MATLAB EXPO

Techno-economic Analysis of the Impact of EV Charging on the Power Grid

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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

Technical

Example Considerations

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

Economic

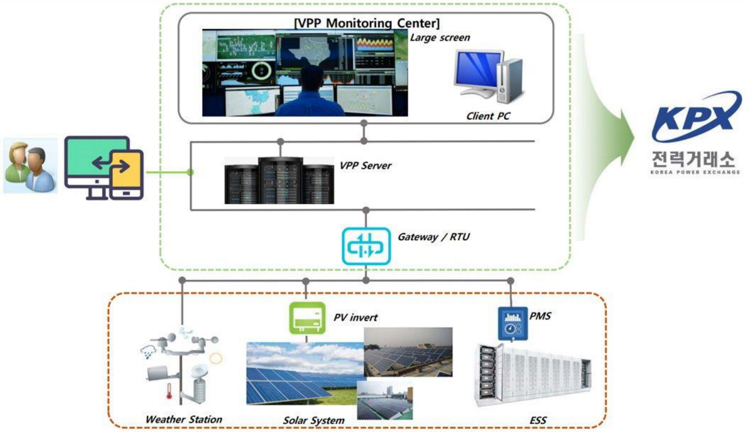
Example Considerations

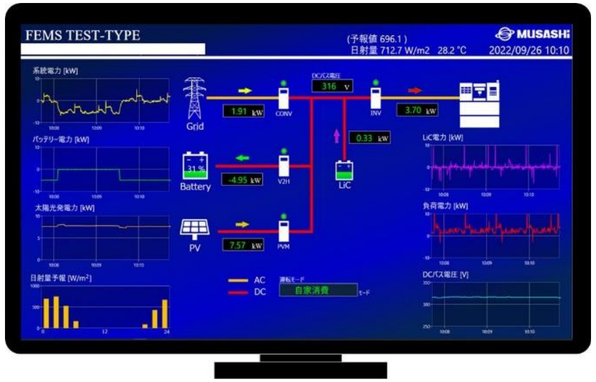
- Energy prices
- Equipment costs
- Maintenance costs
- Business commitments
- Energy trading

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

MathWorks enables techno-economic analysis and optimization





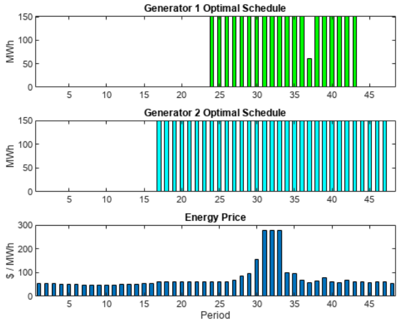
VGEN developed virtual power plant for renewable energy forecasting and energy trading	Musashi Seimitsu Industry developed EMS that minimizes consumption and battery degradation	Otto von Guericke University Magdeburg optimized power flow and energy production

Products enabling workflows

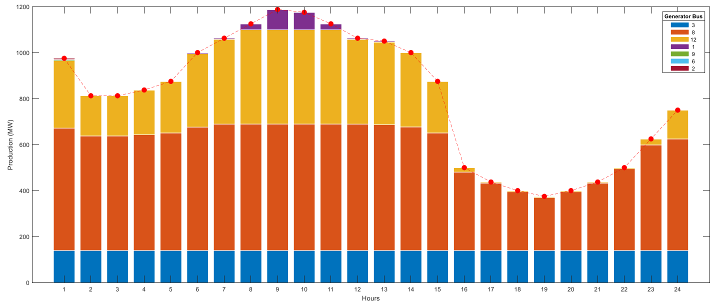
- Optimization Toolbox
- Statistics & Machine Learning Toolbox
- Simscape Electrical
- Simscape Battery
- Parallel Computing Toolbox

Examples

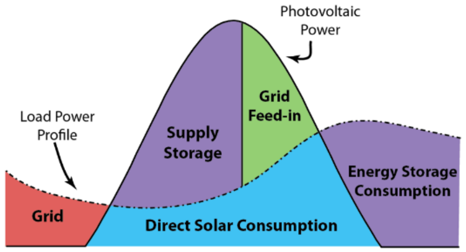
Optimal dispatch



Security-constrained unit commitment



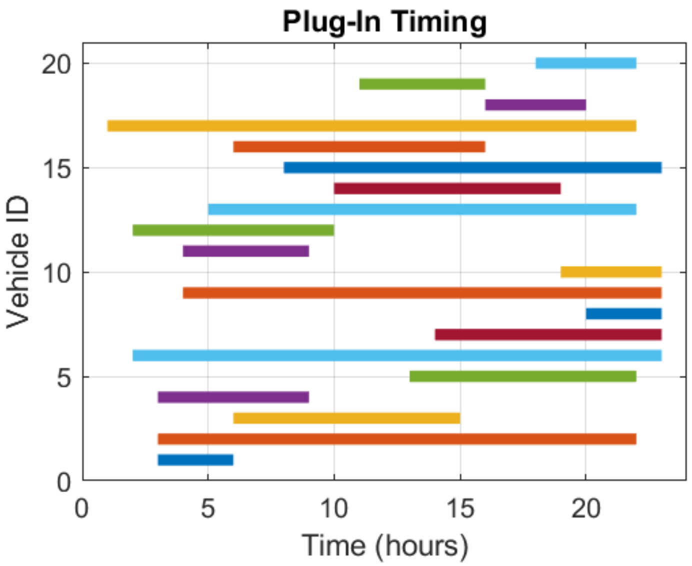
Microgrid EMS

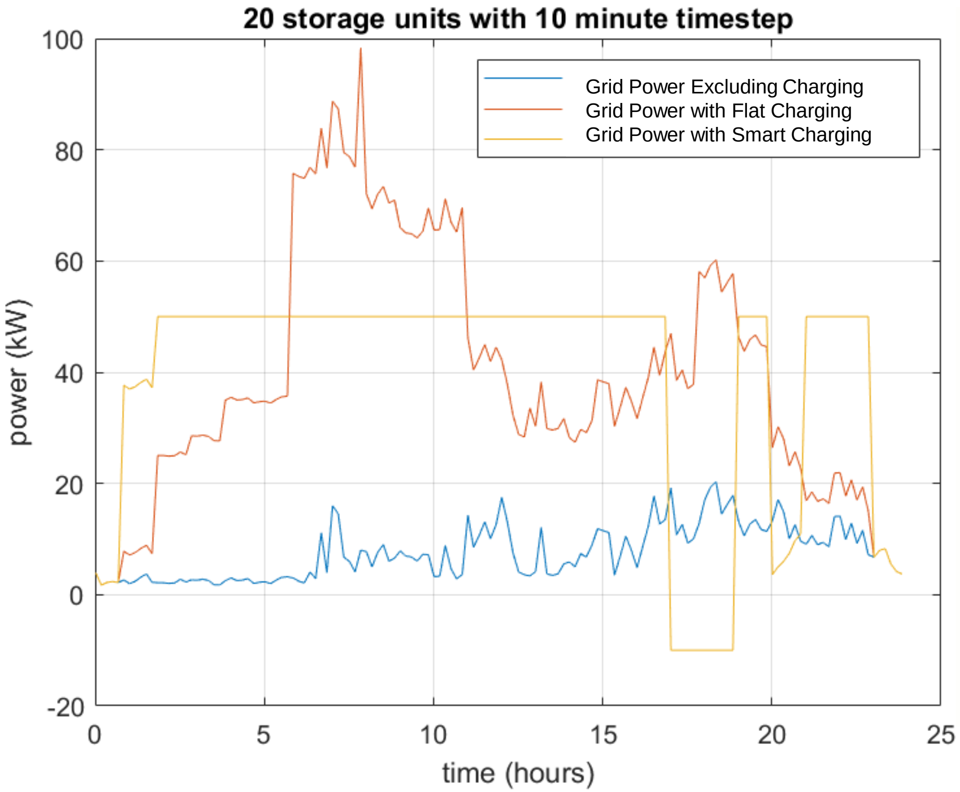


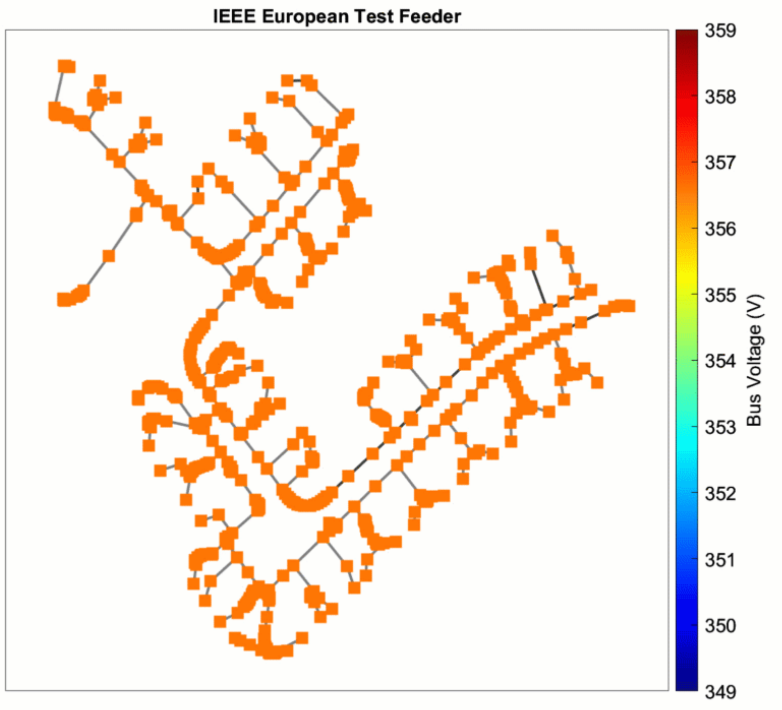
Apply techno-economic optimization to study the impact of EV charging on grid infrastructure

What if…

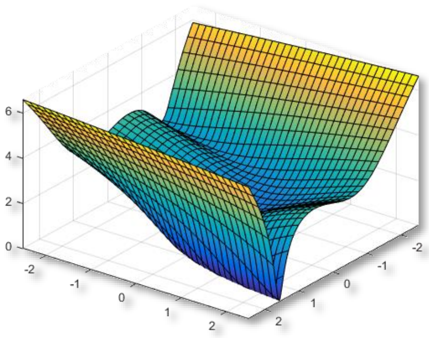
…Charge scheduling accounted for electricity price?
…EVs could supply power to each other?
…Power could be sold back to the grid?

