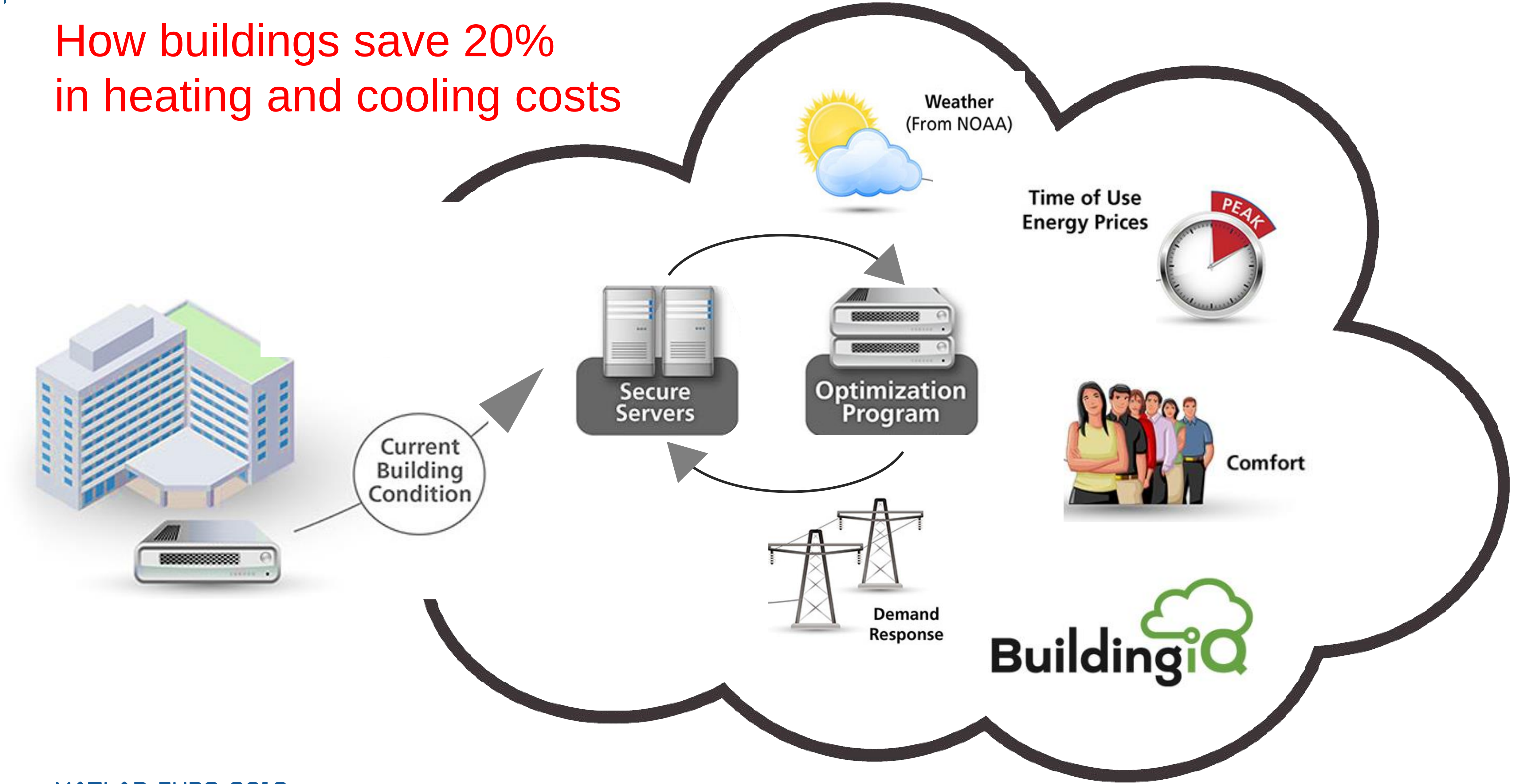
MATLAB EXPO 2019

Optimization in Energy Management Systems

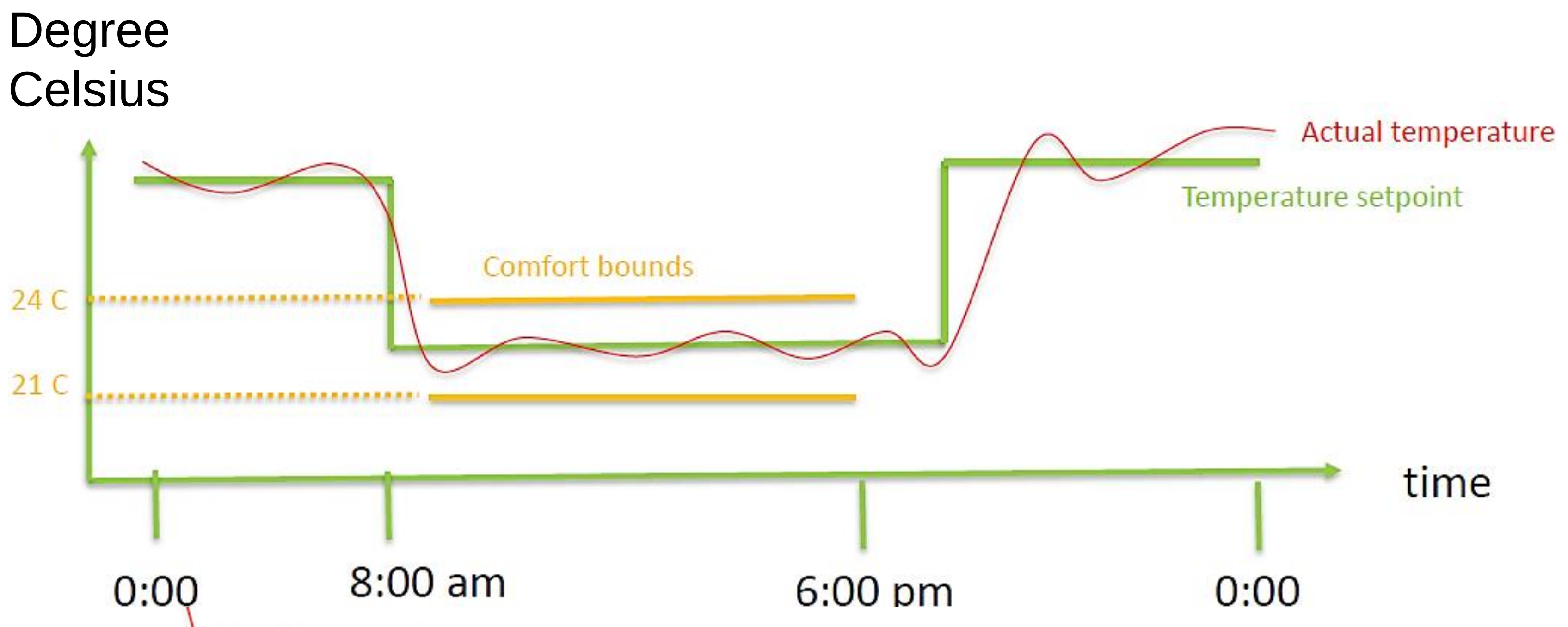
Souvick Chatterjee, PhD

How buildings save 20% in heating and cooling costs



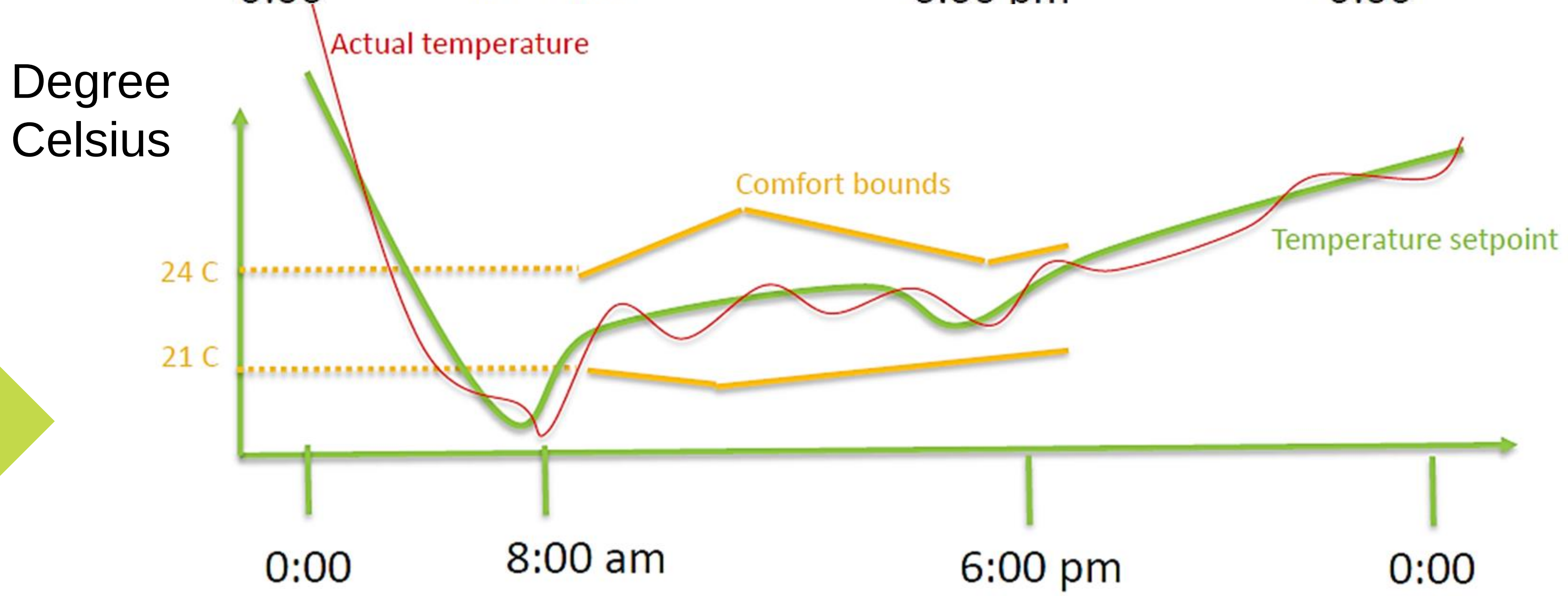
BuildingIQ

Traditional EMS



Smart EMS

