

MATLAB EXPO

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

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MathWorks*



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MathWorks*





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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**

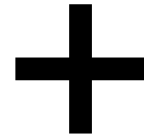


How to adapt for renewable energy sources?

What size storage and solar units do we need?

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

Technical



Economic

Example Considerations



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

Example Considerations

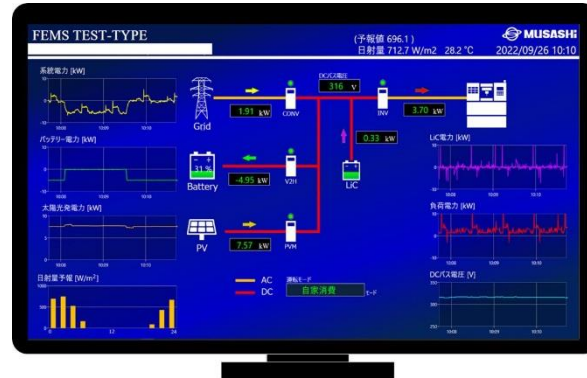
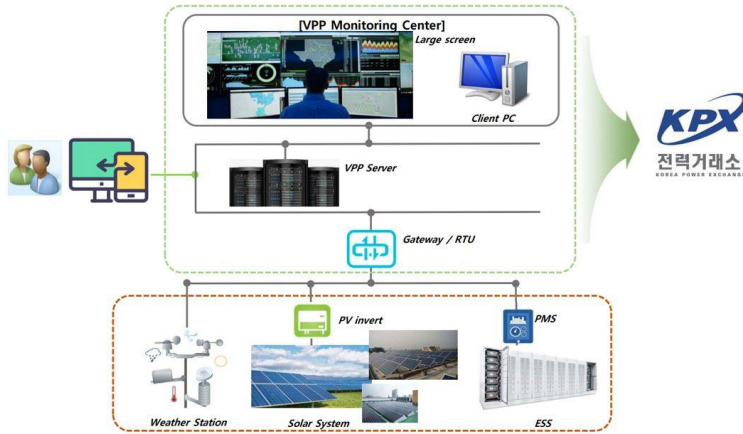


- Energy prices
- Equipment costs
- Maintenance costs
- Business commitments
- Energy trading

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

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

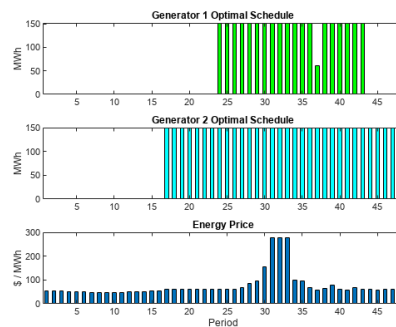
Otto von Guericke University Magdeburg optimized power flow and energy production

Products enabling workflows

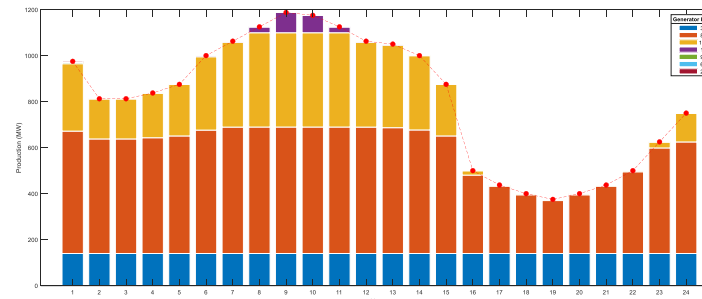
- Optimization Toolbox
- Statistics & Machine Learning Toolbox
- Simscape Electrical
- Simscape Battery
- Parallel Computing Toolbox

Examples

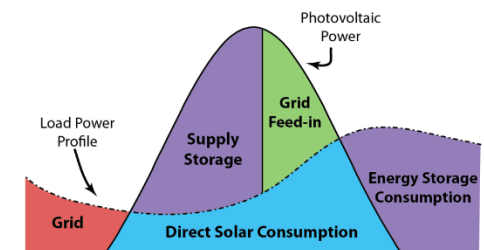
Optimal dispatch



Security-constrained unit commitment



Microgrid EMS

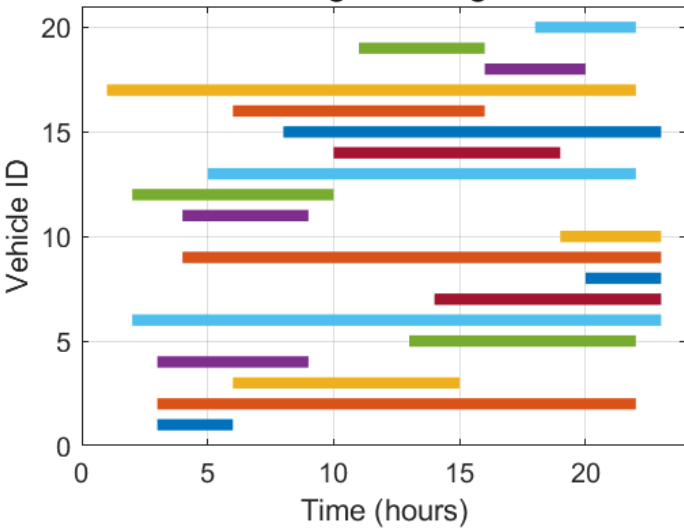


Apply techno-economic optimization to study the impact of EV charging on grid infrastructure

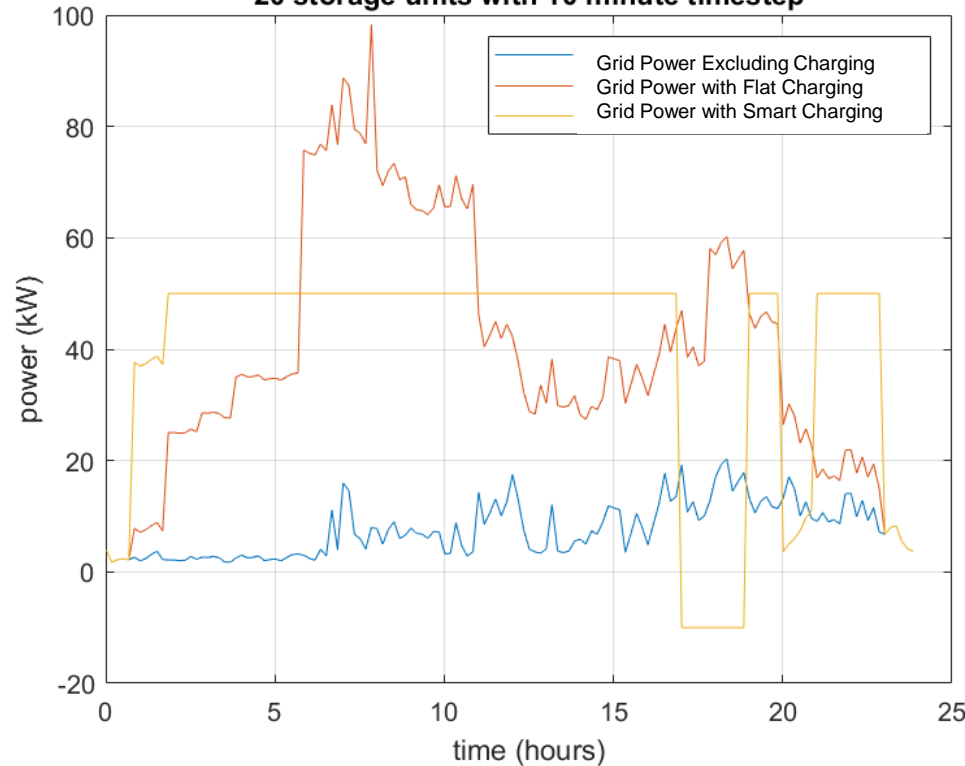
What if...

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

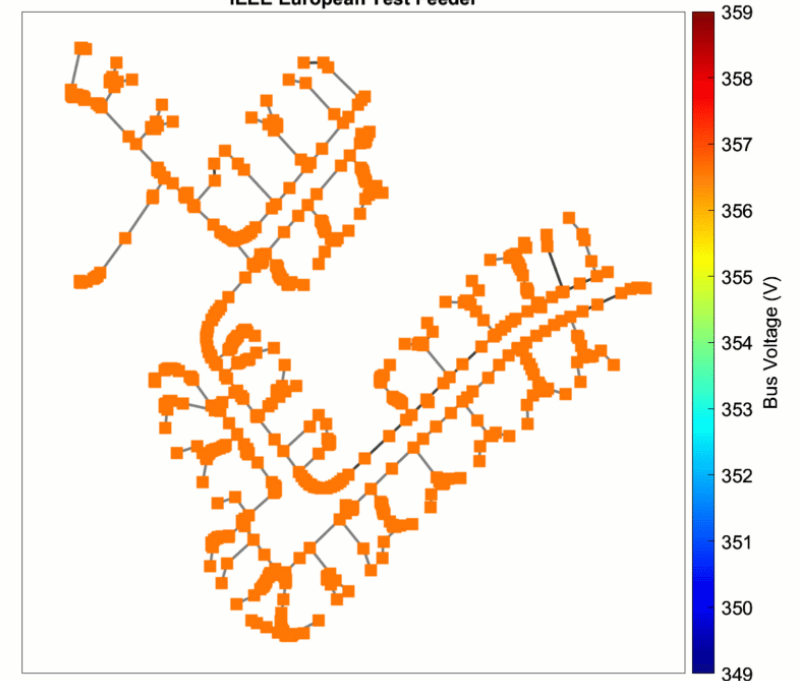
Plug-In Timing



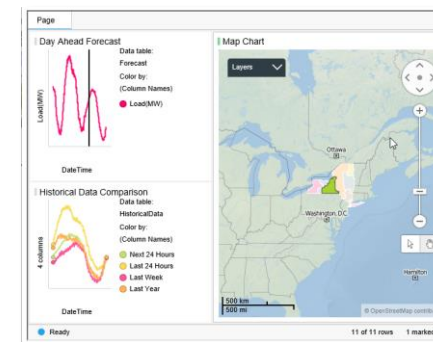
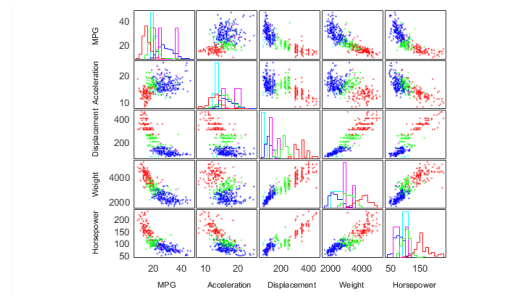
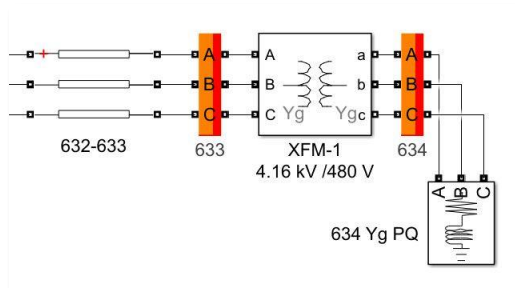
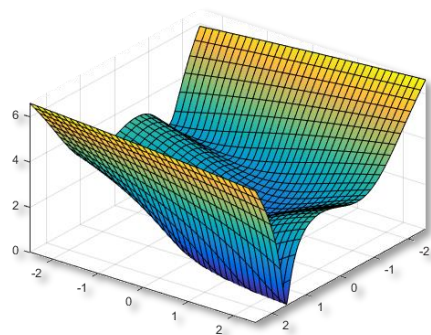
20 storage units with 10 minute timestep