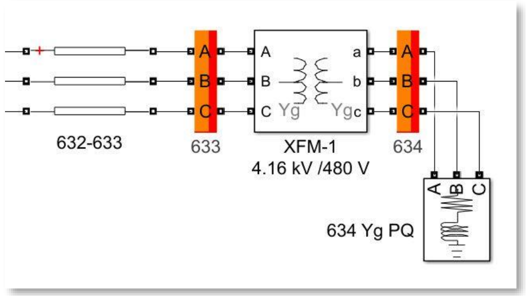


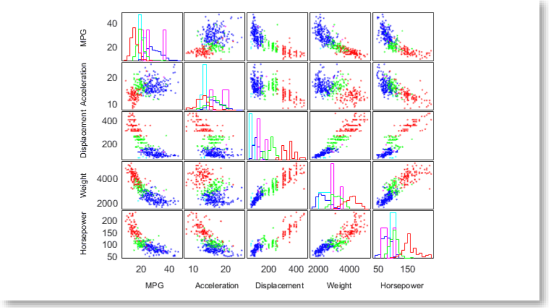


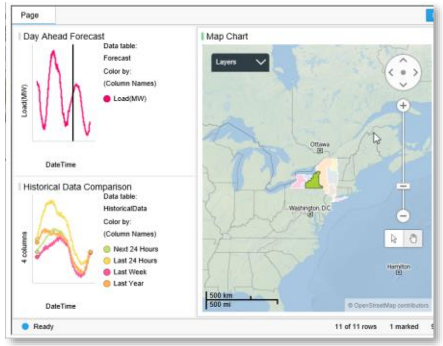


Perform techno-economic optimization in an end-to-end workflow





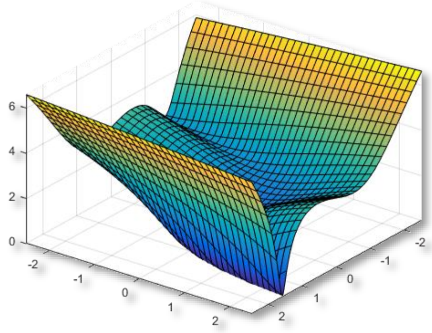


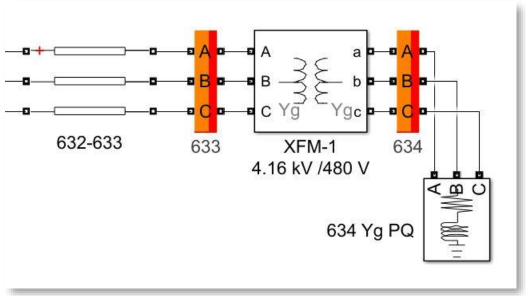


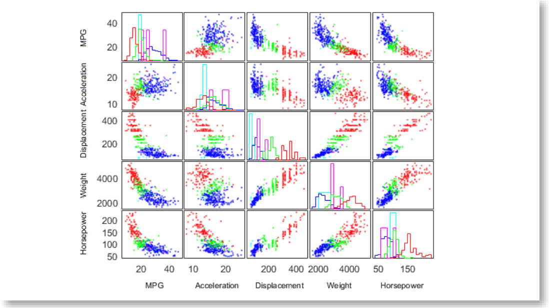
Model and solve optimization → **Grid Simulation** → **Grid Analysis and Visualization** → **Deploy Workflow**

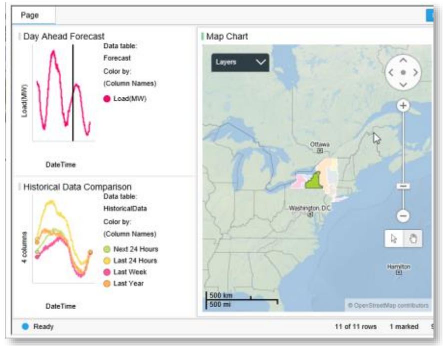
Model and solve optimization	Grid Simulation	Grid Analysis and Visualization	Deploy Workflow
Optimization Toolbox	Simscape Electrical	Parallel Computing Toolbox Statistics & Machine Learning Toolbox	App Designer MATLAB Web App Server MATLAB Compiler

Perform techno-economic optimization in an end-to-end workflow









Model and Solve Optimization → **Grid Simulation** → **Grid Analysis and Visualization** → **Deploy Workflow**

- Model and Solve Optimization: Optimization Toolbox
- Grid Simulation: Simscape Electrical
- Grid Analysis and Visualization: Parallel Computing Toolbox, Statistics & Machine Learning Toolbox
- Deploy Workflow: App Designer, MATLAB Web App Server, MATLAB Compiler

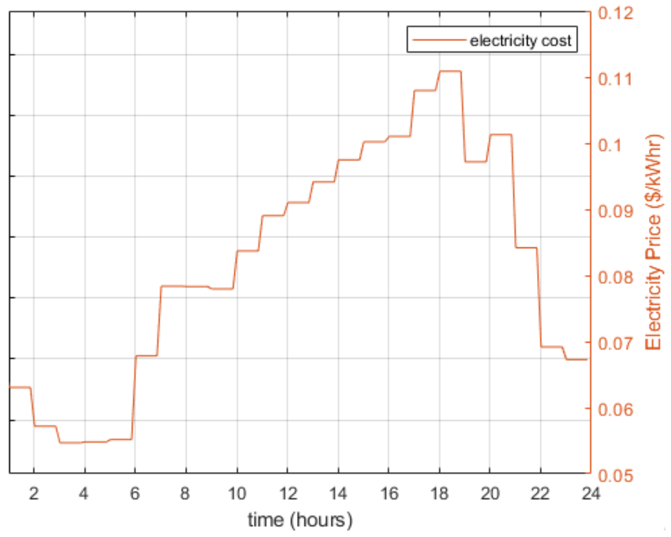
Start by describing the components of the optimization problem

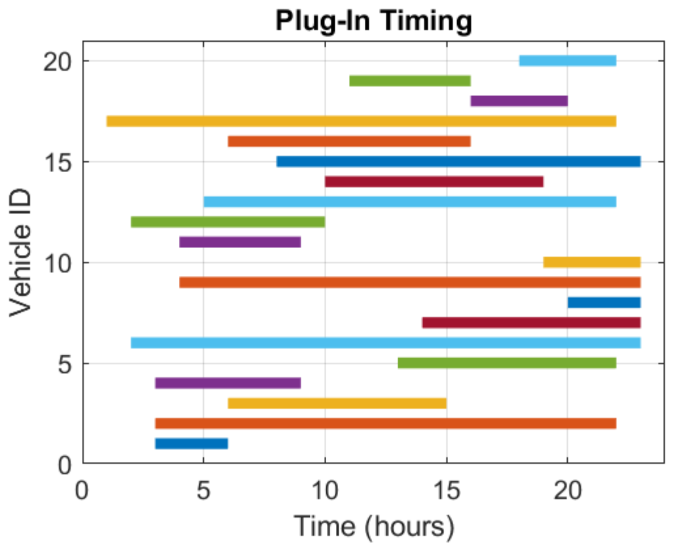
- Input Data:
  - Cost of power from grid over time
  - Time intervals when each EV storage unit is plugged in

- Variables:
  - Power in/out of each storage unit
  - Power bought from/sold to grid

- Constraints:
  - For each unit, SoC must stay between upper and lower charge limits
  - For each unit, final SoC must equal the upper charge limit
  - Grid power must be balanced with storage unit power and system load power
  - Grid power must not exceed upper and lower limits

- Objective:
  - Minimize total cost of electricity





Problem-based optimization workflow enables intuitive formulation of optimization model

- Variable example: Power bought from/sold to grid, subject to limits

$$min \leq gridPower \leq max$$

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

- Constraint example: Grid power must be balanced with storage unit power and system load profile

$$\sum storagePower + loadPower = gridPower$$

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

Problem-based optimization workflow enables intuitive formulation of optimization model