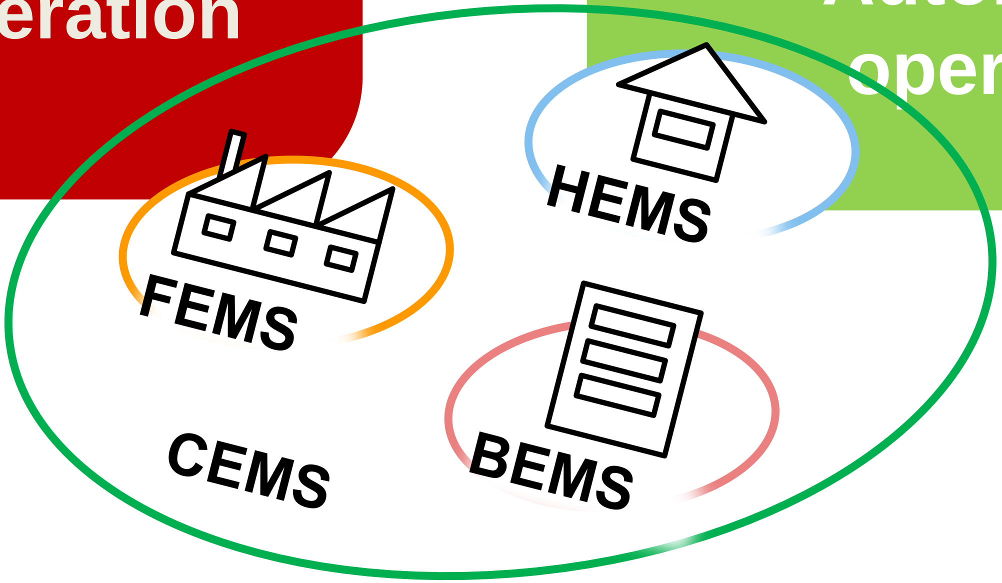
25% cost reduction

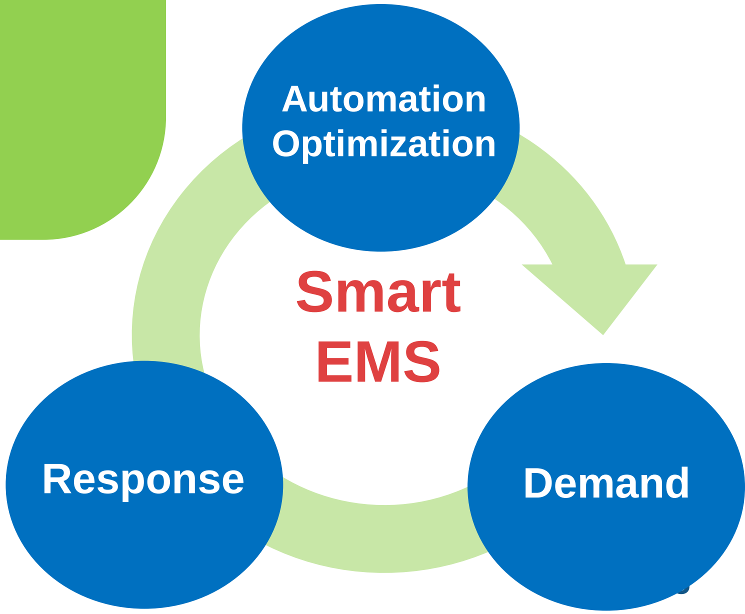


Energy Management Systems (EMS) are a MUST in a smart energy society

Static policies
+
Offline data
+
Manual operation

Dynamic policies
+
Realtime data
+
Automated operation



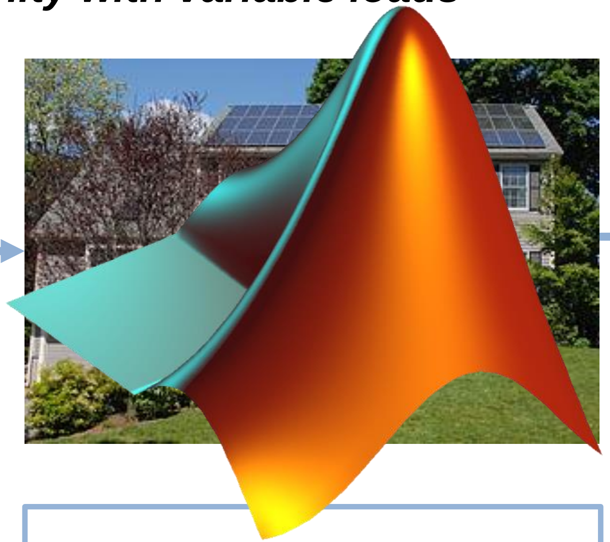