IEEE European Test Feeder



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



Model and solve optimization

Grid Simulation

Grid Analysis and Visualization

Deploy Workflow

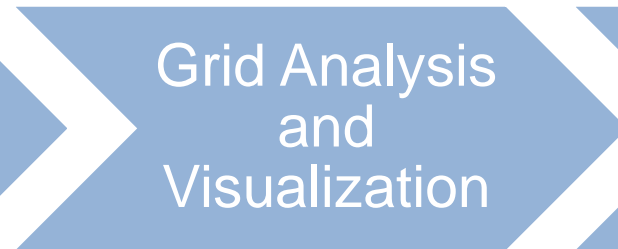
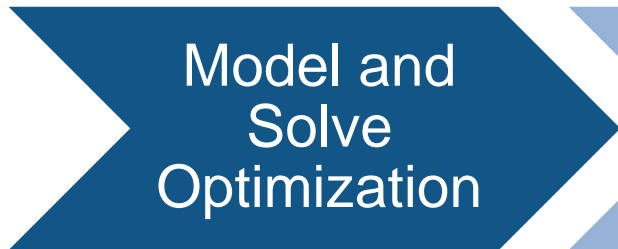
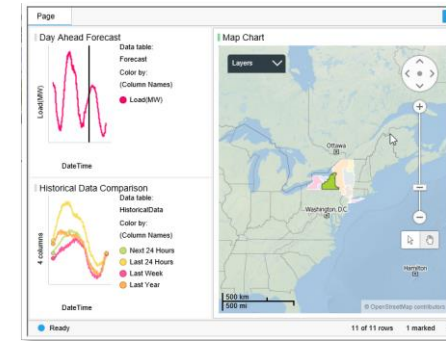
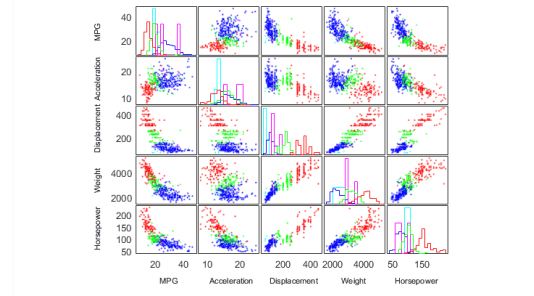
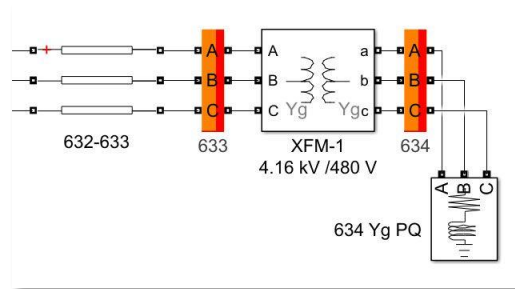
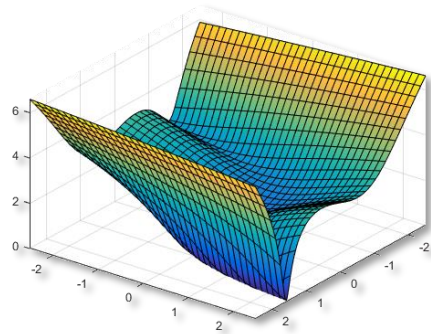
Optimization Toolbox

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



Optimization Toolbox

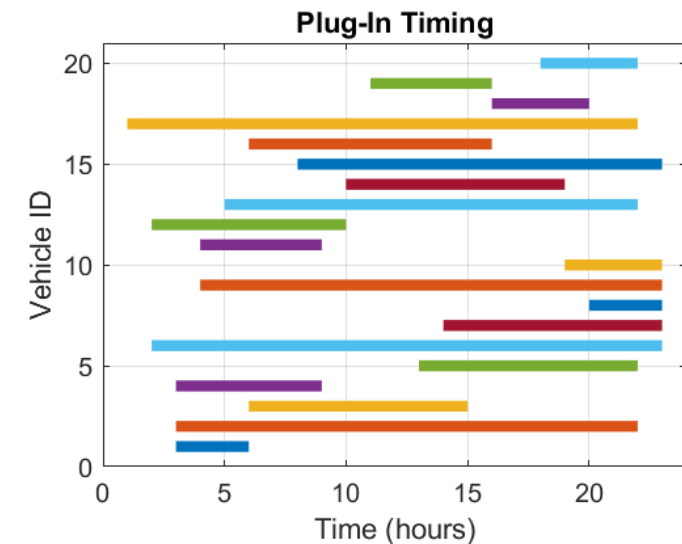
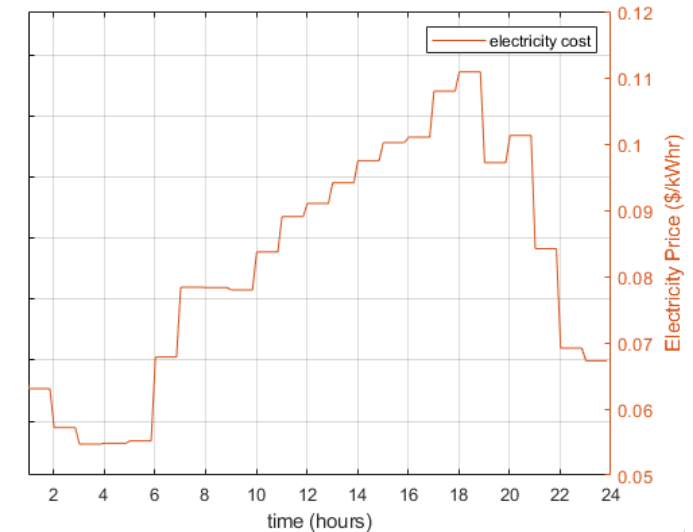
Simscape Electrical

Parallel Computing Toolbox
 Statistics & Machine Learning Toolbox

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

$$\min \leq \text{gridPower} \leq \max$$

```
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

$$\sum \text{storagePower} + \text{loadPower} = \text{gridPower}$$