- Objective example: Minimize total cost of electricity

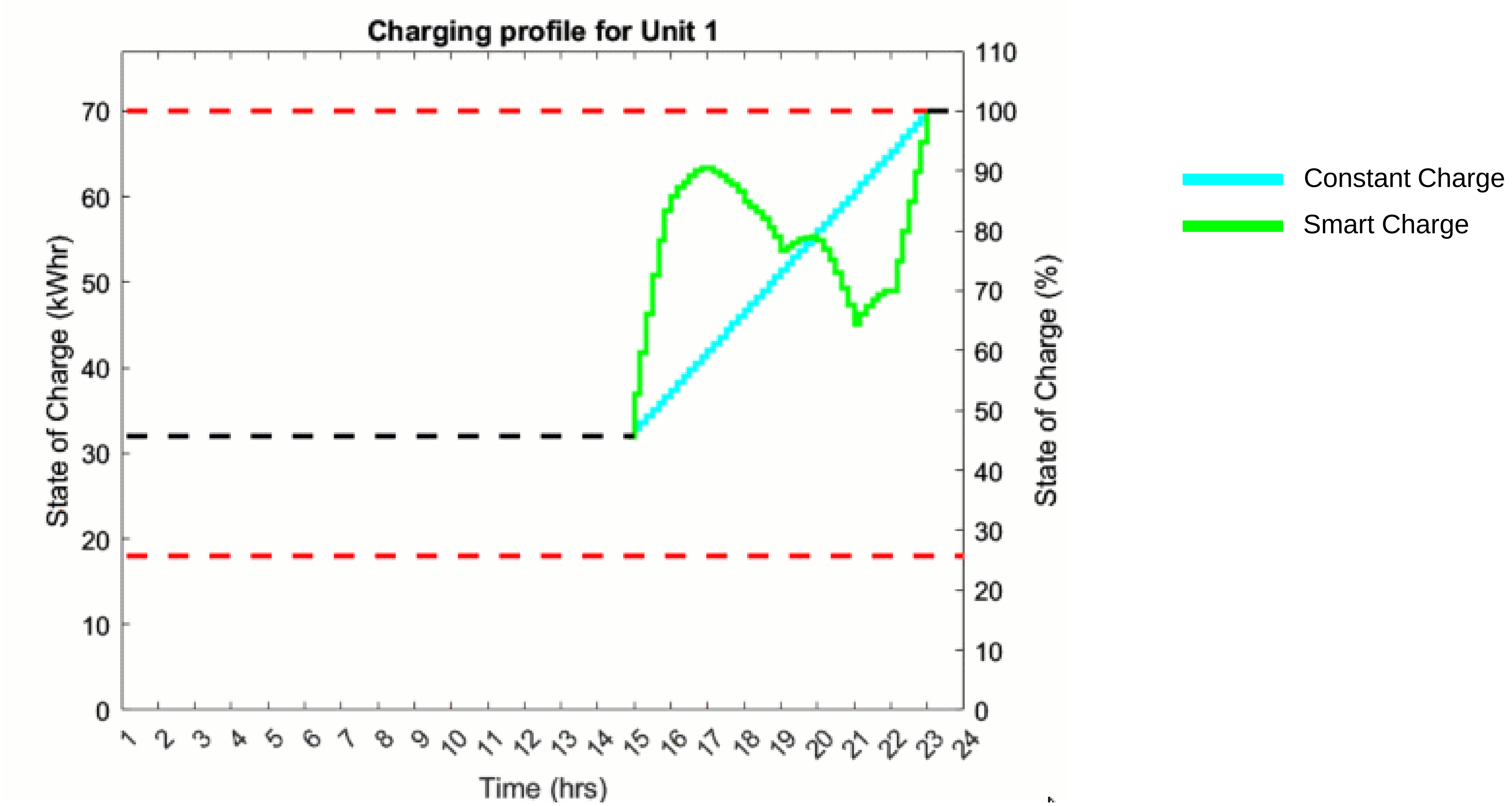
$$totalCost = gridPower \times price$$

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

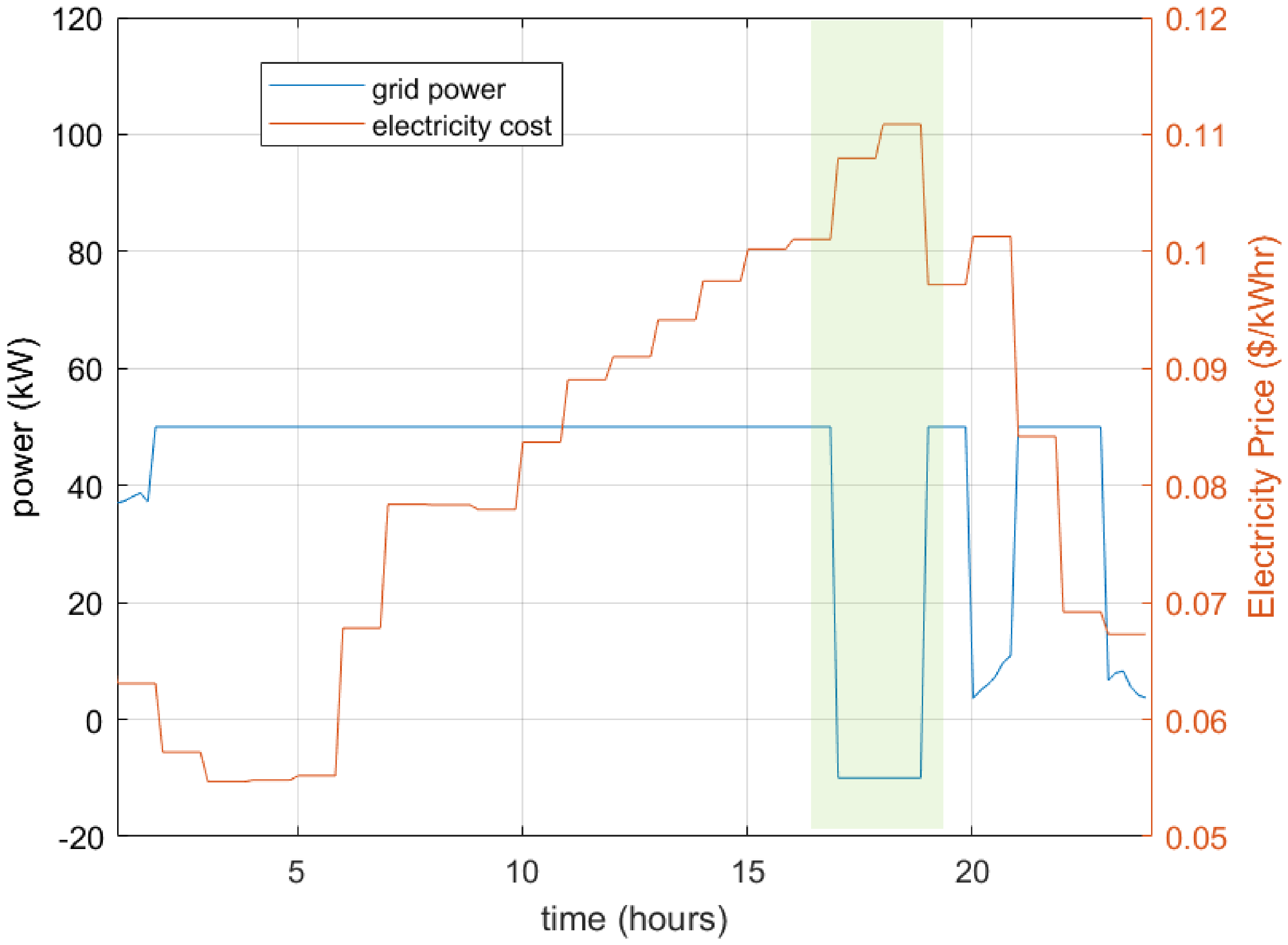
- Solve problem

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

Smart charging applies time-varying power for system benefit

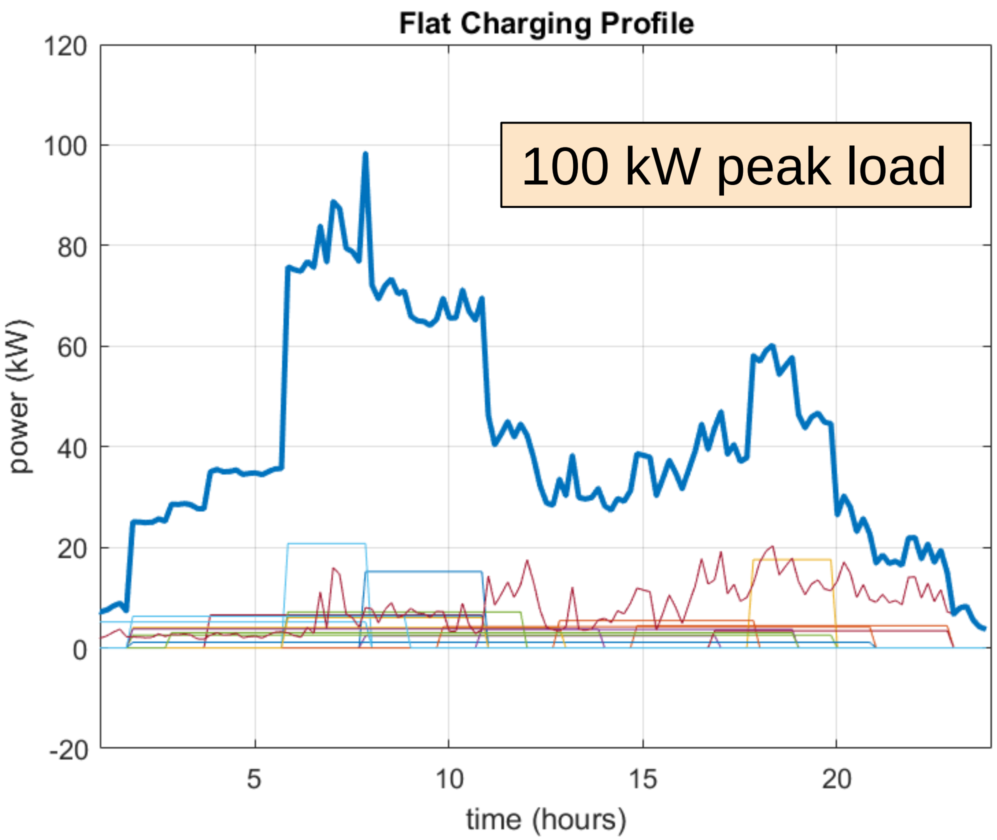


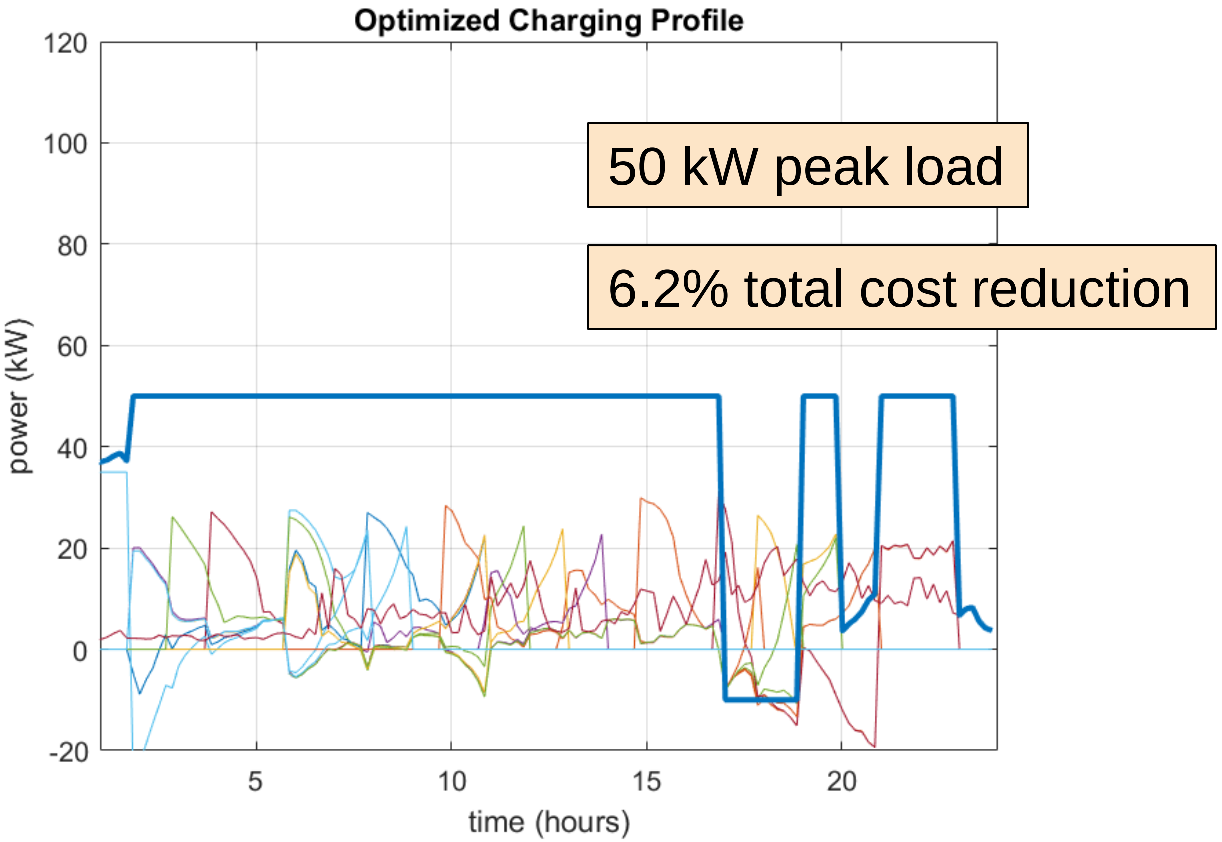
Smart charging feeds power back to grid when grid price is highest



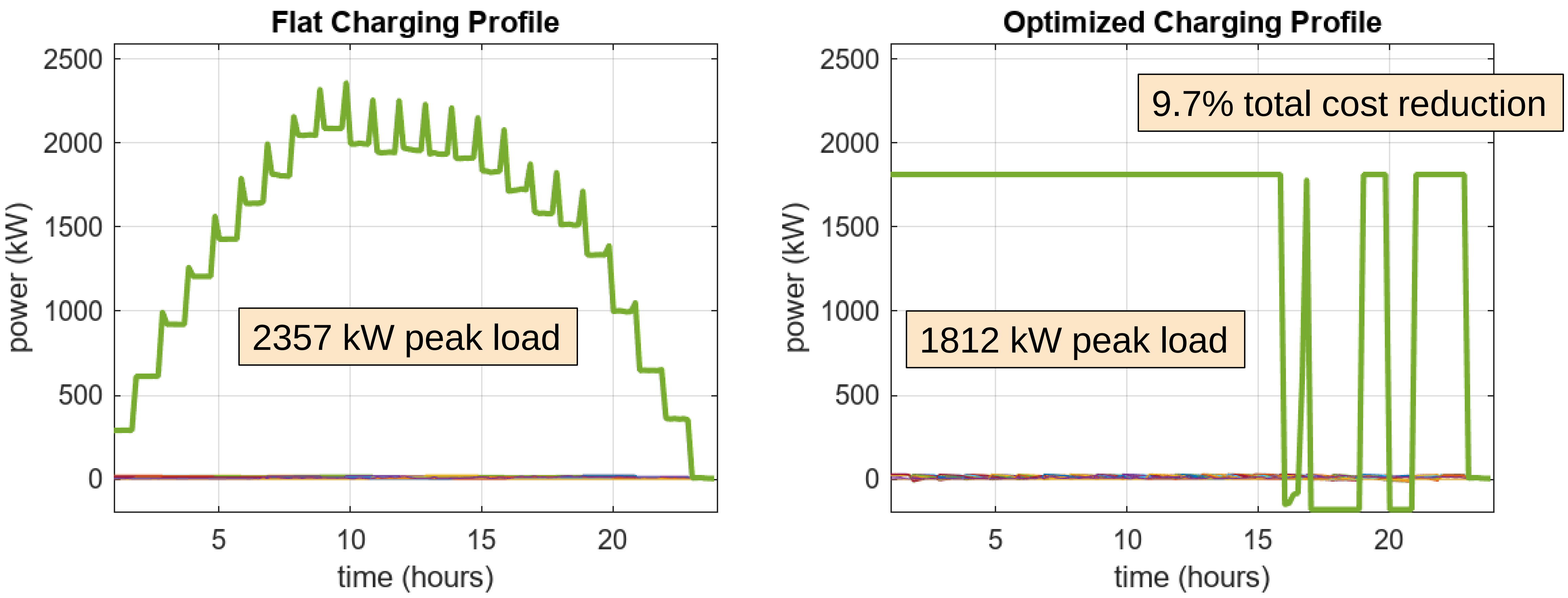
Smart charging is 6.2% cheaper than flat charging in this scenario