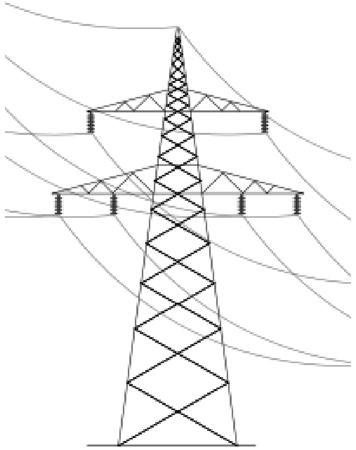
Community EMS

Using Model-Based Design and Optimization

CEMS example – ***community with variable loads***

PV Panels:
- MPPT Control
- Power electronics





Decision Logic:
- Store/draw power
- Use external grid
- Optimize energy

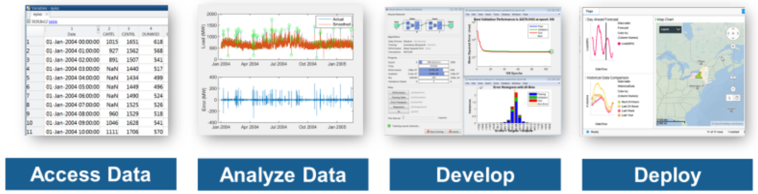