```
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

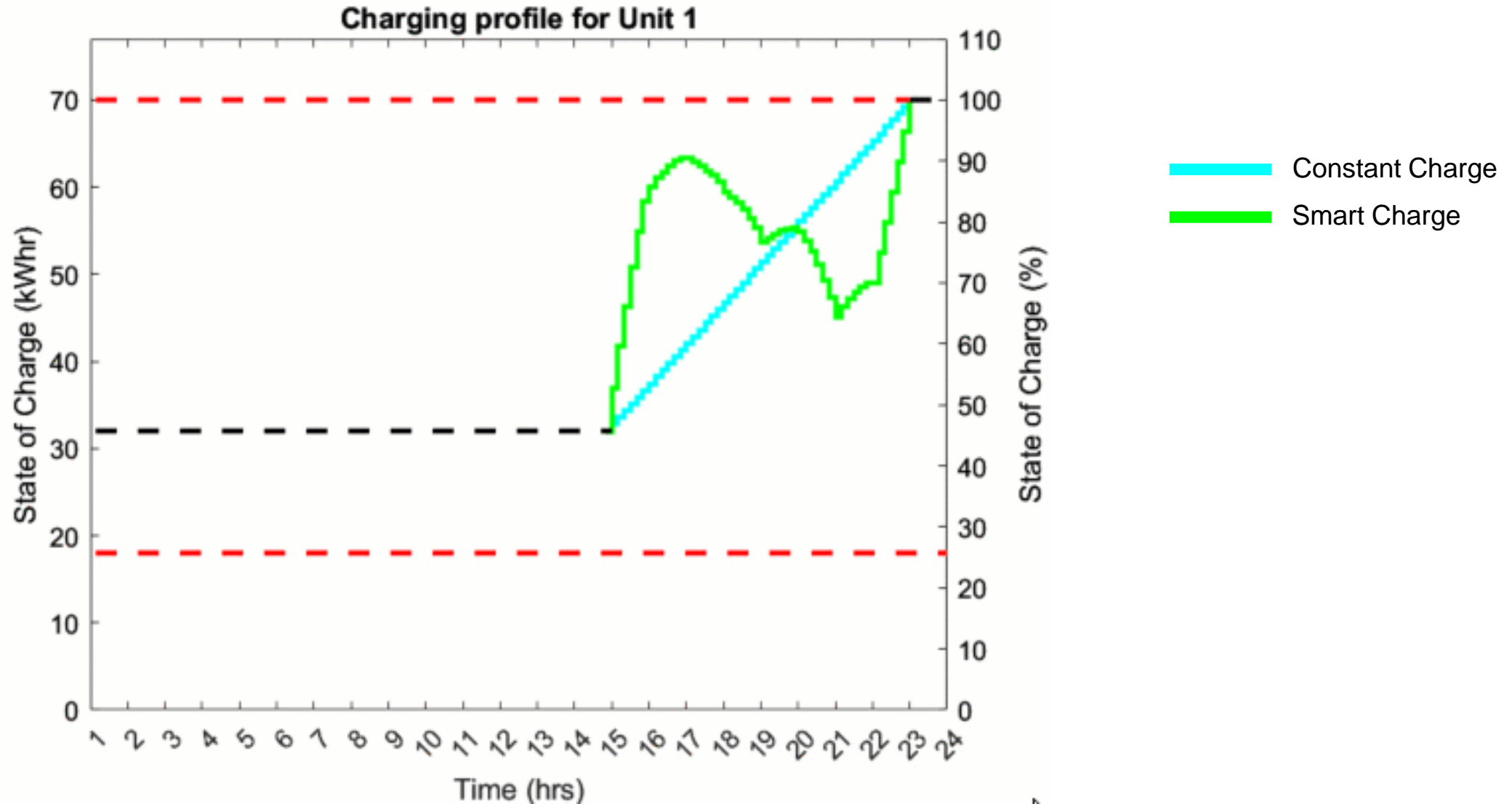
$$totalCost = gridPower \times price$$

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

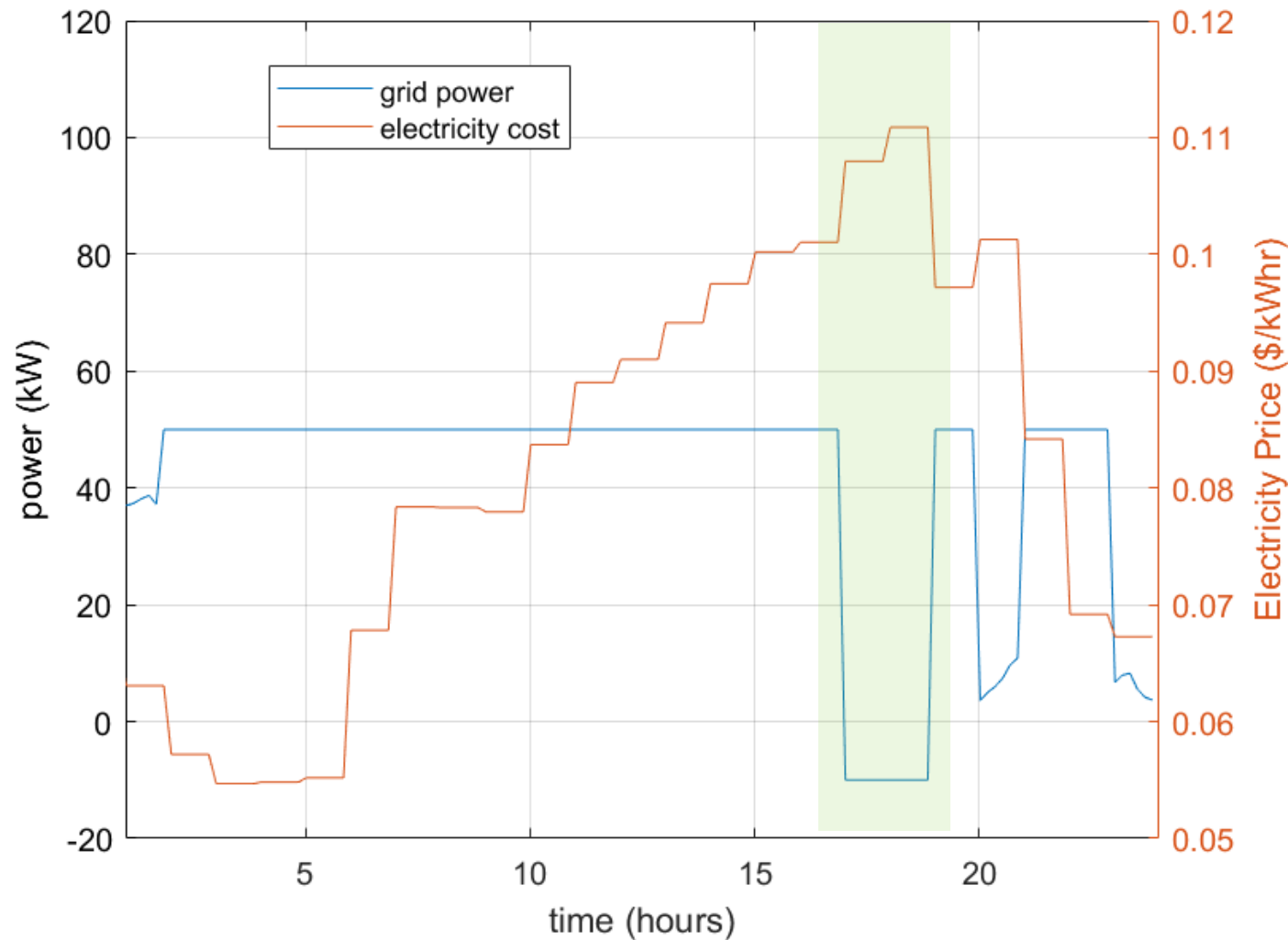
- Solve problem

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


Smart charging applies time-varying power for system benefit

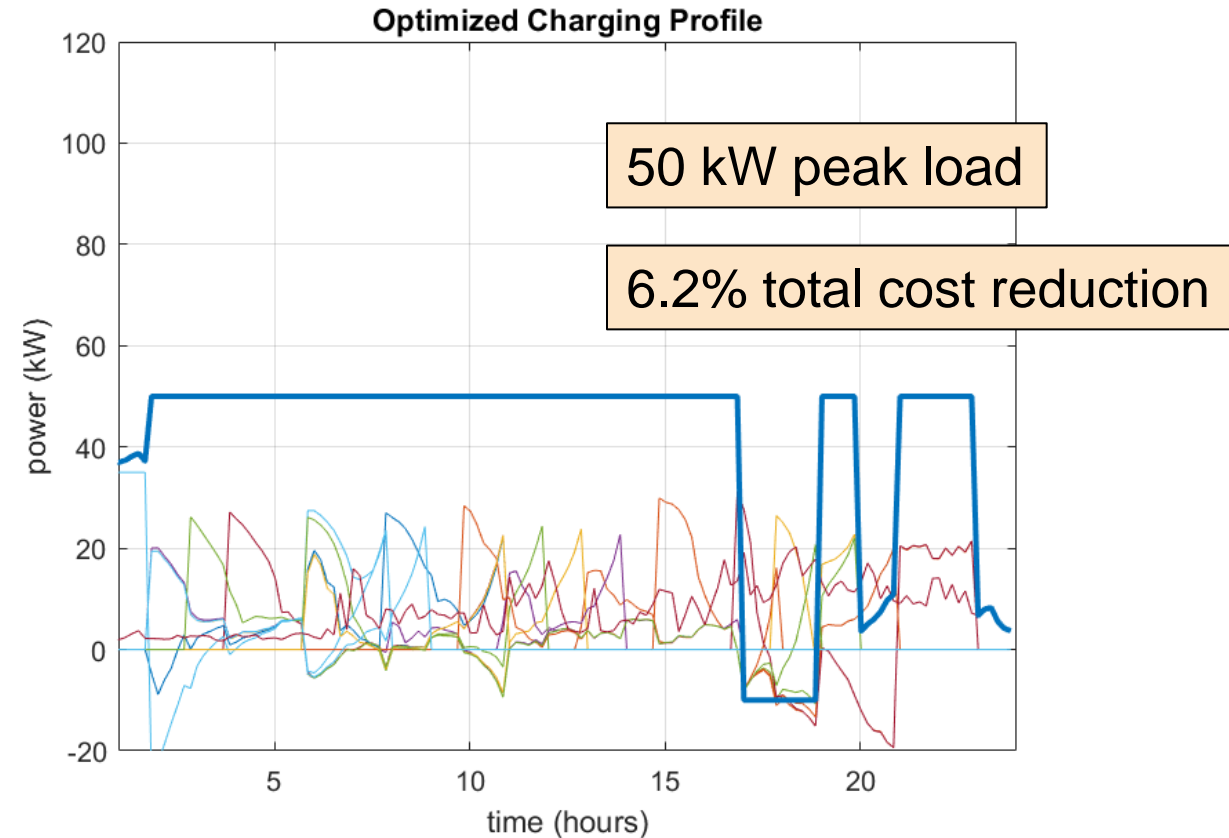
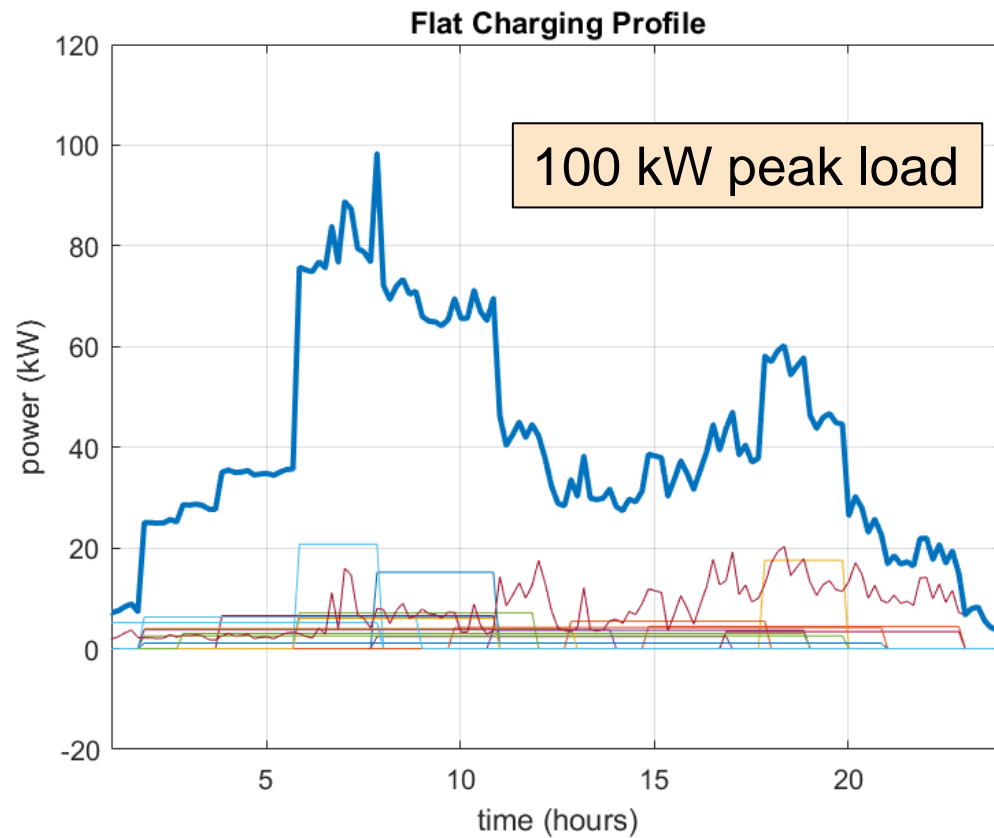


Smart charging feeds power back to grid when grid price is highest

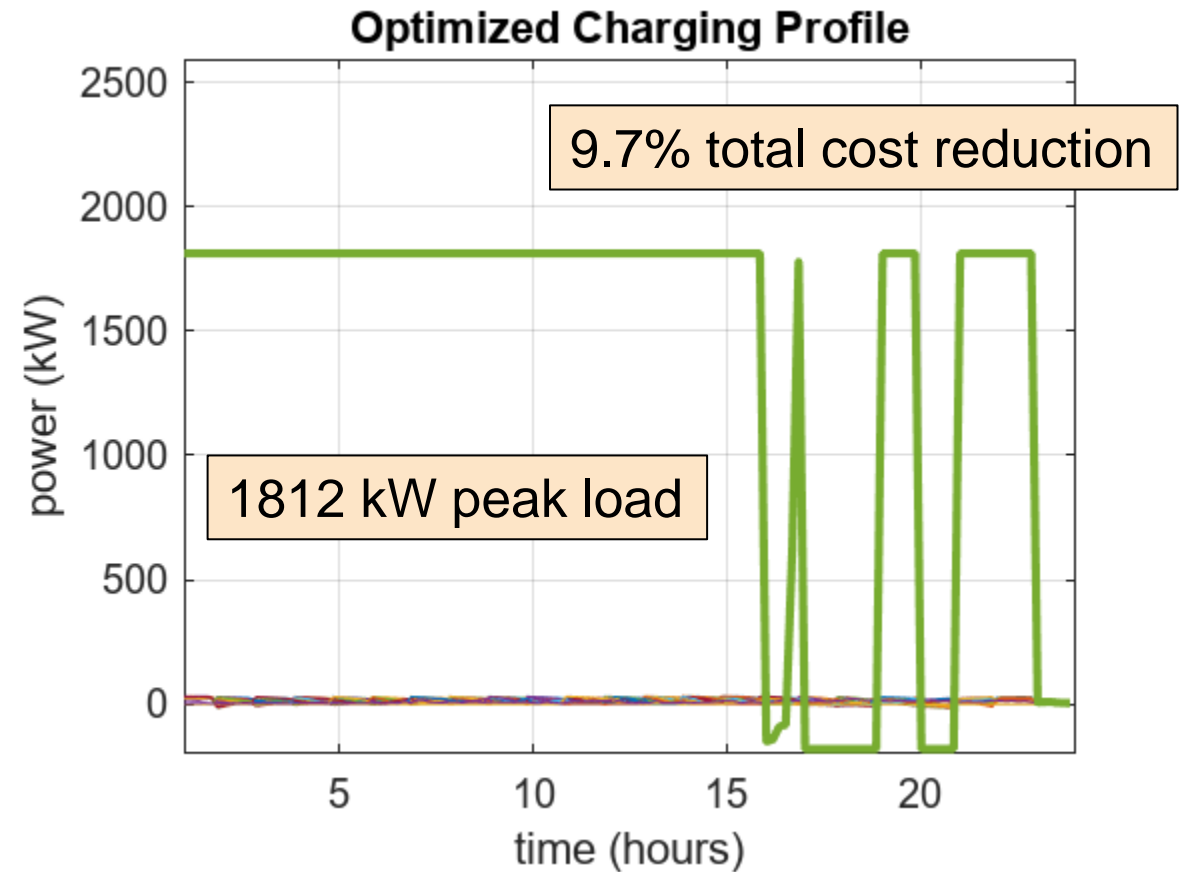
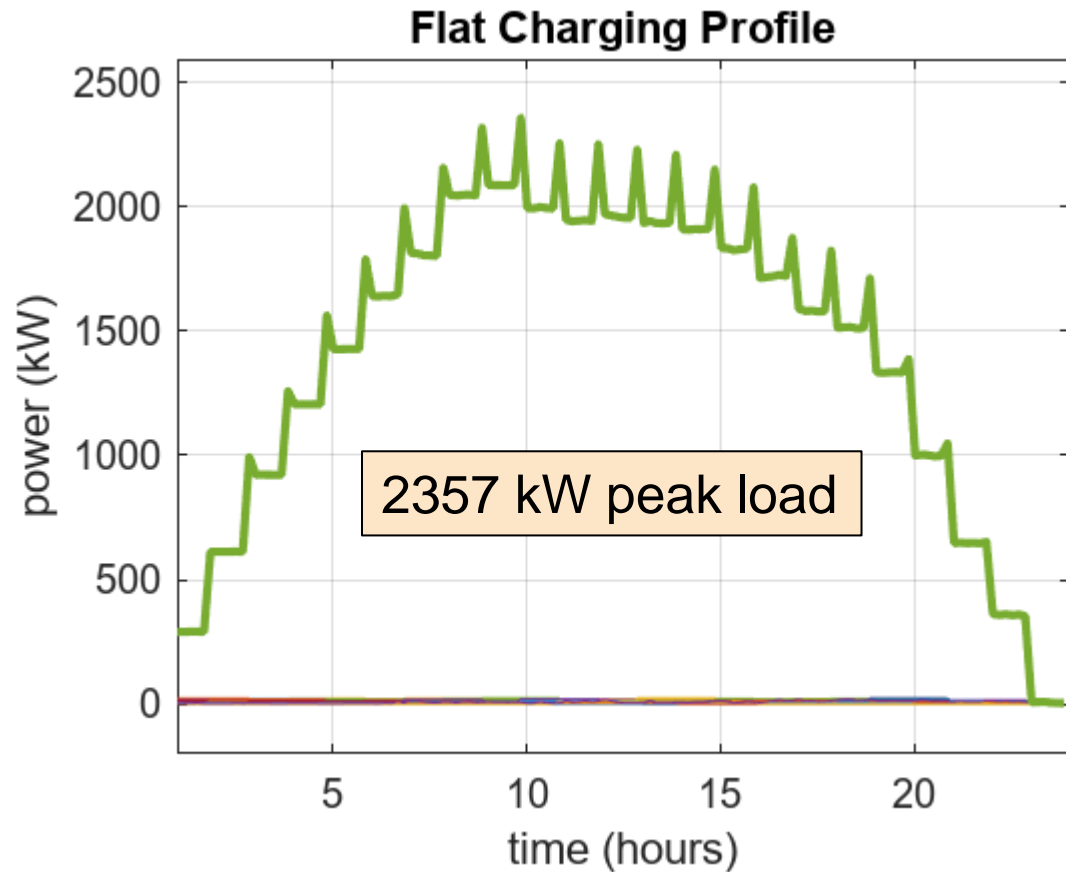


