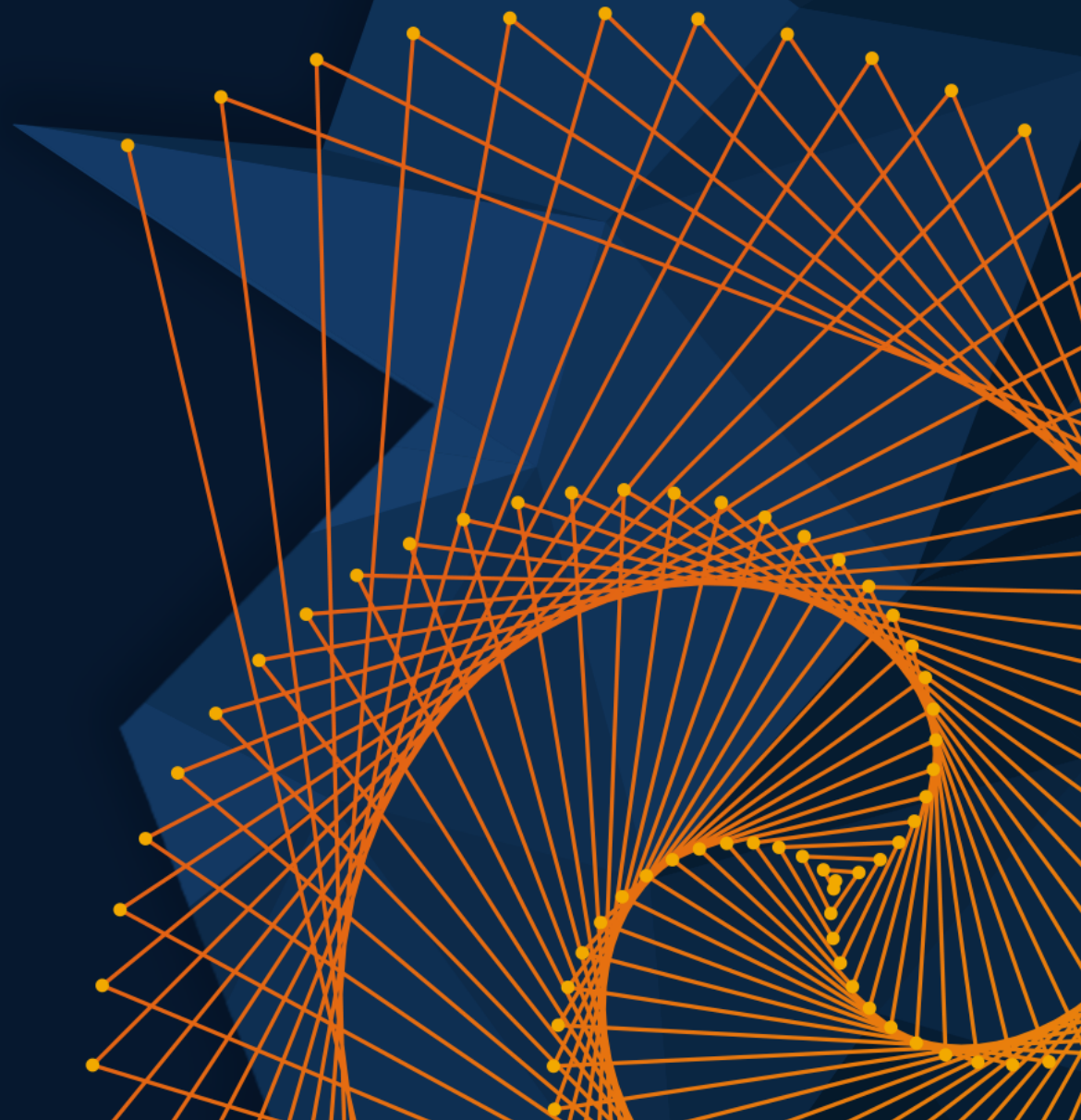
Key Takeaways

- **Iterate on New Ideas faster with Simulation**
  - Speeding up journey from an idea to implementation
  - Design Battery Packs using App Based Workflows
  - Prototype on real-time hardware

- **Assessing technology readiness**
  - Renewables Integration Studies and Energy Storage
  - Control Design for Efficient Load Management
  - Optimization Based Energy Management Systems

MATLAB EXPO

Thank you



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