Battery System:
- Charge controls
- Discharge controls
- Power electronics

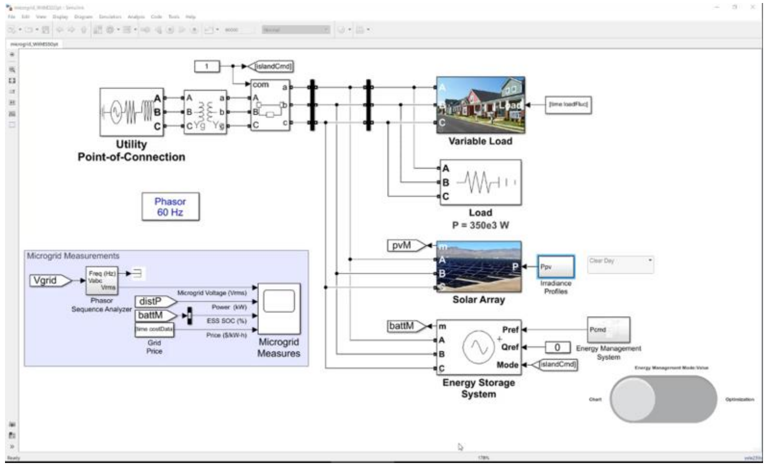
What do you need to build a smart EMS?

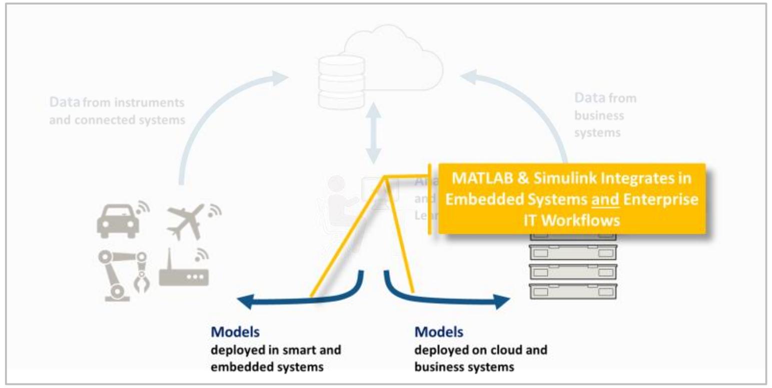
- Integrated development environment
  - Data science
  - Predictive modeling
  - Optimization
  - Control
  - System Design