Smart charging is 6.2% cheaper than flat charging in this scenario

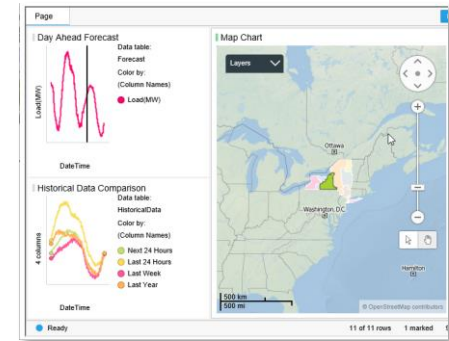
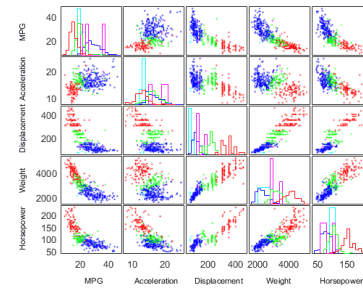
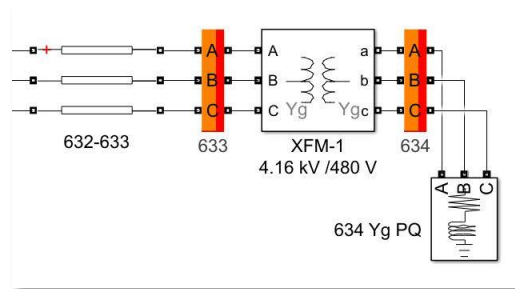
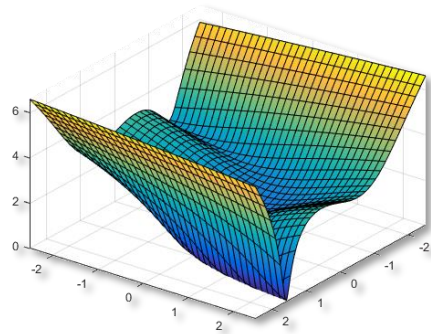
Optimized charging profile minimizes overall cost and limits peak load



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

Optimization Toolbox

Grid Simulation

Simscape Electrical

Grid Analysis and Visualization

Parallel Computing Toolbox
Statistics & Machine Learning Toolbox

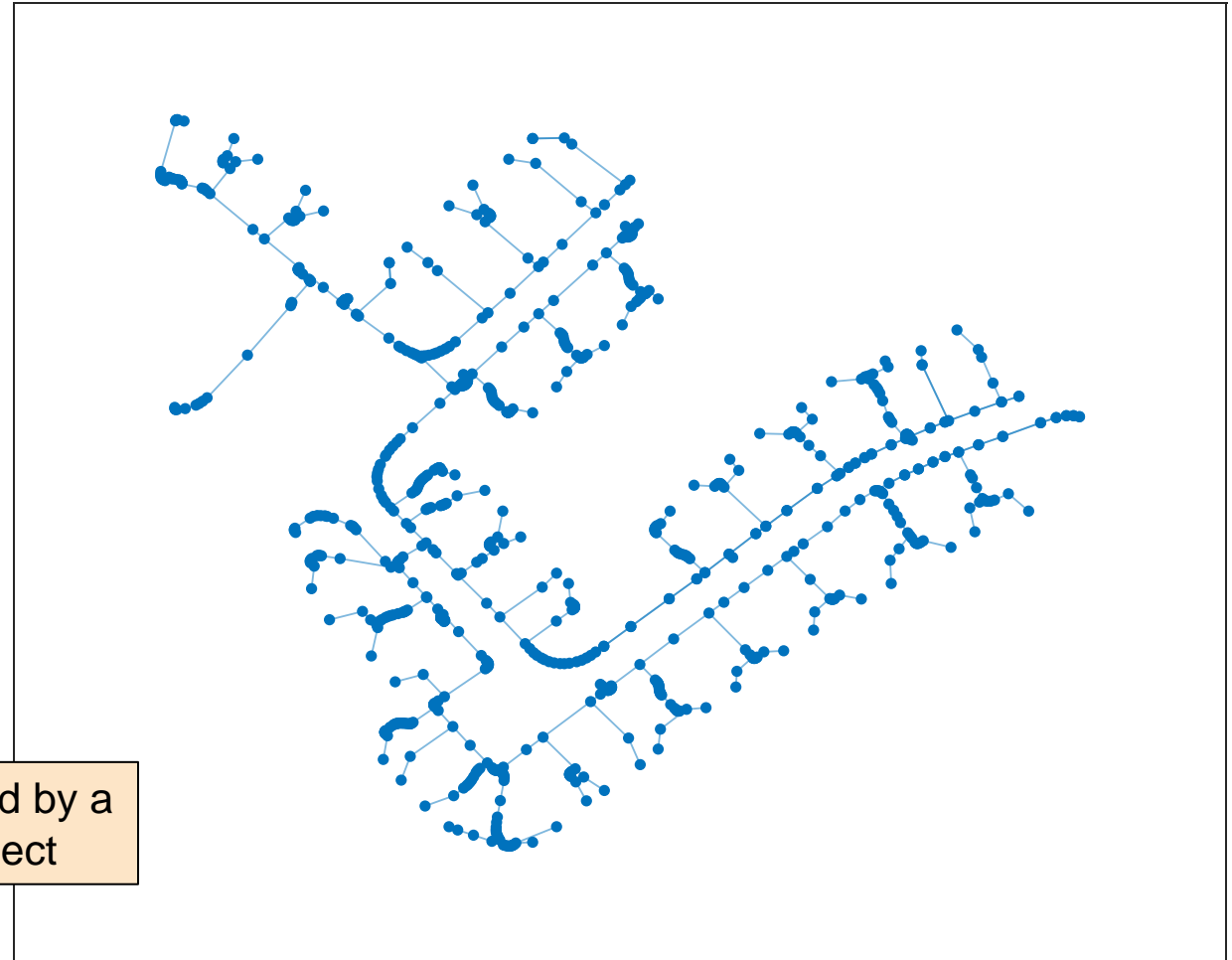
Deploy Workflow

App Designer
MATLAB Web App Server
MATLAB Compiler

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.

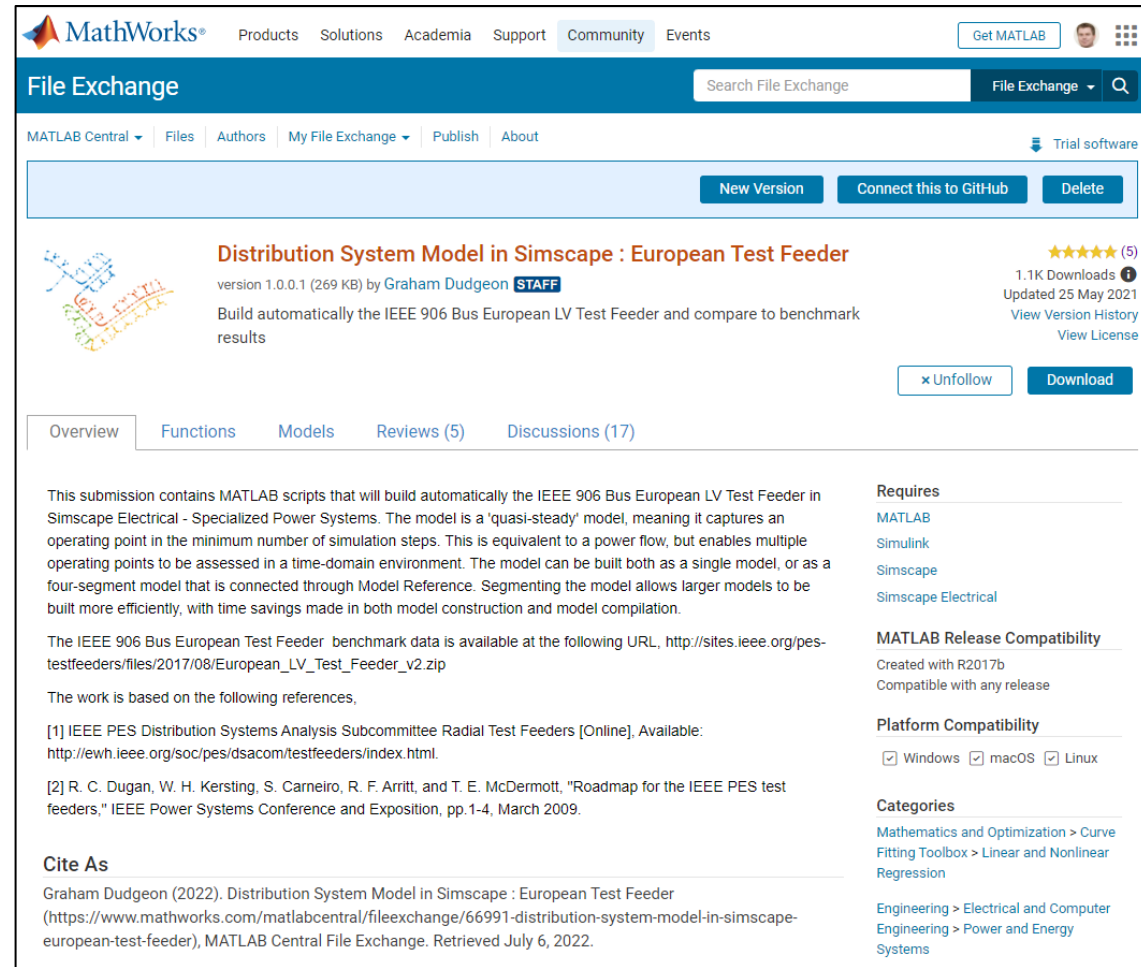
IEEE European Test Feeder



This image is rendered by a
MATLAB graph object

IEEE European Test Feeder

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



The screenshot shows the MathWorks File Exchange interface. At the top, there is a navigation bar with 'MathWorks' logo and links for Products, Solutions, Academia, Support, Community, and Events. A search bar is present on the right. Below the navigation bar, the page title is 'File Exchange'. The main content area features a card for the 'Distribution System Model in Simscape : European Test Feeder' by Graham Dudgeon, a staff member. The card includes a version number (1.0.0.1), file size (269 KB), and a description: 'Build automatically the IEEE 906 Bus European LV Test Feeder and compare to benchmark results'. It also shows a star rating of 5 stars, 1.1K downloads, and an update date of 25 May 2021. Action buttons for 'New Version', 'Connect this to GitHub', and 'Delete' are visible. Below the card, there are tabs for 'Overview', 'Functions', 'Models', 'Reviews (5)', and 'Discussions (17)'. The 'Overview' tab is selected, displaying a detailed description of the model, its requirements (MATLAB, Simulink, Simscape, Simscape Electrical), MATLAB release compatibility (R2017b), and platform compatibility (Windows, macOS, Linux). The 'Cite As' section provides a citation for the model.