Optimized charging profile minimizes overall cost and limits peak load

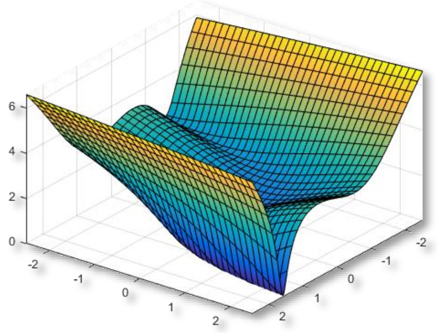


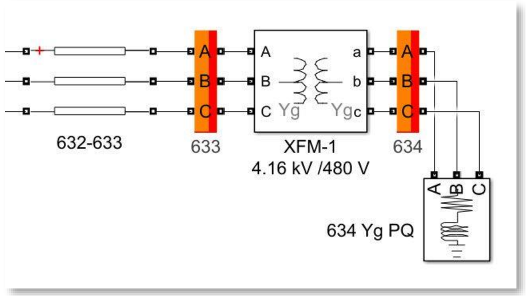


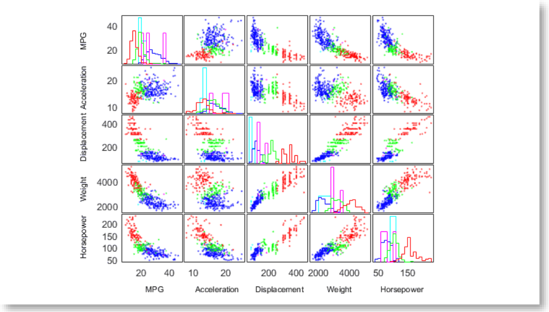
Scaled up study (906 units) continues to show cost and peak load benefits

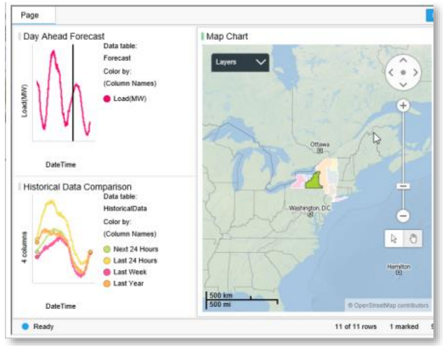


Perform techno-economic optimization in an end-to-end workflow









Model and Solve Optimization → **Grid Simulation** → **Grid Analysis and Visualization** → **Deploy Workflow**

- **Model and Solve Optimization**: Optimization Toolbox
- **Grid Simulation**: Simscape Electrical
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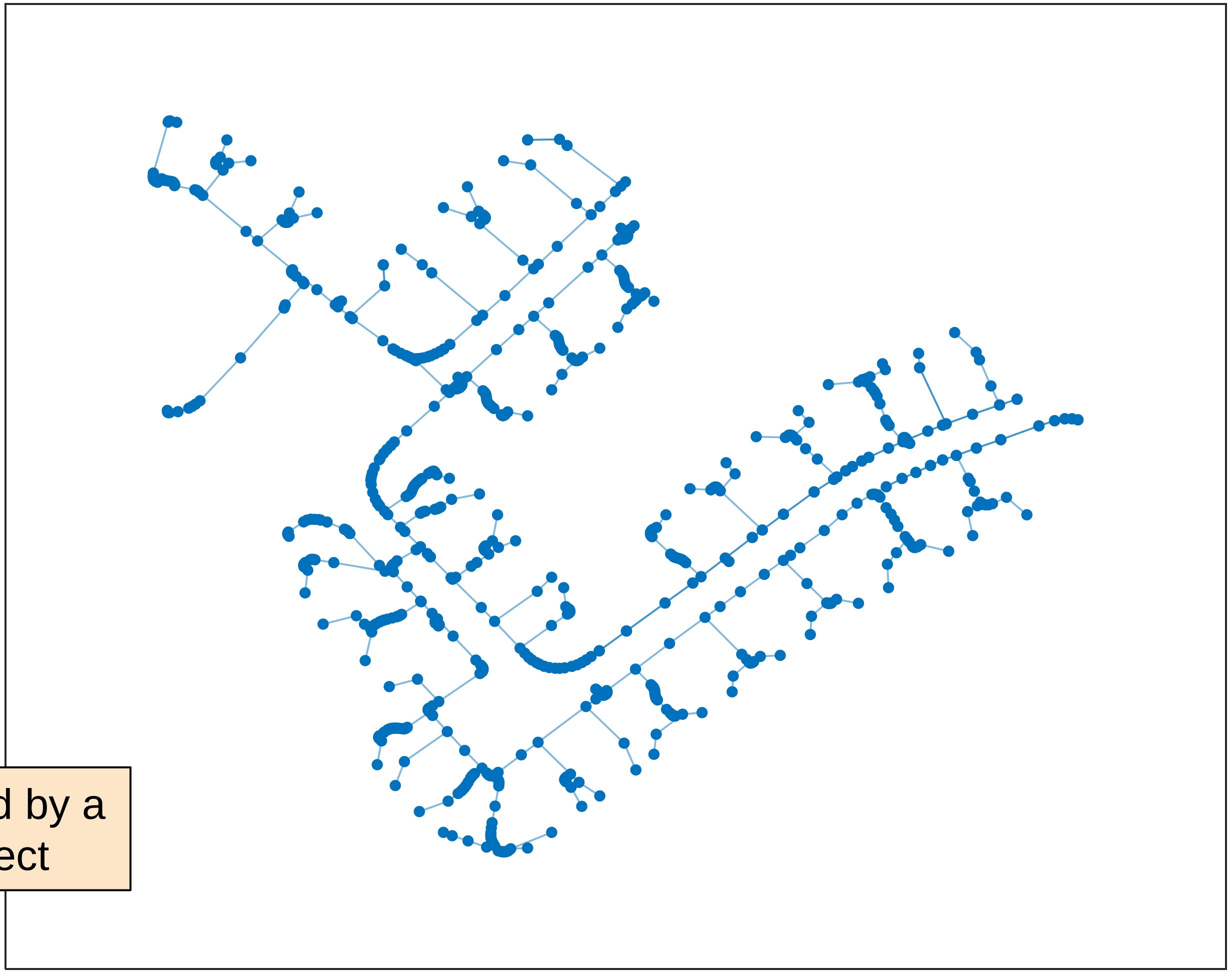
- **Deploy Workflow**: App Designer, MATLAB Web App Server, MATLAB Compiler

IEEE European Test Feeder

We will evaluate the charging profiles on the IEEE European Test Feeder. This is a 906 bus three-phase distribution system published by the IEEE AMPS Distribution System Analysis Subcommittee. Network data is available at the link shown below.

IEEE European Test Feeder

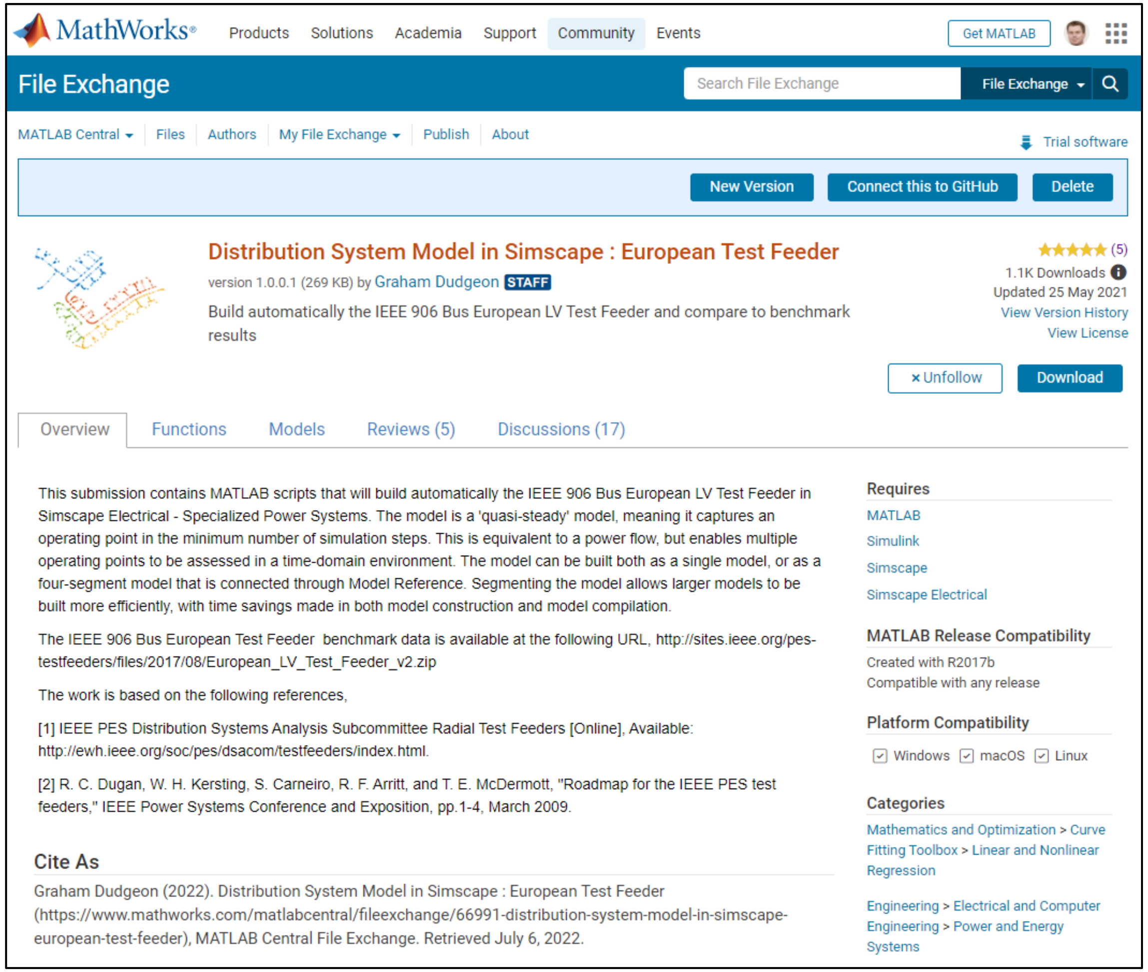


This image is rendered by a MATLAB graph object

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

IEEE European Test Feeder

Files that build the IEEE European Test Feeder in Simscape Electrical are available for download on MathWorks File Exchange.