- Virtual prototyping

- Deployment options
  - Deploy to embedded systems
  - Deploy to enterprise systems

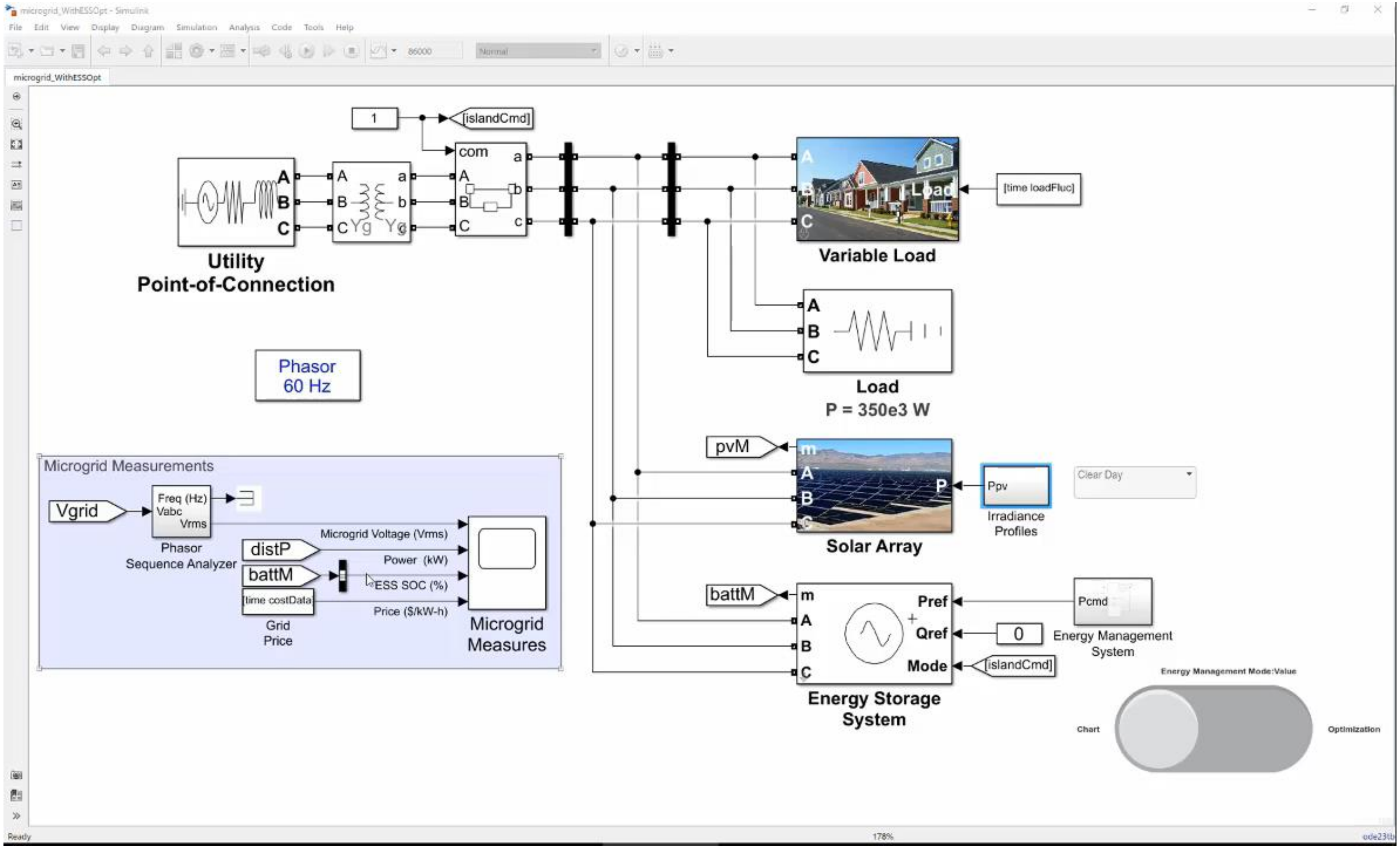






Challenges

- Access and preprocess both engineering and business data
- Build data-driven and physics-based models