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Distribution System Model in Simscape : European Test Feeder ★★★★★ (5)
1.1K Downloads Updated 25 May 2021
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version 1.0.0.1 (269 KB) by **Graham Dudgeon** **STAFF**

Build automatically the IEEE 906 Bus European LV Test Feeder and compare to benchmark results

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Overview Functions Models Reviews (5) Discussions (17)

This submission contains MATLAB scripts that will build automatically the IEEE 906 Bus European LV Test Feeder in Simscape Electrical - Specialized Power Systems. The model is a 'quasi-steady' model, meaning it captures an operating point in the minimum number of simulation steps. This is equivalent to a power flow, but enables multiple operating points to be assessed in a time-domain environment. The model can be built both as a single model, or as a four-segment model that is connected through Model Reference. Segmenting the model allows larger models to be built more efficiently, with time savings made in both model construction and model compilation.

The IEEE 906 Bus European Test Feeder benchmark data is available at the following URL, http://sites.ieee.org/pes-testfeeders/files/2017/08/European_LV_Test_Feeder_v2.zip

The work is based on the following references,

[1] IEEE PES Distribution Systems Analysis Subcommittee Radial Test Feeders [Online], Available: <http://ewh.ieee.org/soc/pes/dsacom/testfeeders/index.html>.

[2] R. C. Dugan, W. H. Kersting, S. Carneiro, R. F. Arritt, and T. E. McDermott, "Roadmap for the IEEE PES test feeders," IEEE Power Systems Conference and Exposition, pp.1-4, March 2009.

Cite As

Graham Dudgeon (2022). Distribution System Model in Simscape : European Test Feeder (<https://www.mathworks.com/matlabcentral/fileexchange/66991-distribution-system-model-in-simscape-european-test-feeder>), MATLAB Central File Exchange. Retrieved July 6, 2022.

Requires

MATLAB
Simulink
Simscape
Simscape Electrical

MATLAB Release Compatibility

Created with R2017b
Compatible with any release

Platform Compatibility

Windows macOS Linux

Categories

Mathematics and Optimization > Curve Fitting Toolbox > Linear and Nonlinear Regression

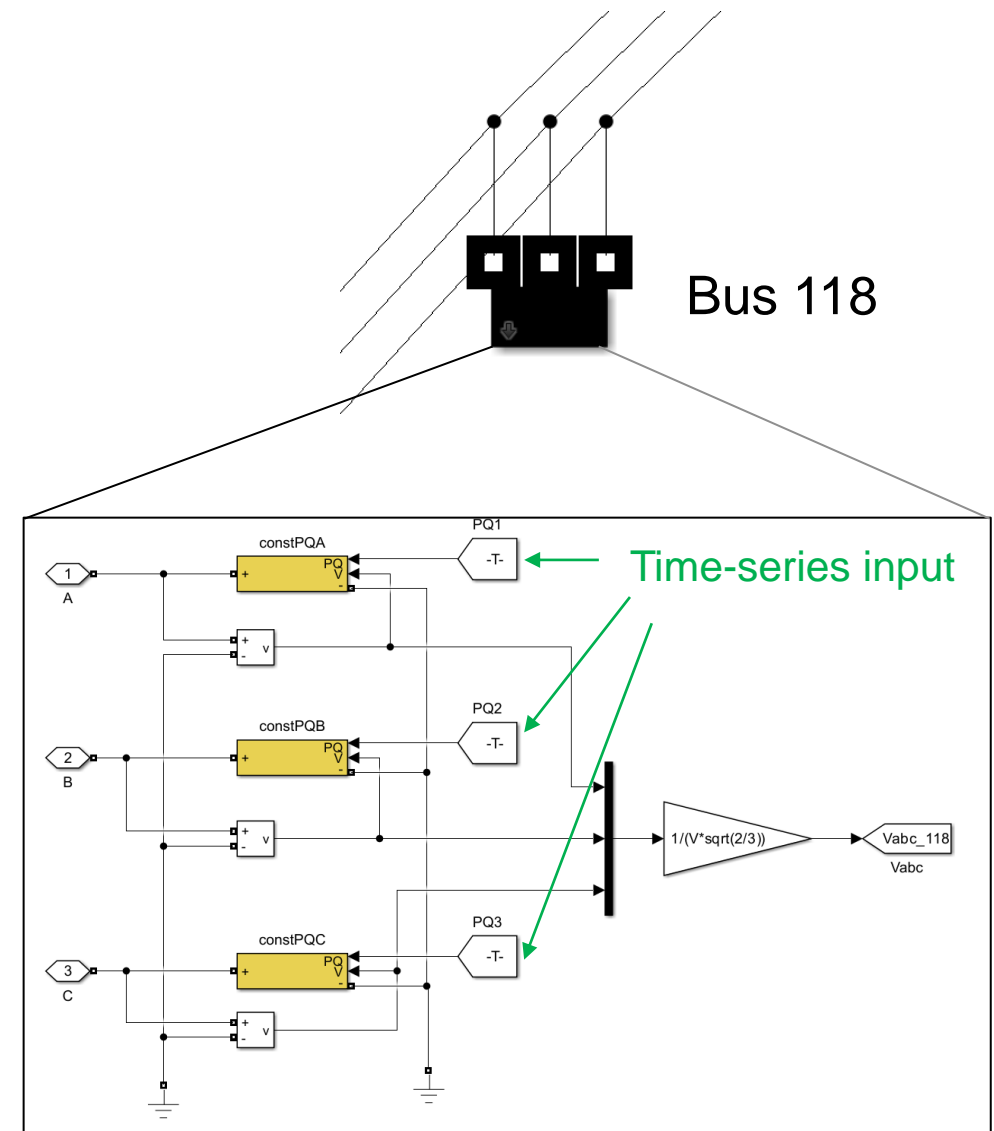
Engineering > Electrical and Computer Engineering > Power and Energy Systems

<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.

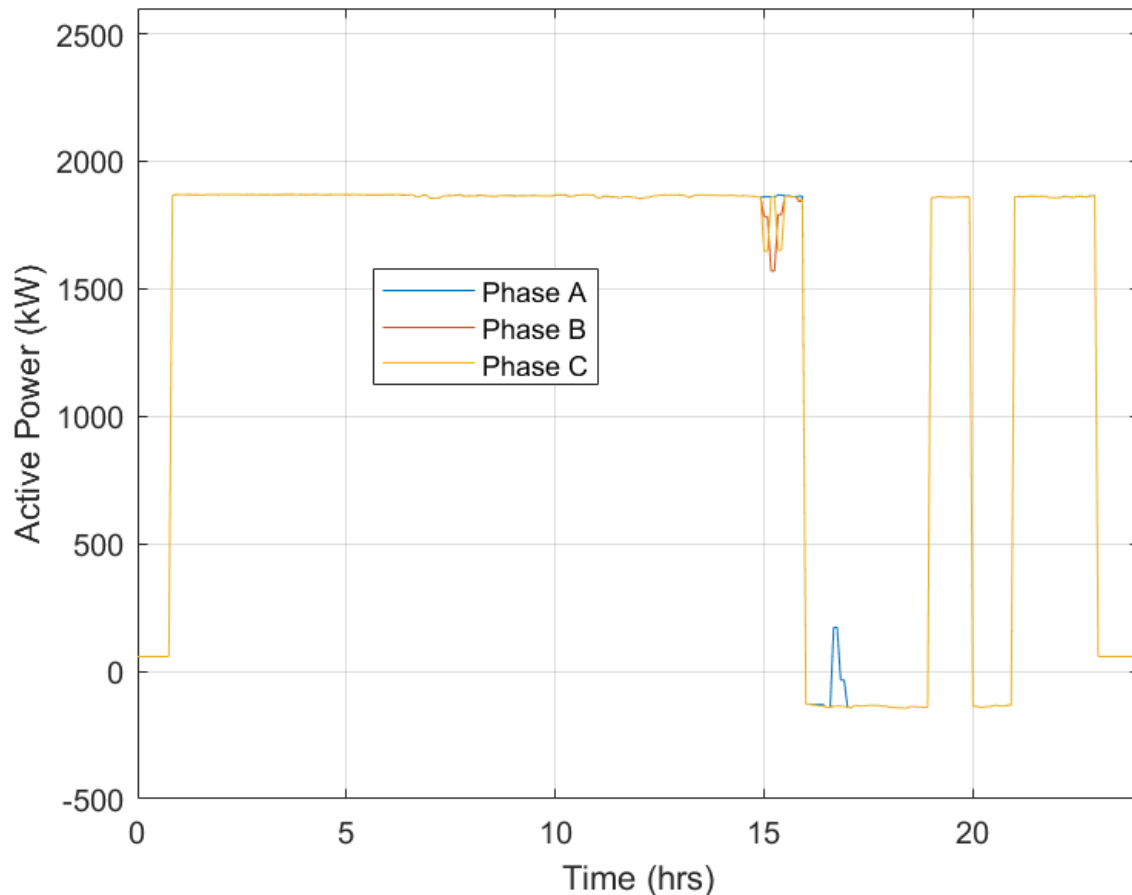
Our first scenario is where each of the 2718 nodes has a storage unit, and we optimize each phase separately. There are 906 storage units per phase...



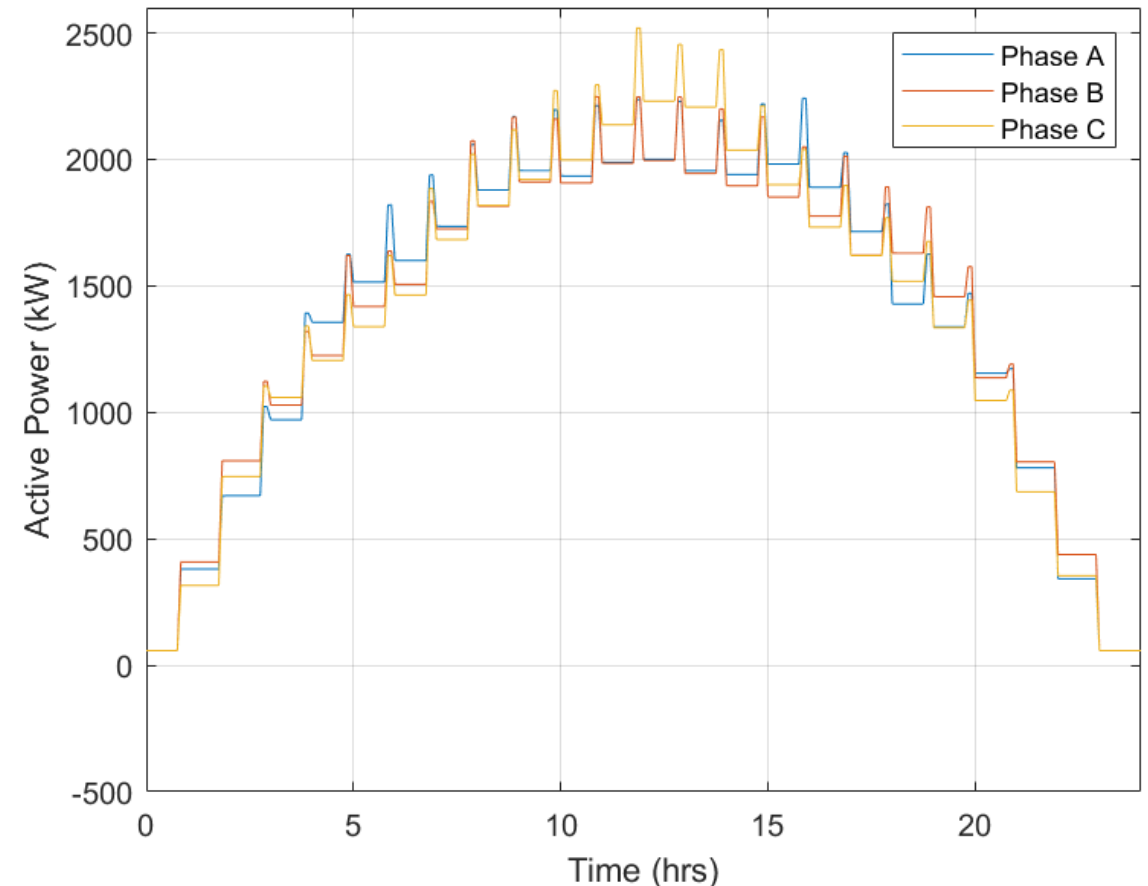
Configure grid simulation for scenario evaluation

With $T_s = 300s$, 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.