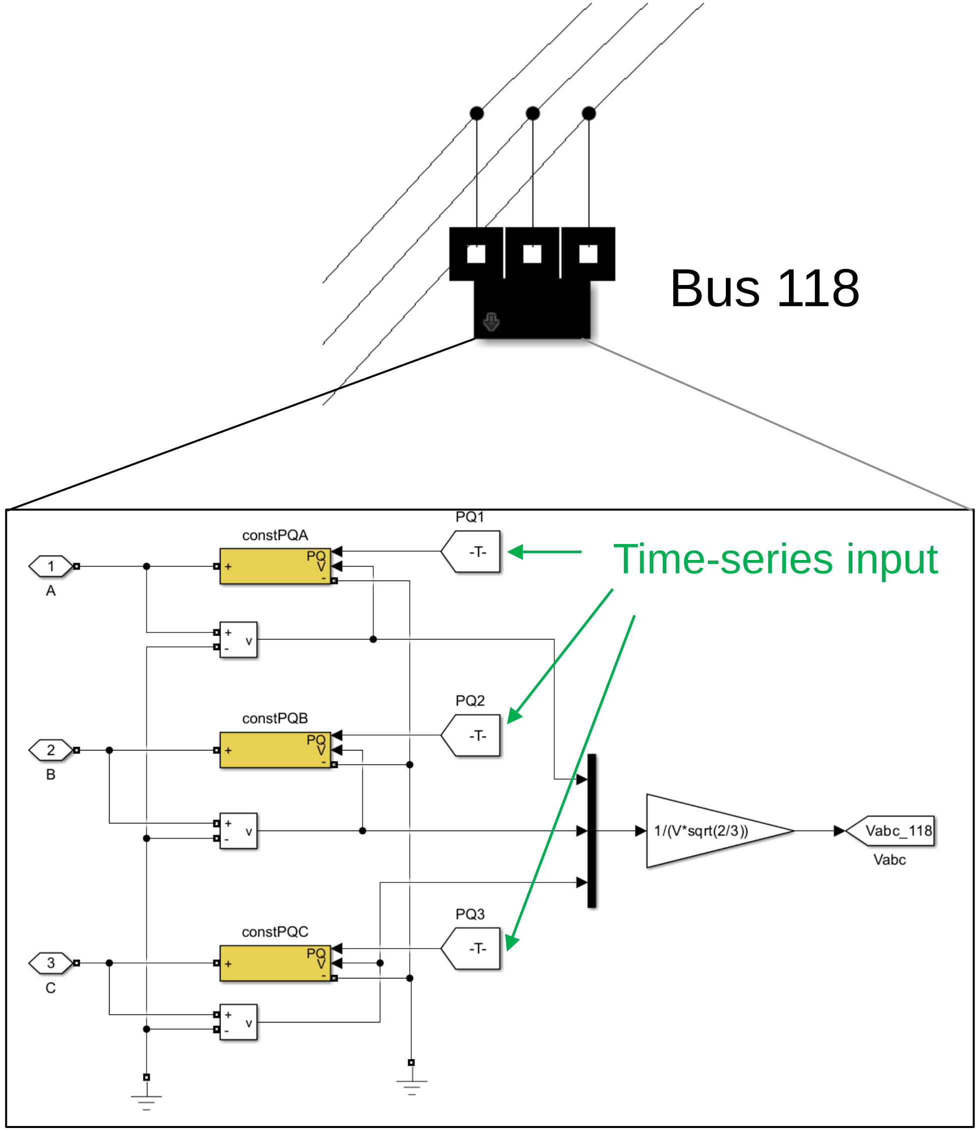


https://www.mathworks.com/matlabcentral/fileexchange/66991-distribution-system-model-in-simscape-european-test-feeder

Configure grid simulation for scenario evaluation

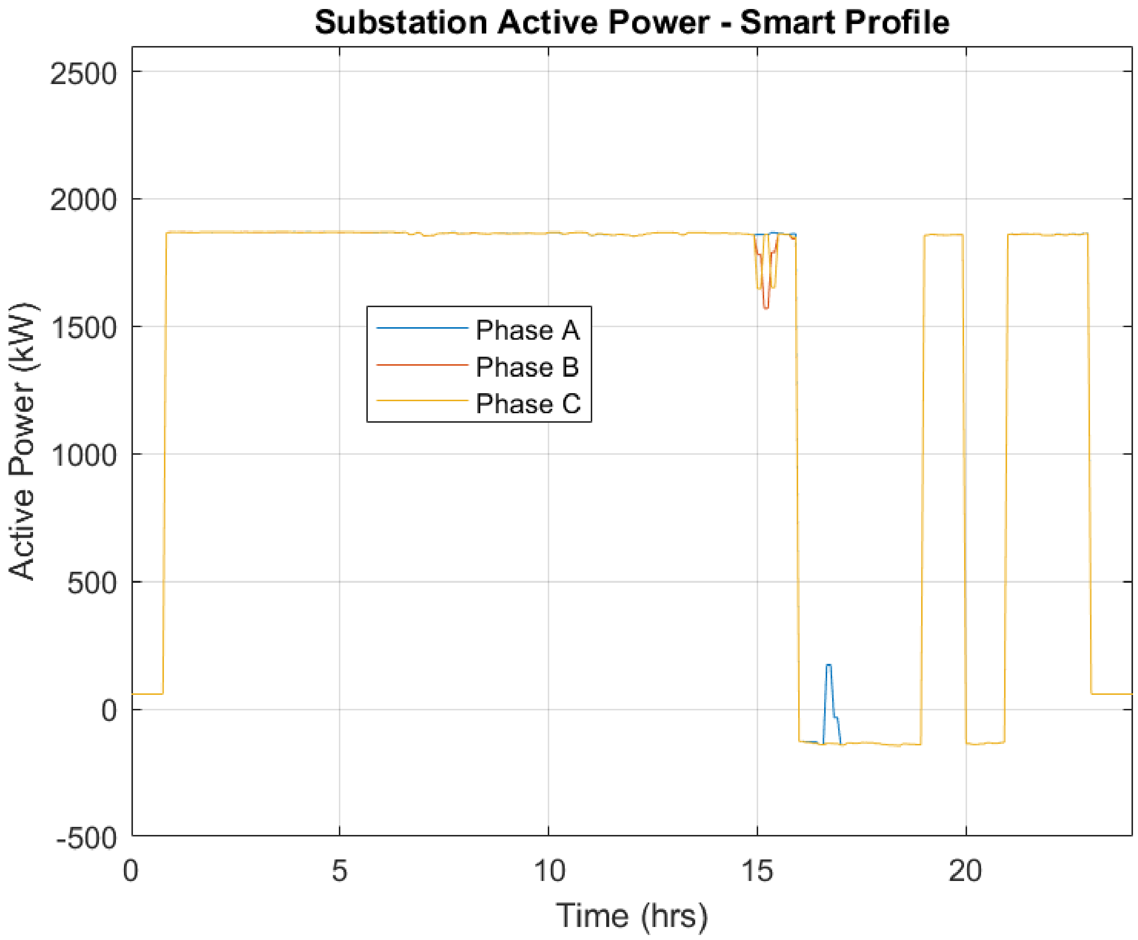
For the greatest flexibility with scenario evaluation, we place a bi-directional power input at each node, where we can input a given power profile as time-series data. For this system, we have 2718 possible power inputs.

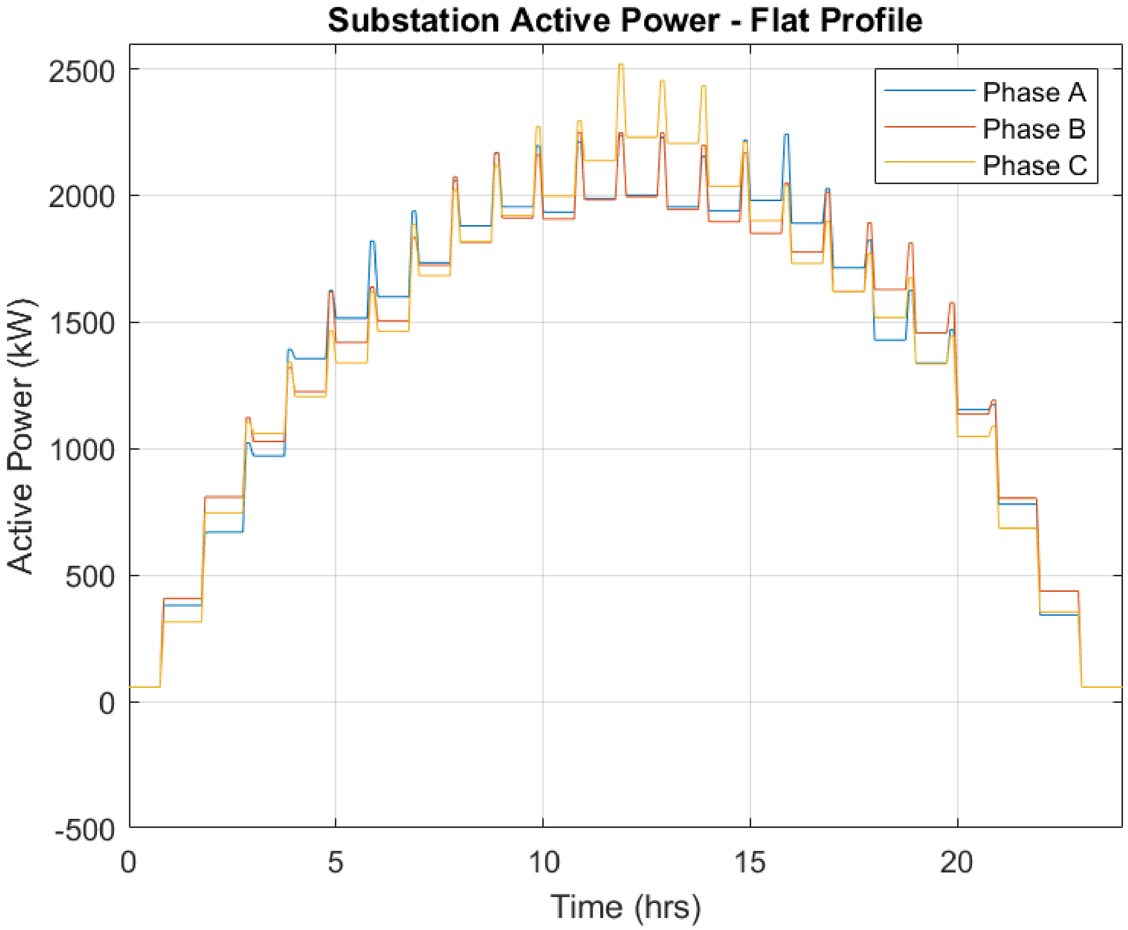
Our first scenario is where each of the 2718 nodes has a storage unit, and we optimize each phase separately. There are 906 storage units per phase…