- Model and simulate equipment performance
- Design algorithms to optimally control equipment
- Deploy into systems -- from embedded to enterprise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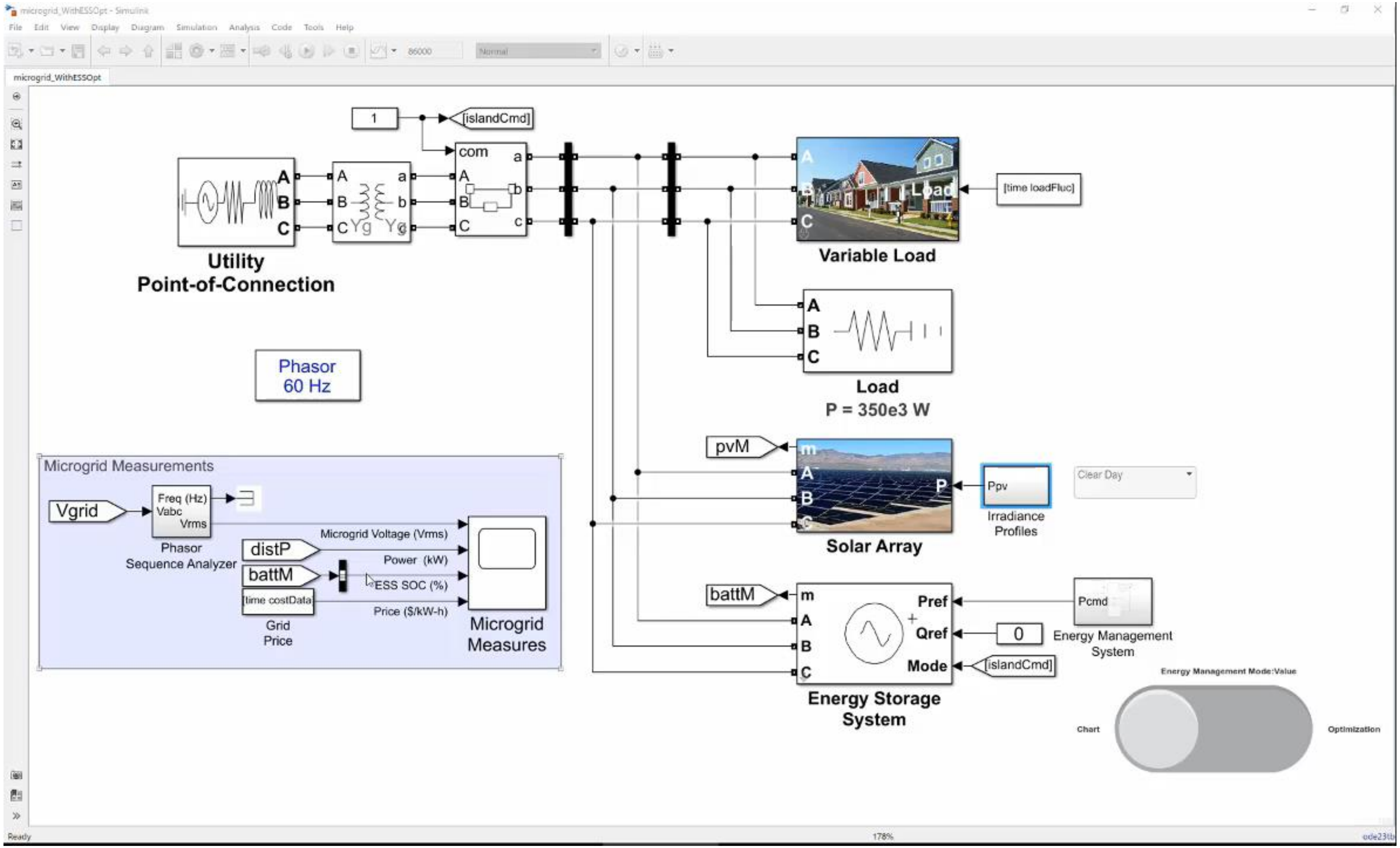