Substation Active Power - Smart Profile

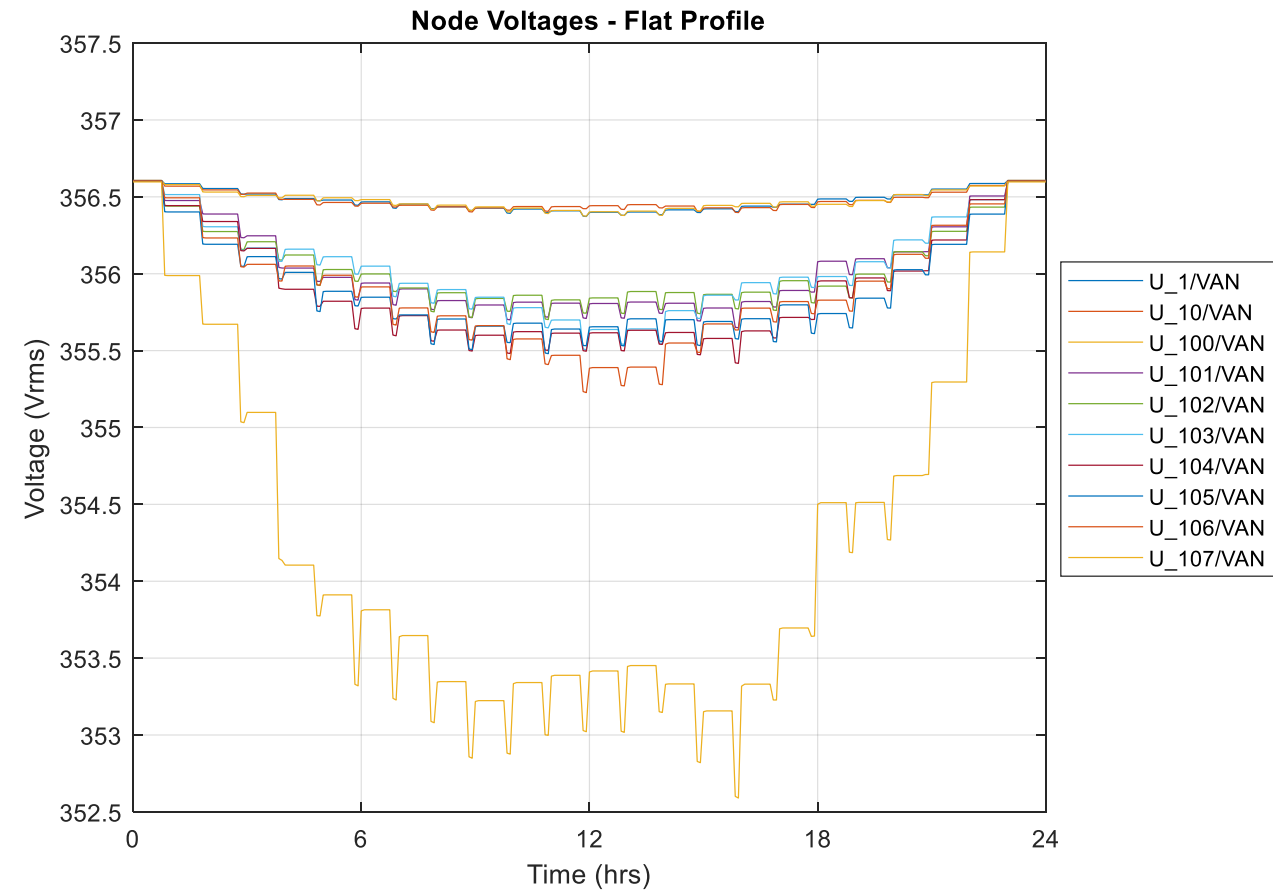
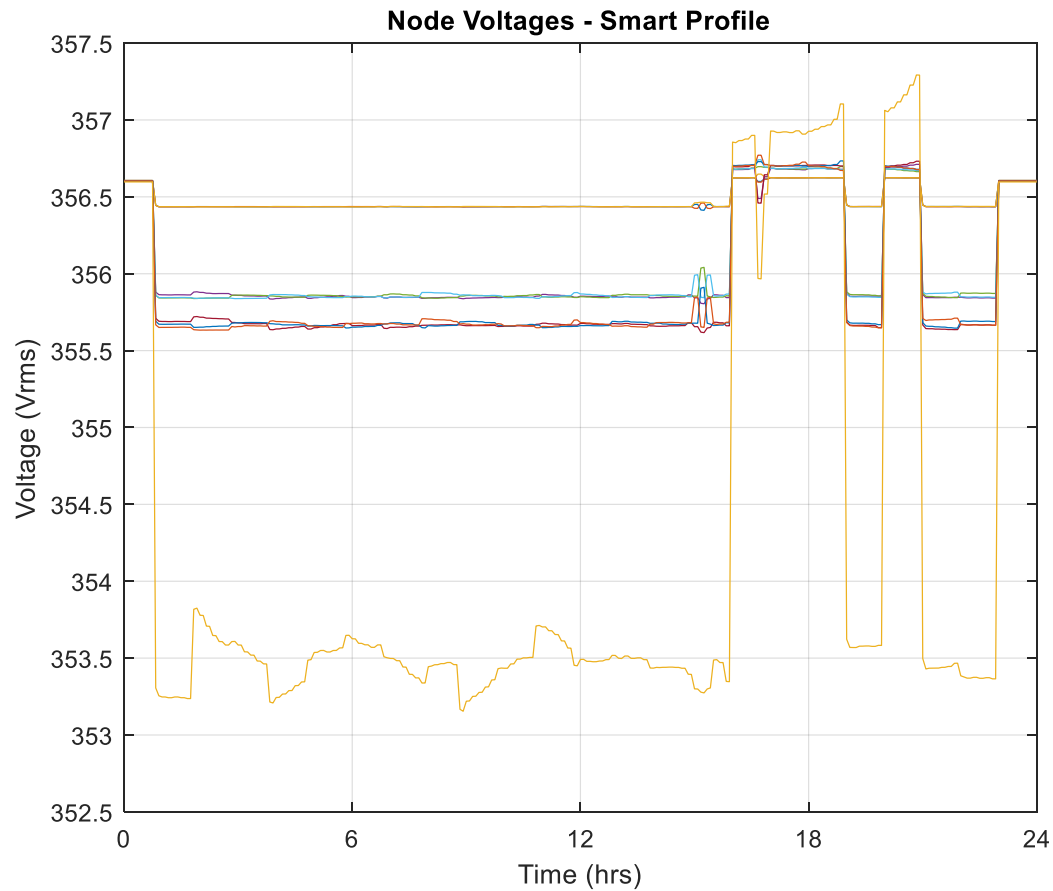


Substation Active Power - Flat Profile

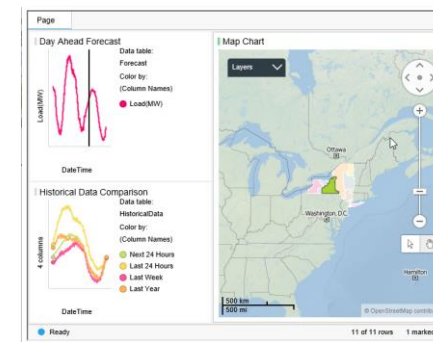
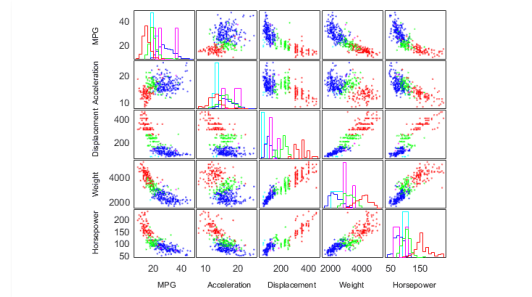
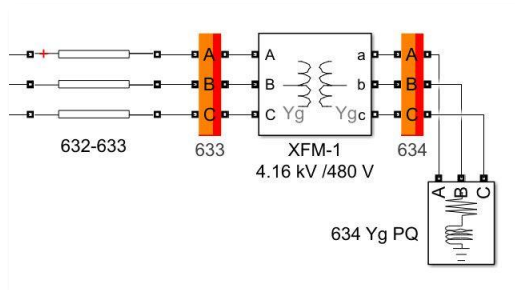
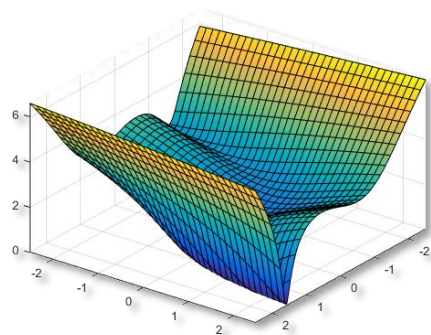