Configure grid simulation for scenario evaluation

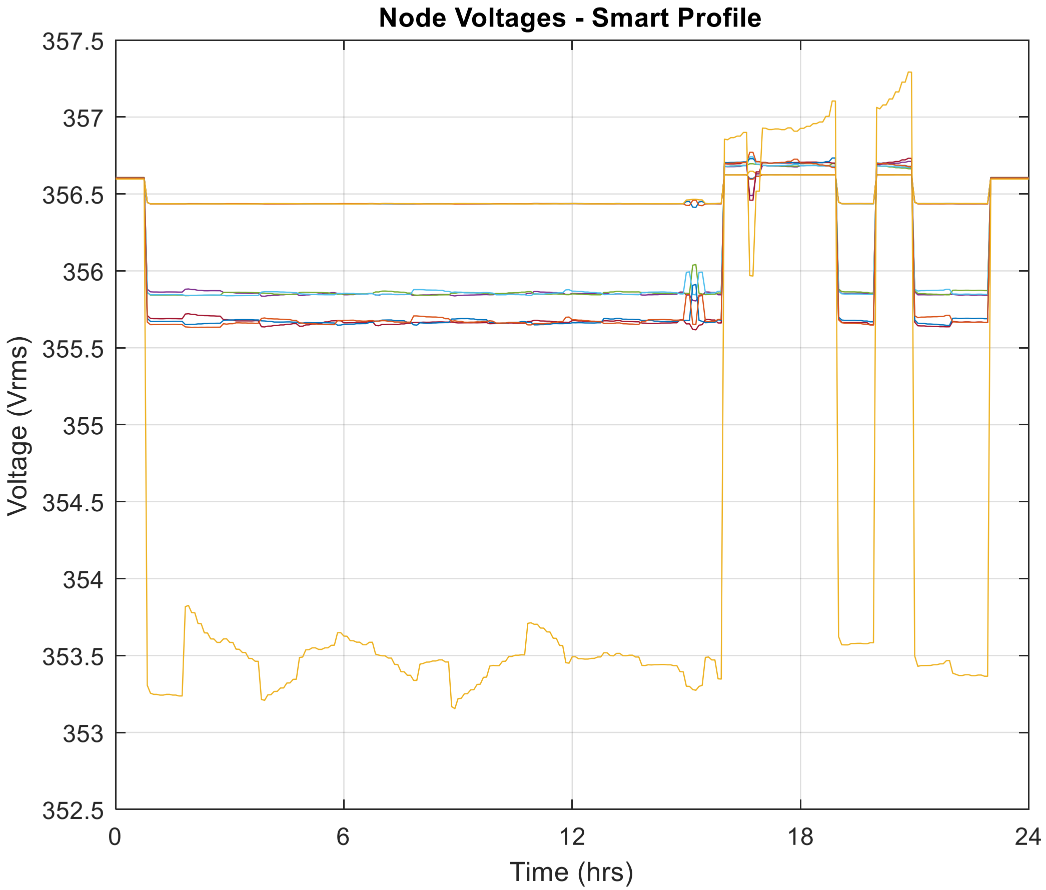
With Ts = 300s, the phasor grid simulation takes approx. 6 seconds for the 24-hour scenario. The differences between each phase is primarily due to different plug-in durations.

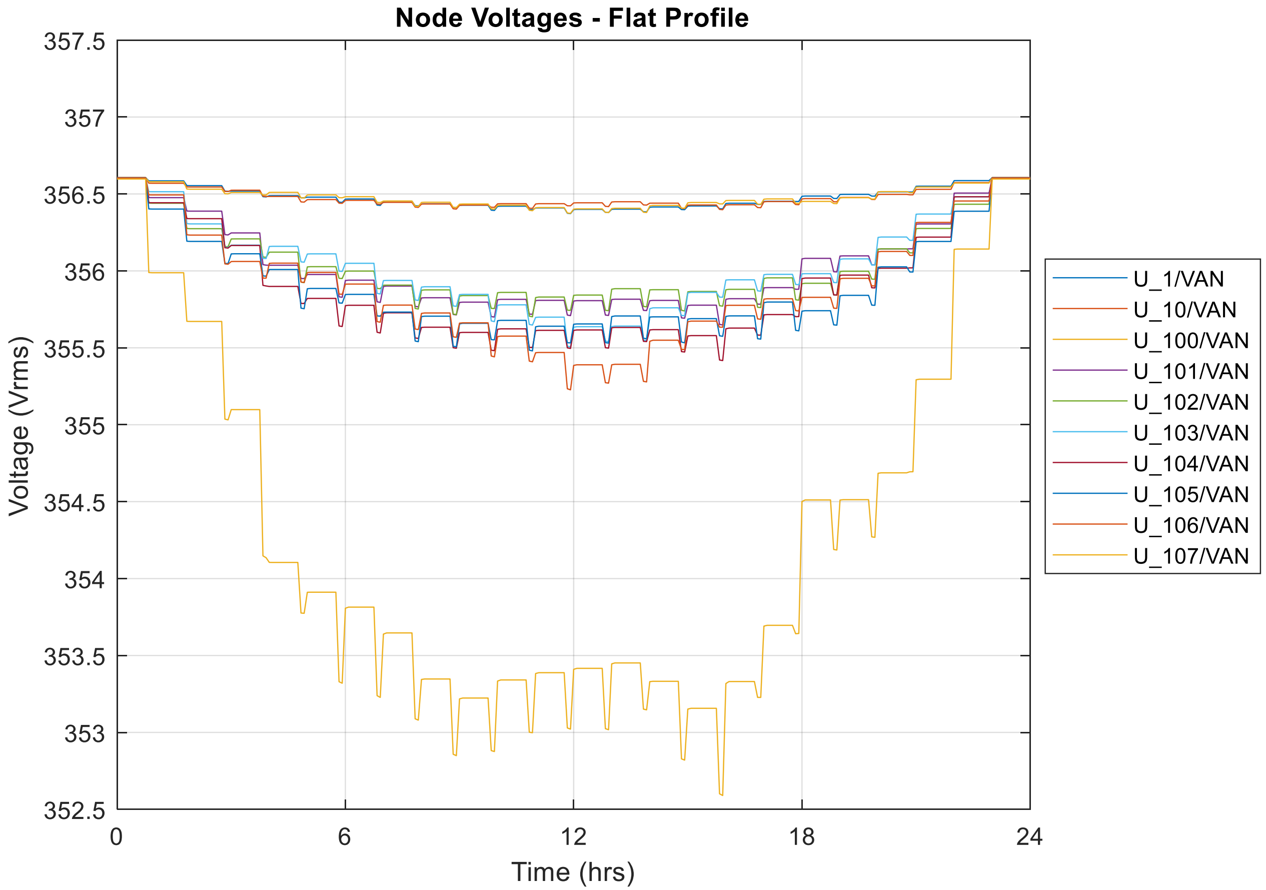




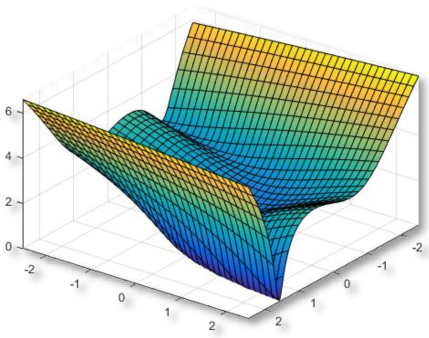
Configure grid simulation for scenario evaluation

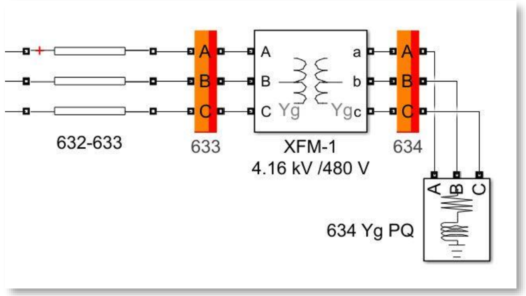
With a grid simulation, we also have access to voltage and current profiles.

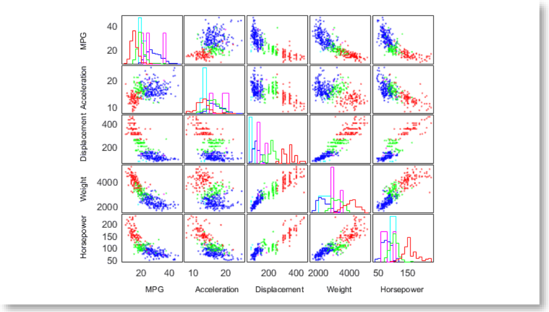


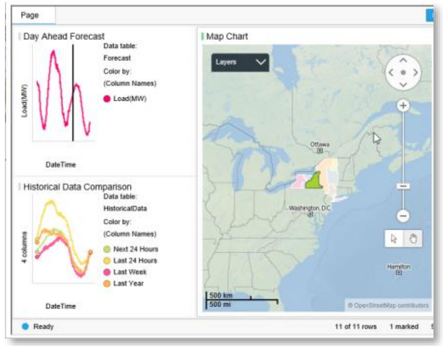


Perform techno-economic optimization in an end-to-end workflow









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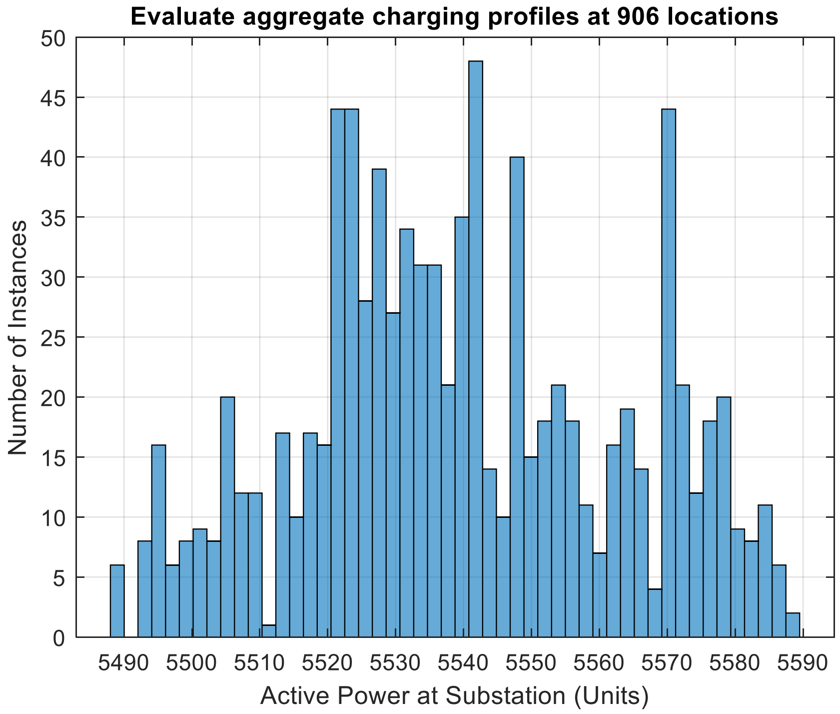
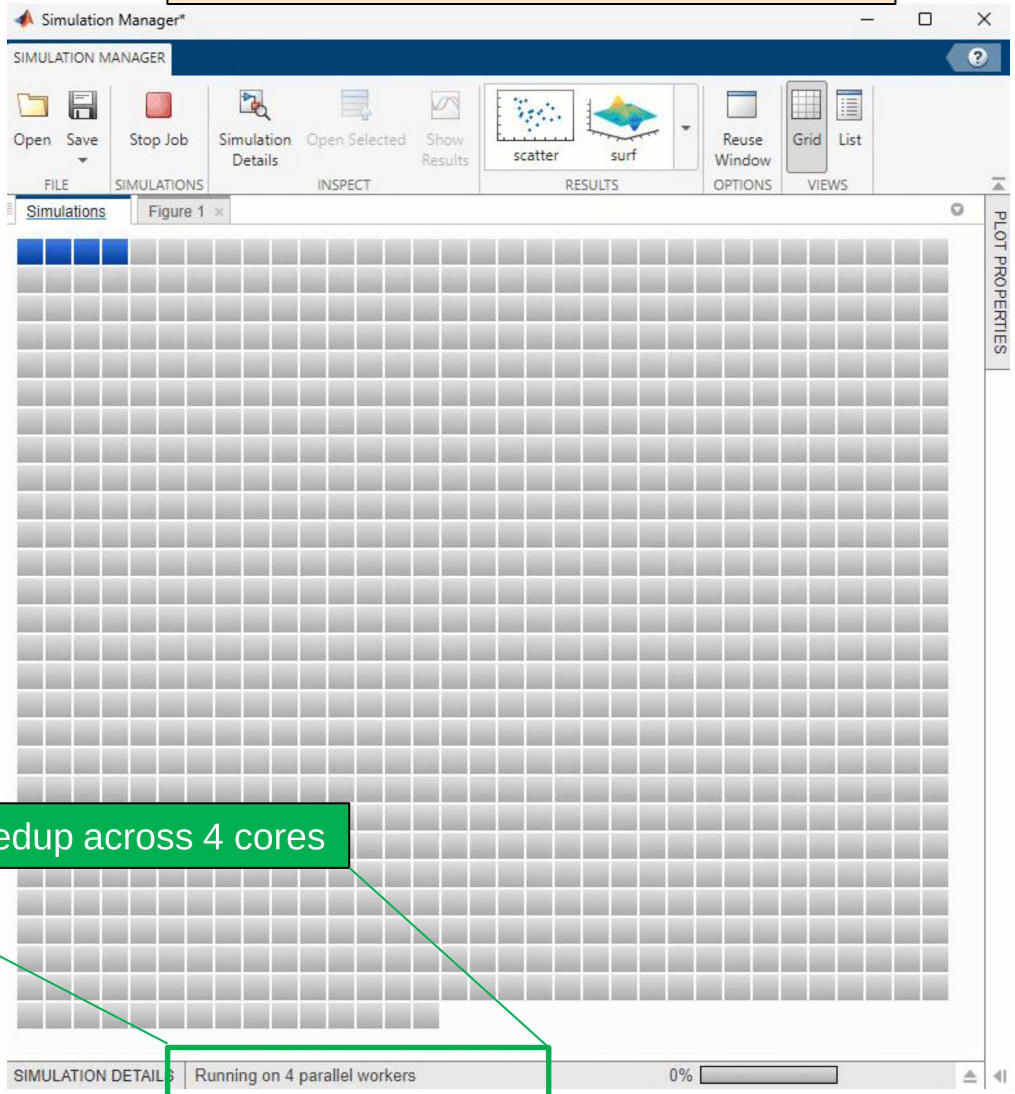
Multiple scenarios on multiple cores