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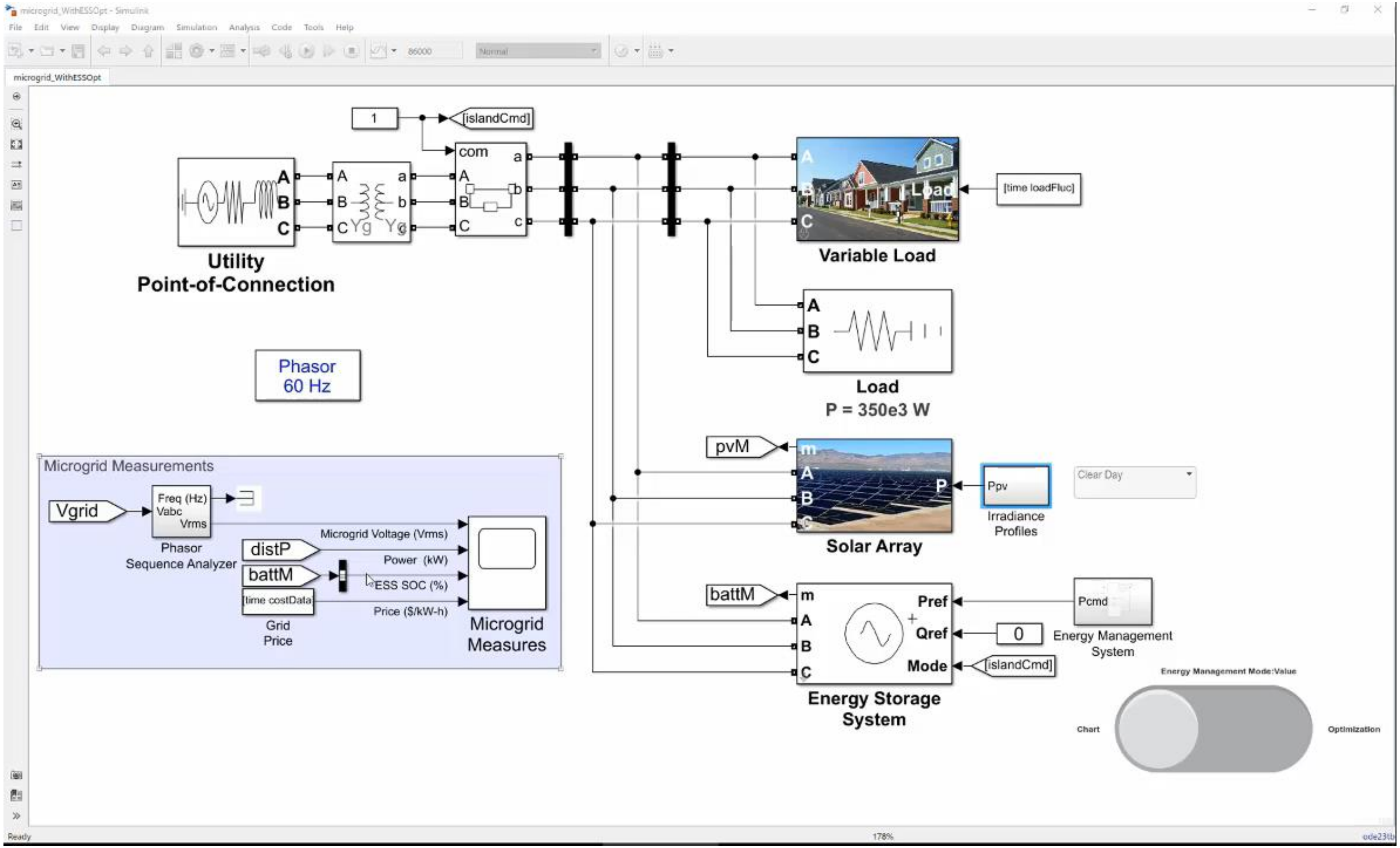