Configure grid simulation for scenario evaluation

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



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



Model and Solve Optimization

Grid Simulation

Grid Analysis and Visualization

Deploy Workflow

Optimization Toolbox

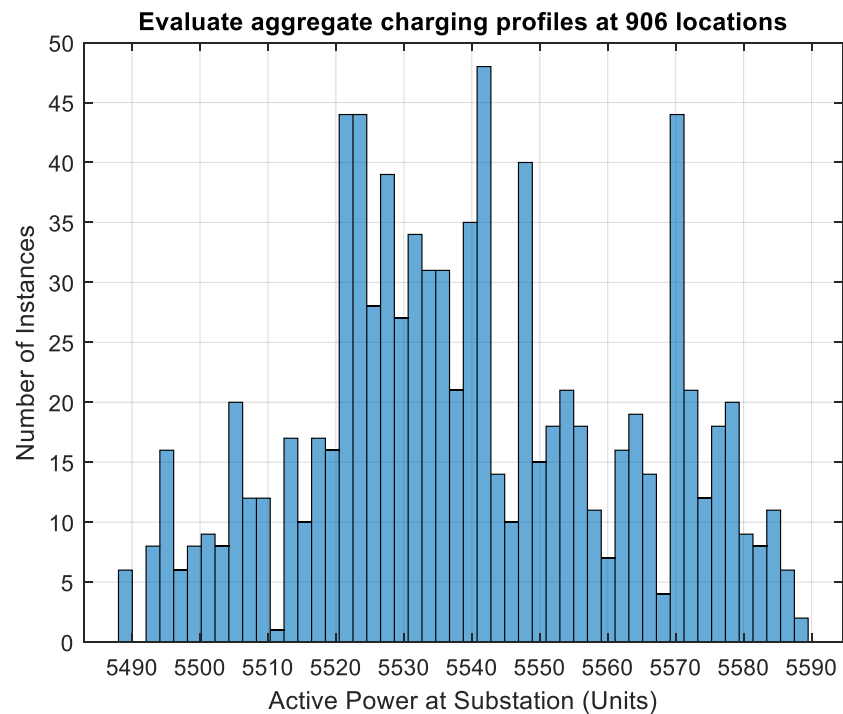
Simscape Electrical

Parallel Computing Toolbox
Statistics & Machine Learning Toolbox

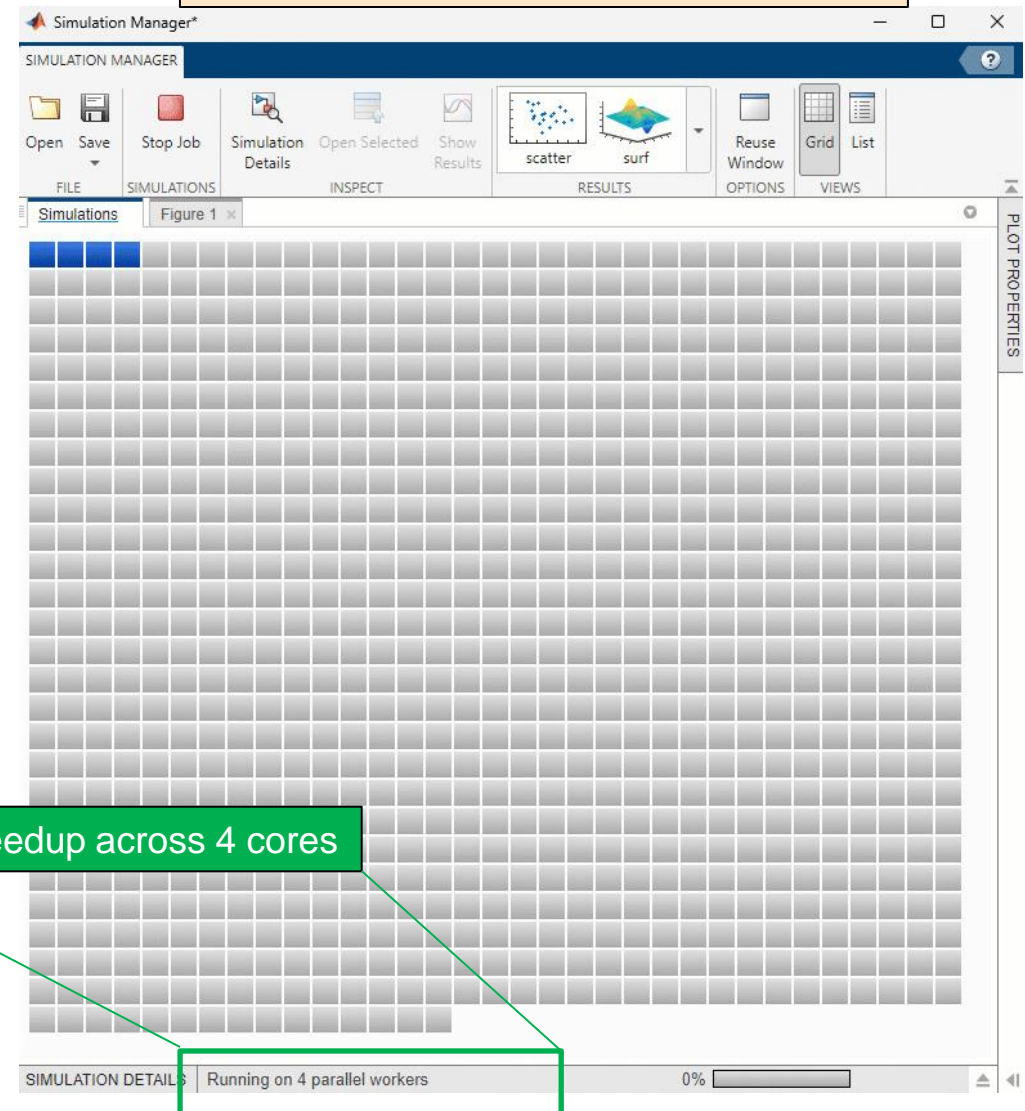
App Designer
MATLAB Web App Server
MATLAB Compiler

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.

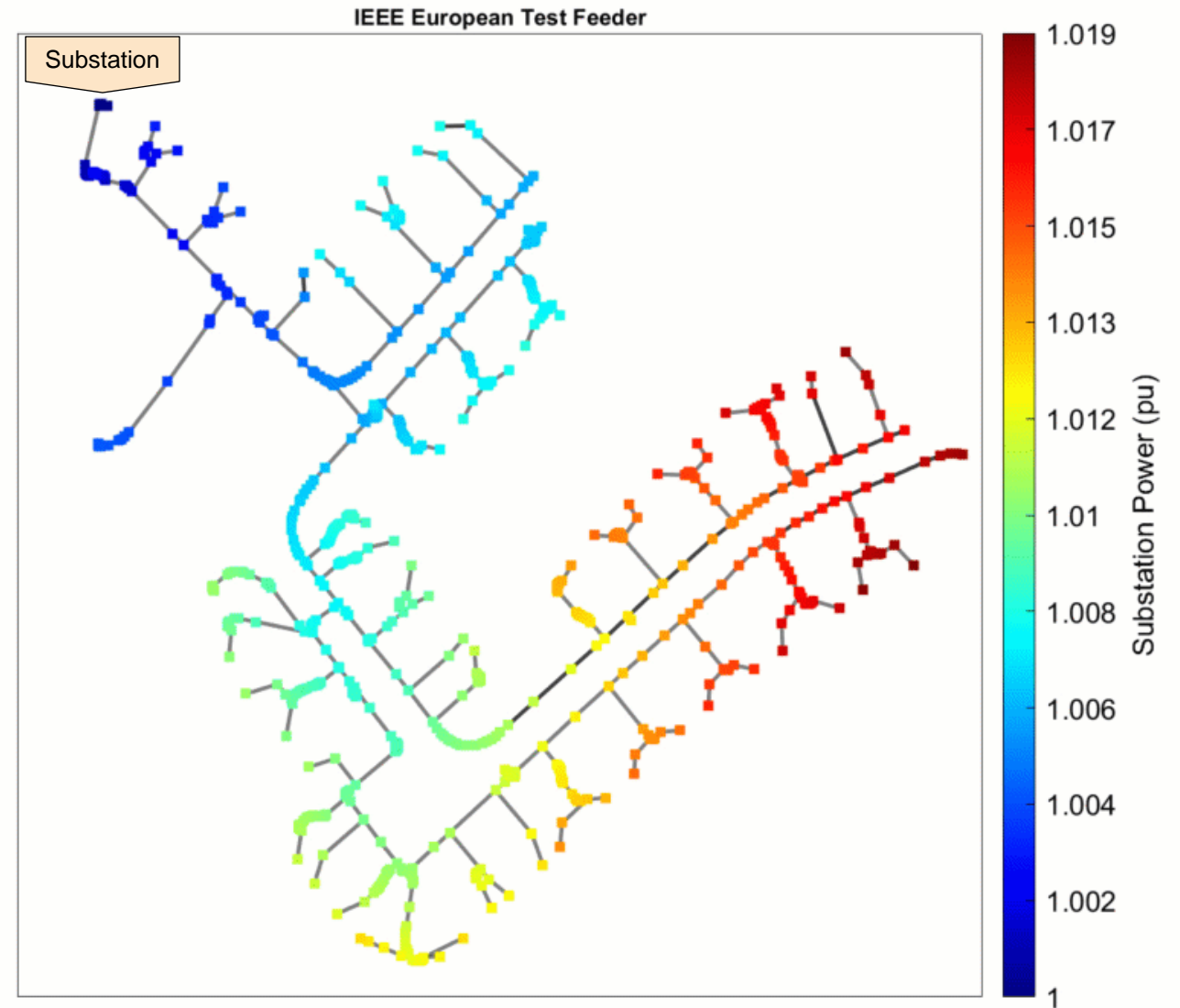
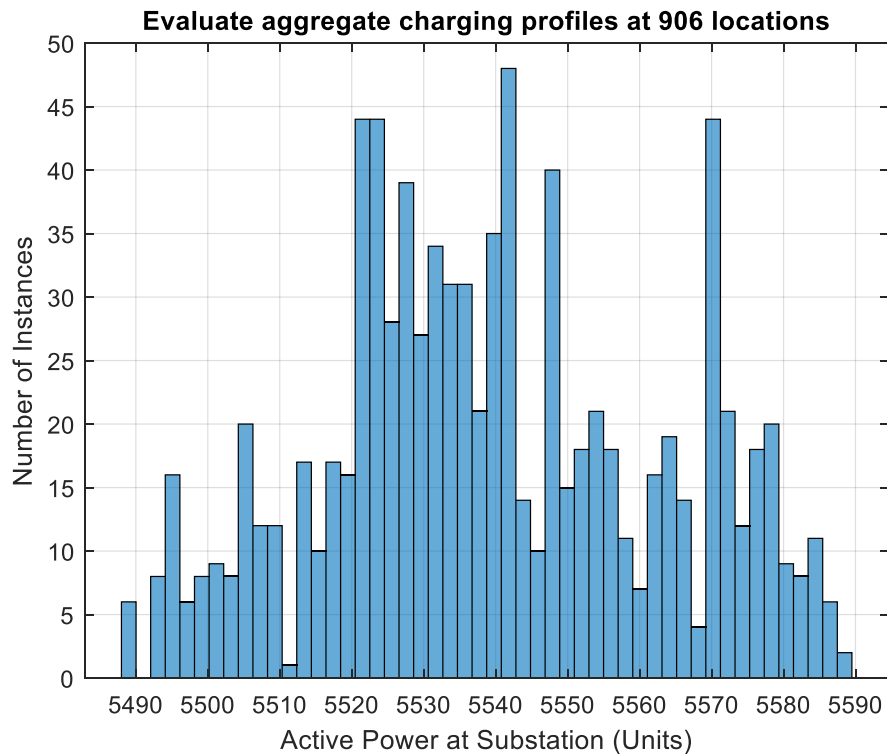


Animation speed up x60 of 906 scenarios

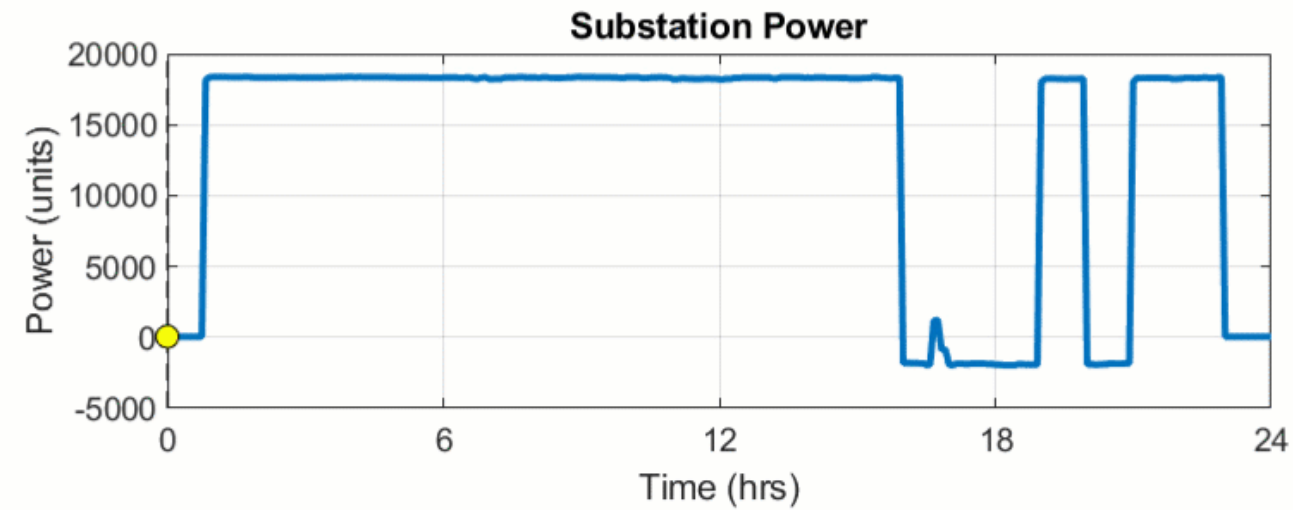


Multiple scenarios on multiple cores

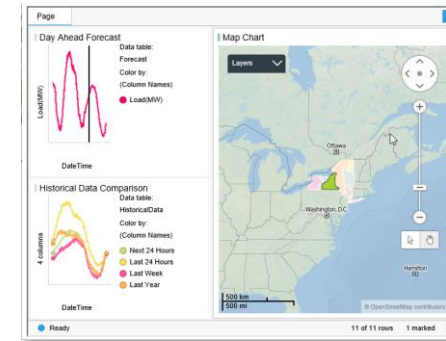
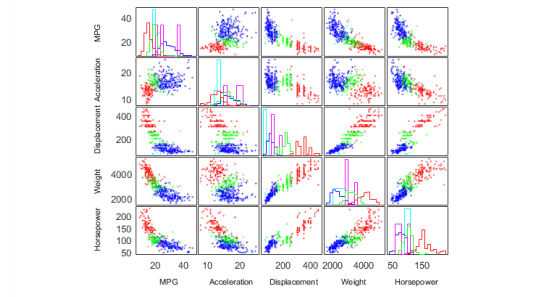
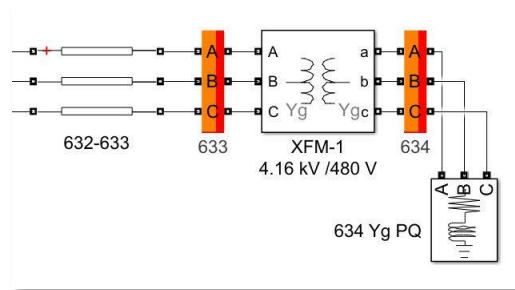
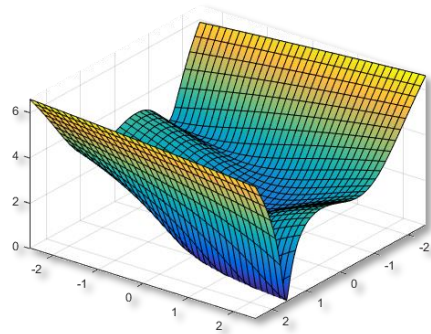
Statistical analysis and visualization enhances our understanding of the grid impact