Our next scenario explores aggregated storage units connected to a single bus – We have 906 scenarios to evaluate. Using parallel computing, we can evaluate multiple scenarios in a time-efficient manner.



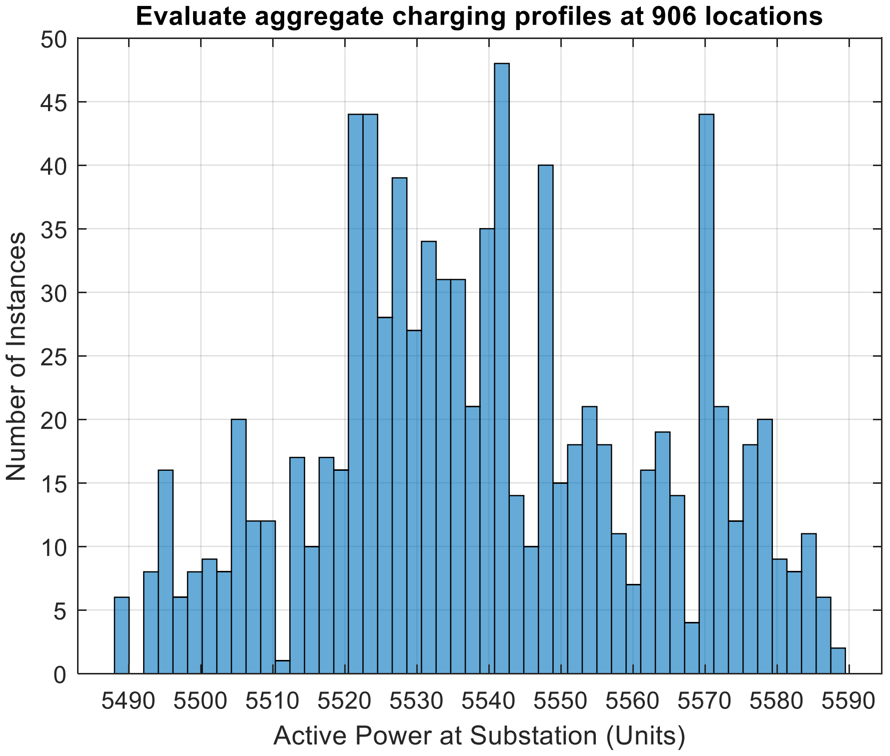
Animation speed up x60 of 906 scenarios

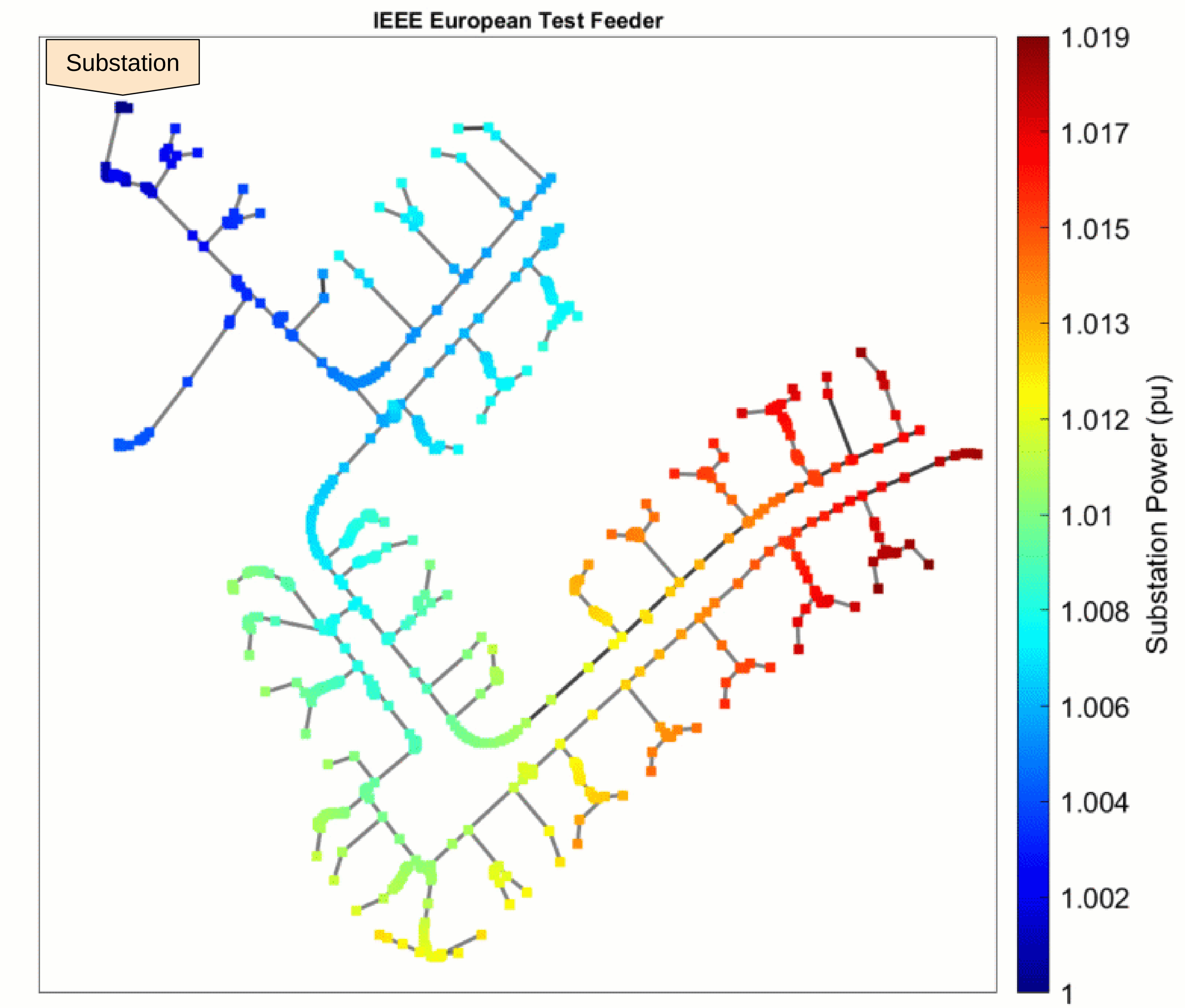


3.5x speedup across 4 cores

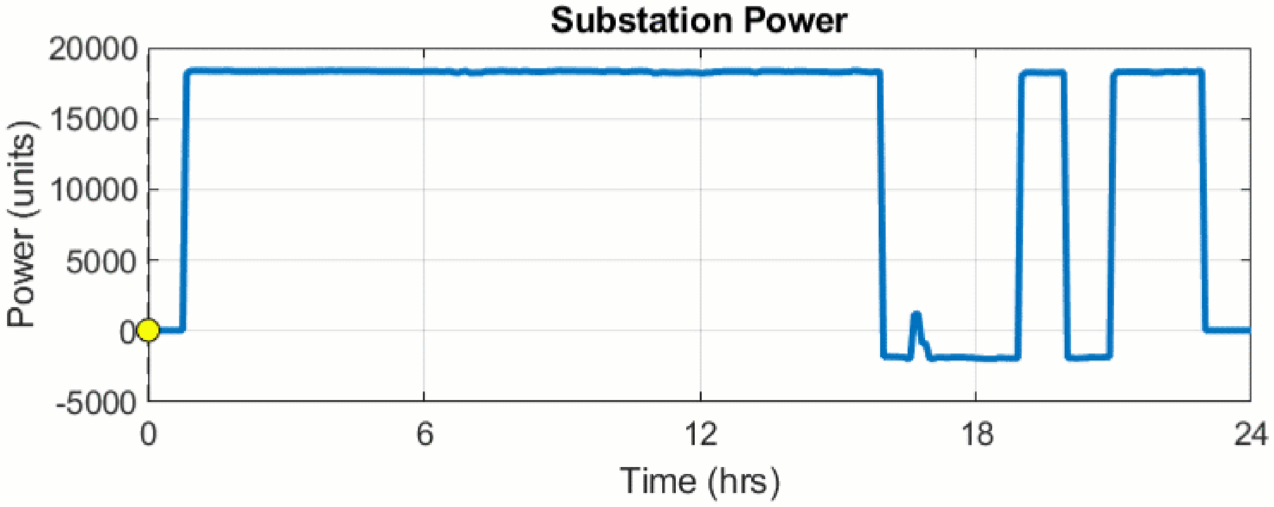
Multiple scenarios on multiple cores

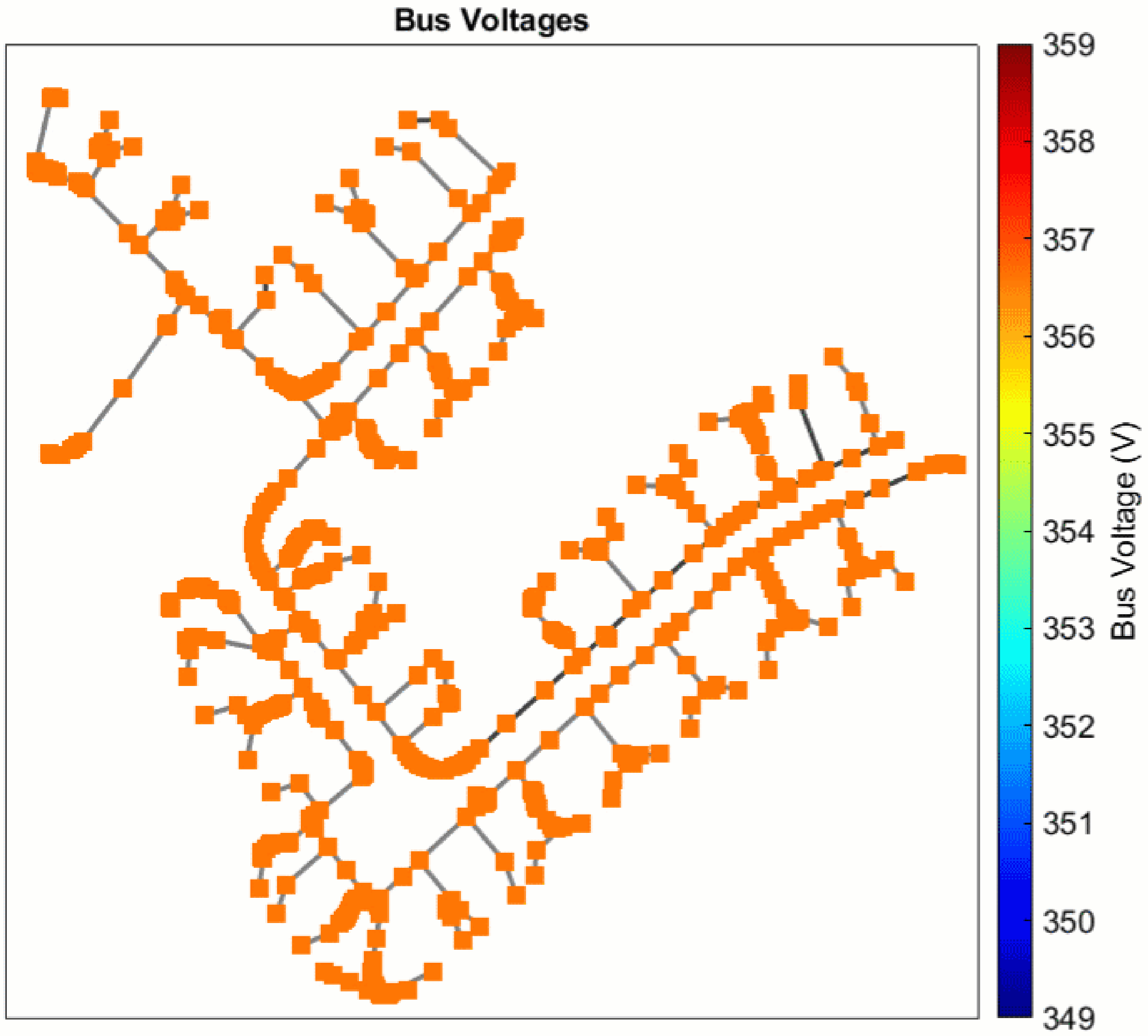
Statistical analysis and visualization enhances our understanding of the grid impact



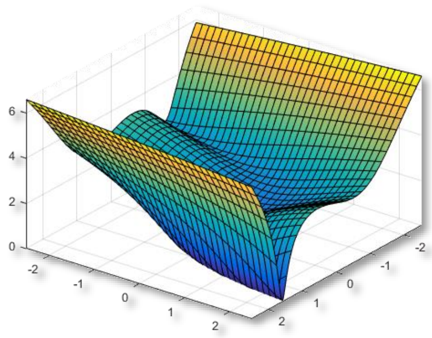


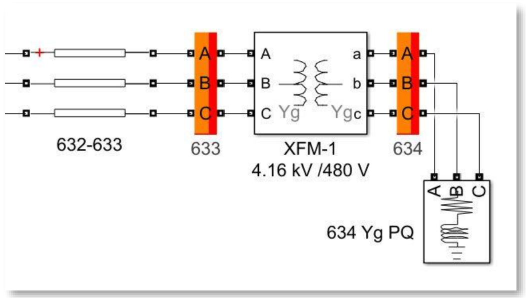
Enhanced visualization - voltage levels across 24 hours

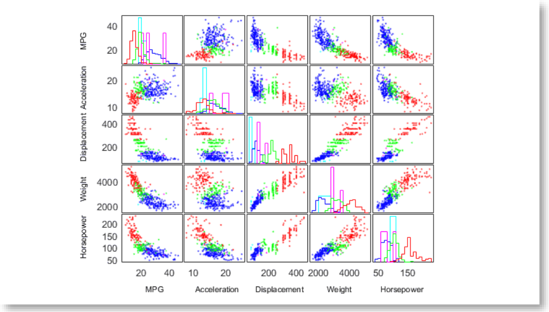


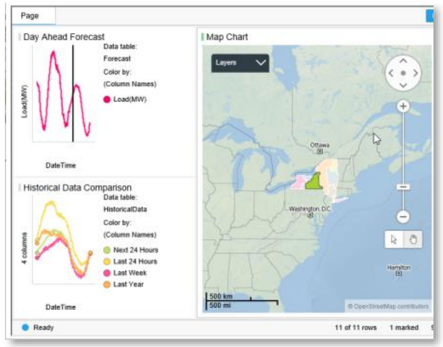


Perform techno-economic optimization in an end-to-end workflow









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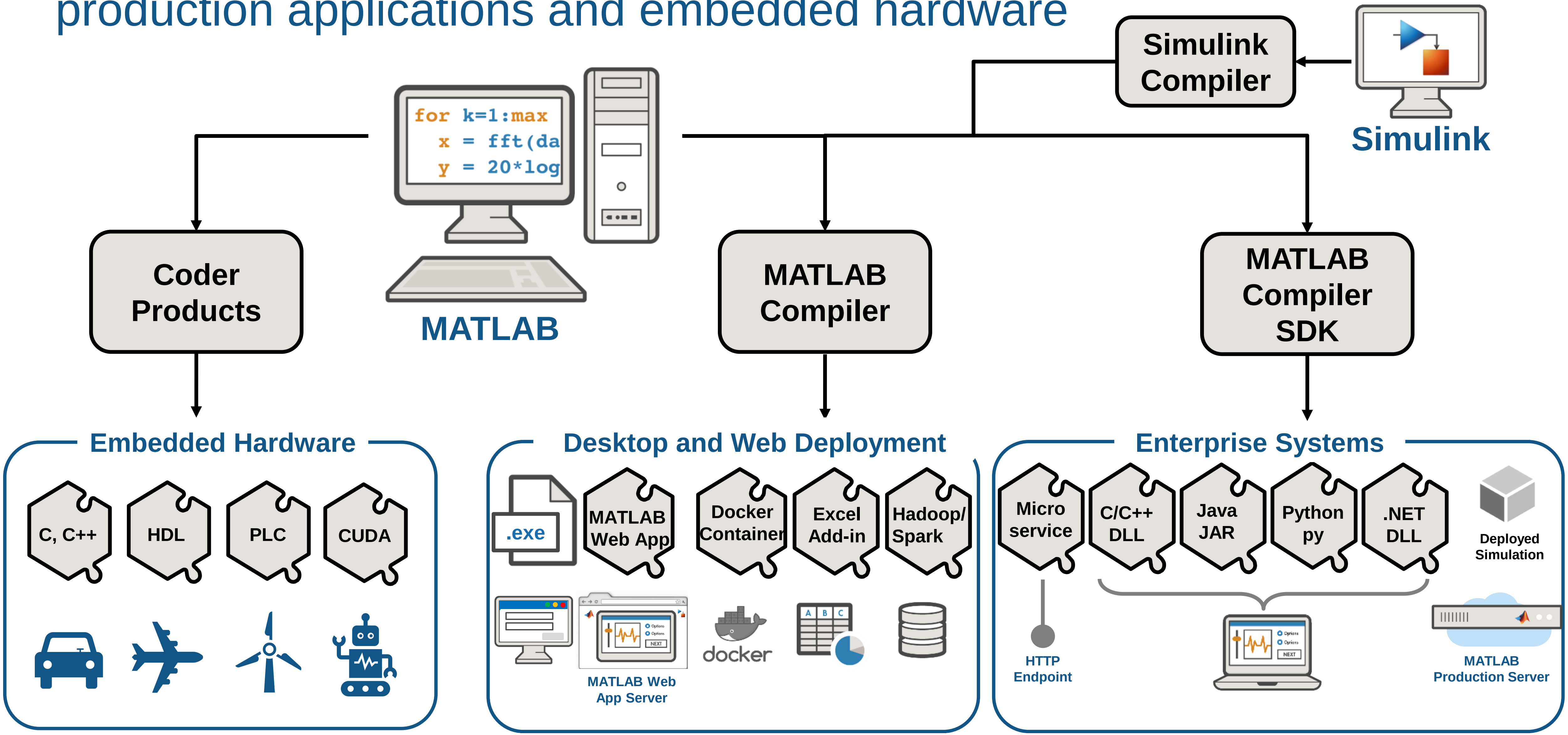
Optimization Toolbox

Simscape Electrical

Parallel Computing Toolbox
Statistics & Machine Learning Toolbox

App Designer