Enhanced visualization - voltage levels across 24 hours



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



Model and Solve Optimization

Grid Simulation

Grid Analysis and Visualization

Deploy Workflow

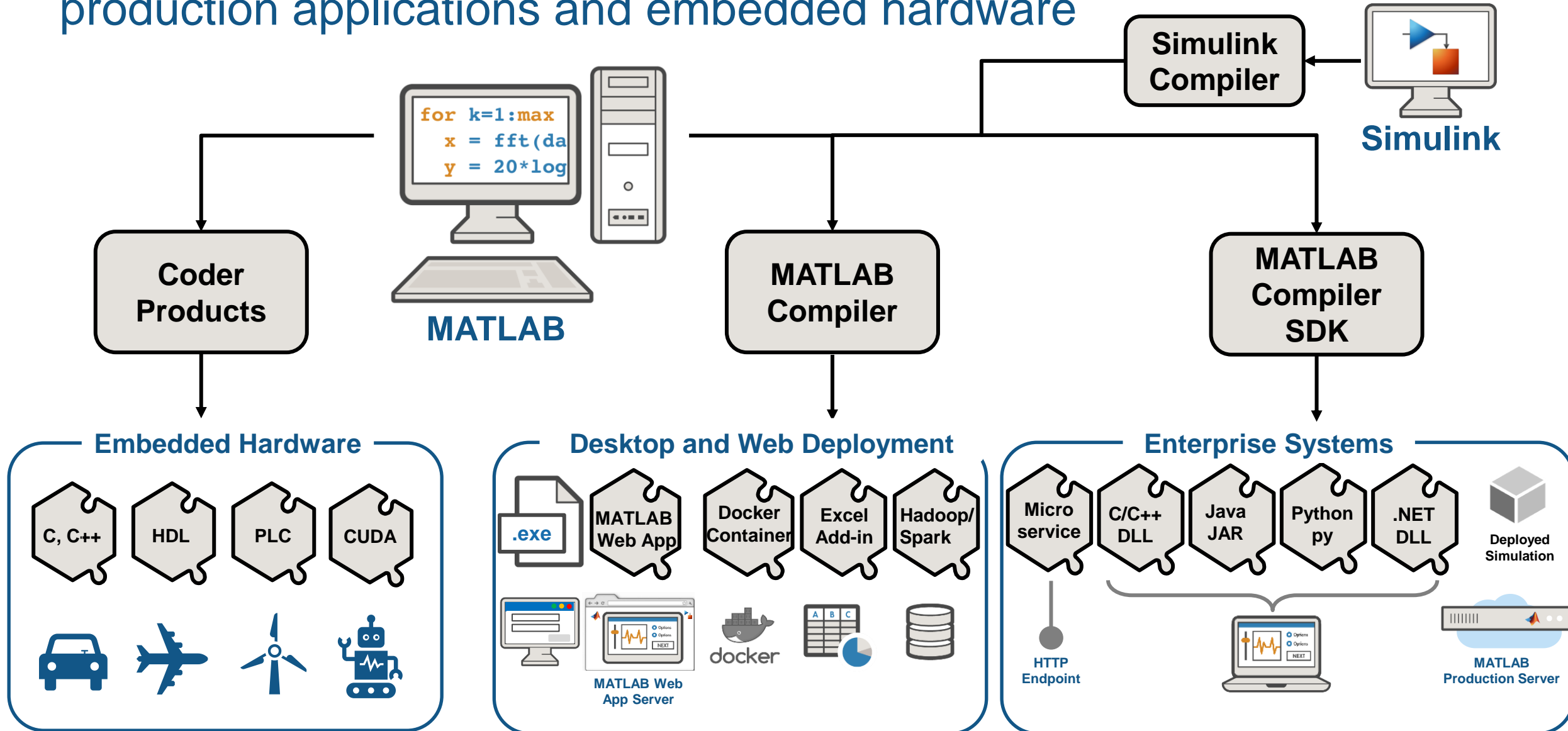
Optimization Toolbox

Simscape Electrical

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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



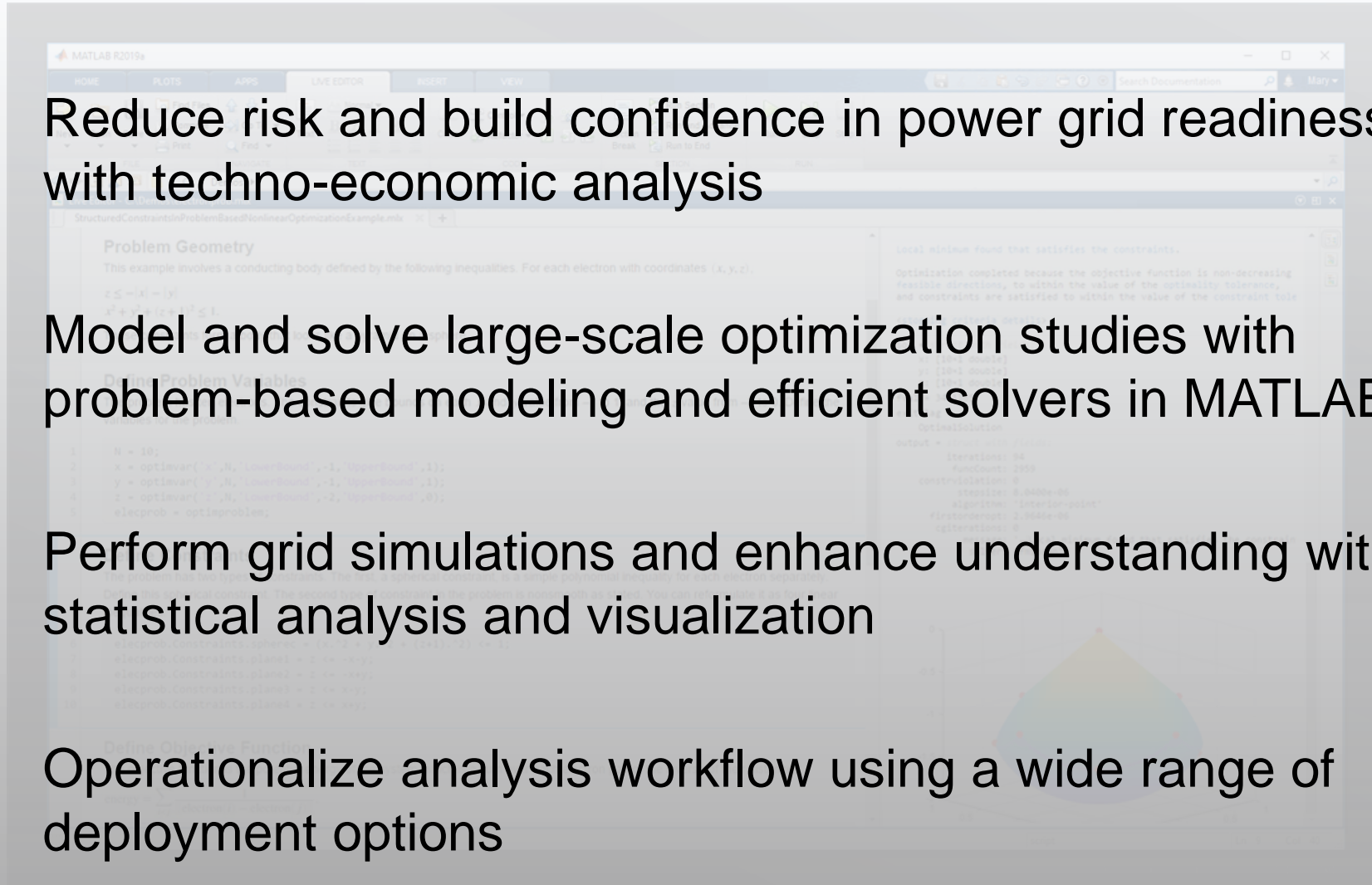
Model and solve large-scale optimization studies with problem-based modeling and efficient solvers in MATLAB



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

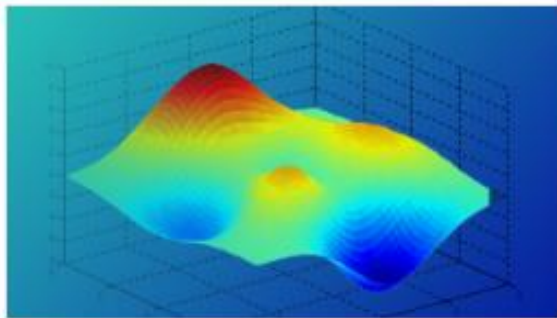


[Optimization Onramp](#)



[Simscape Onramp](#)

Instructor-led Training

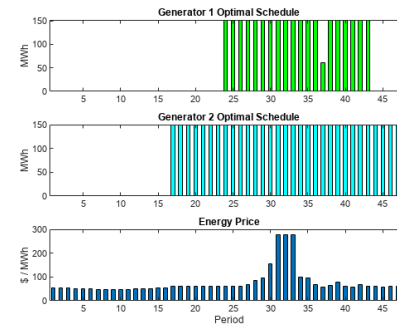


[Optimization Techniques in MATLAB](#)

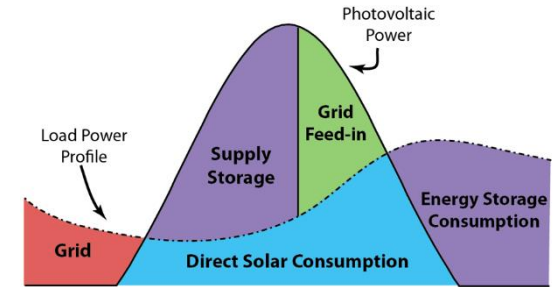


[Modeling Electrical Power Systems with Simscape](#)

Examples



[Optimal Dispatch](#)

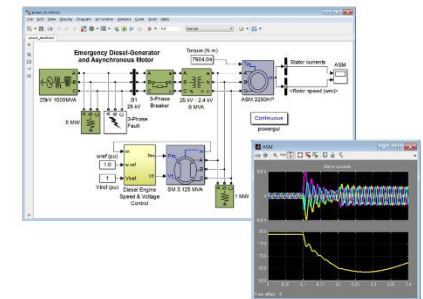


[Microgrid EMS](#)

Consulting Solutions



[Load Forecasting](#)



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MATLAB EXPO

Thank you



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