MATLAB Web App Server
MATLAB Compiler

Deploy techno-economic analysis and optimization workflows to production applications and embedded hardware



Key takeaways

- Reduce risk and build confidence in power grid readiness with techno-economic analysis
- Model and solve large-scale optimization studies with problem-based modeling and efficient solvers in MATLAB
- Perform grid simulations and enhance understanding with statistical analysis and visualization
- Operationalize analysis workflow using a wide range of deployment options

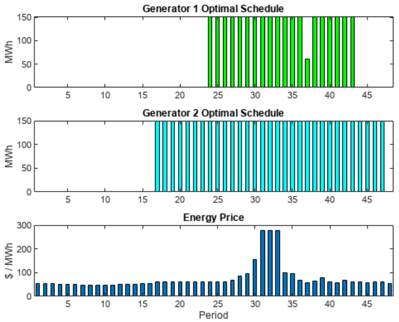
Take the next step and learn more

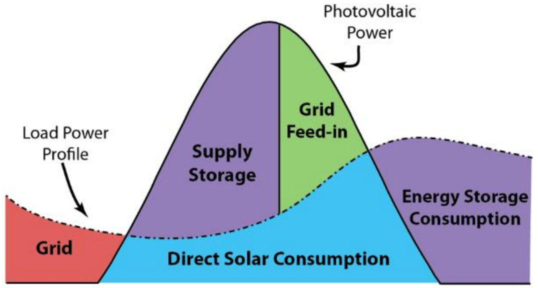
Free Self-Paced Training

Optimization Onramp

Simscape Onramp

Examples

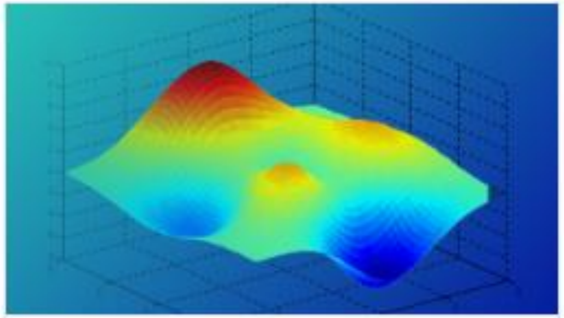




Optimal Dispatch

Microgrid EMS

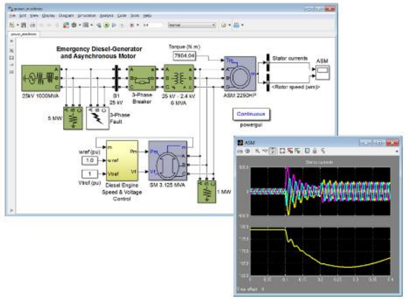
Instructor-led Training



Optimization Techniques in MATLAB

Modeling Electrical Power Systems with Simscape

Consulting Solutions



Load Forecasting

Power Systems Simulation

MATLAB EXPO

Thank you

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