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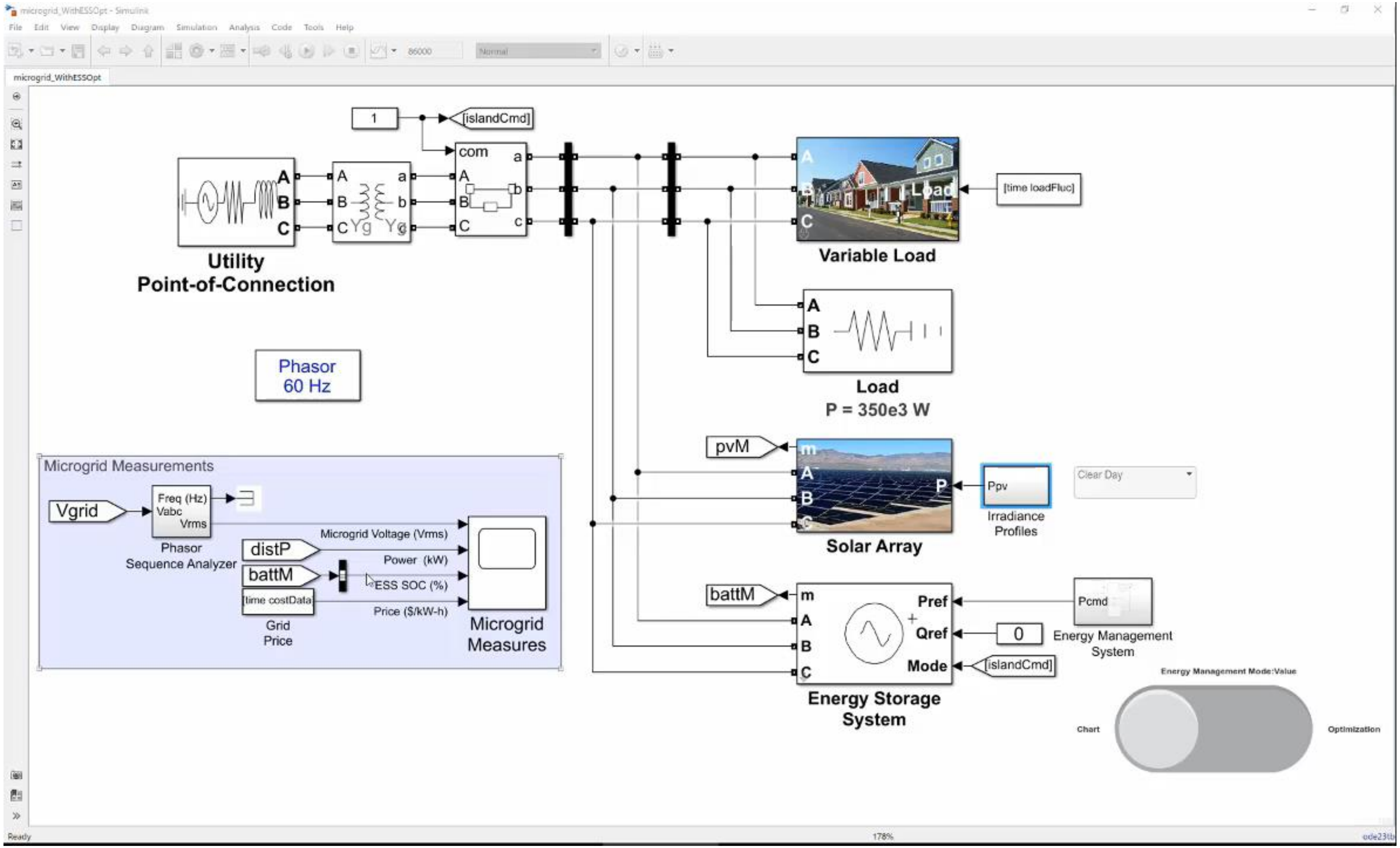
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Policy Comparison - Cloudy Day

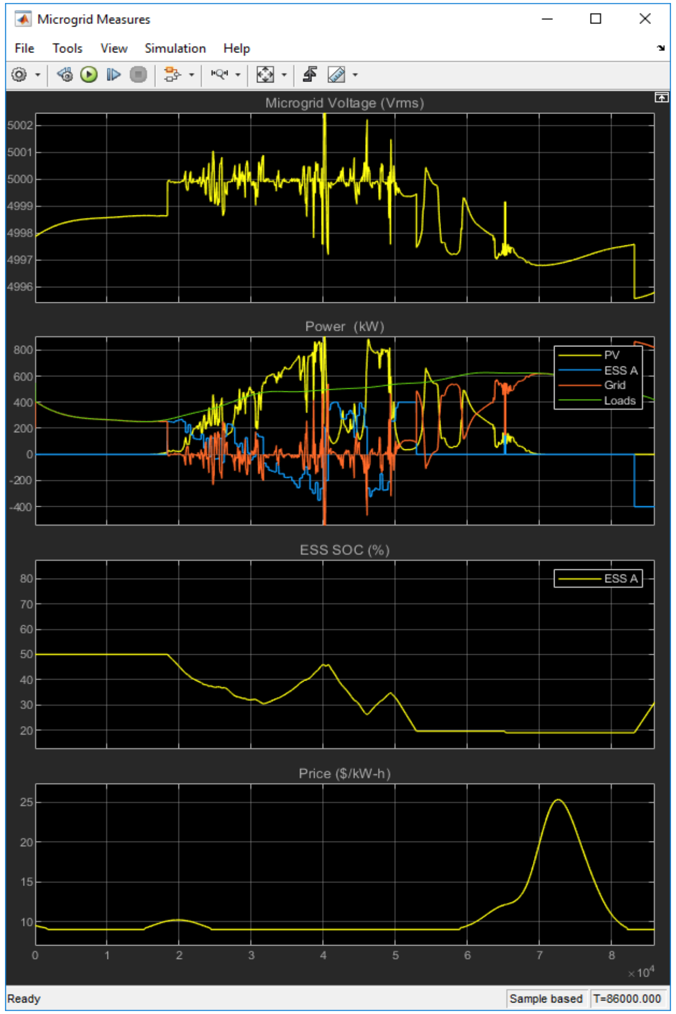
Grid voltage

Power

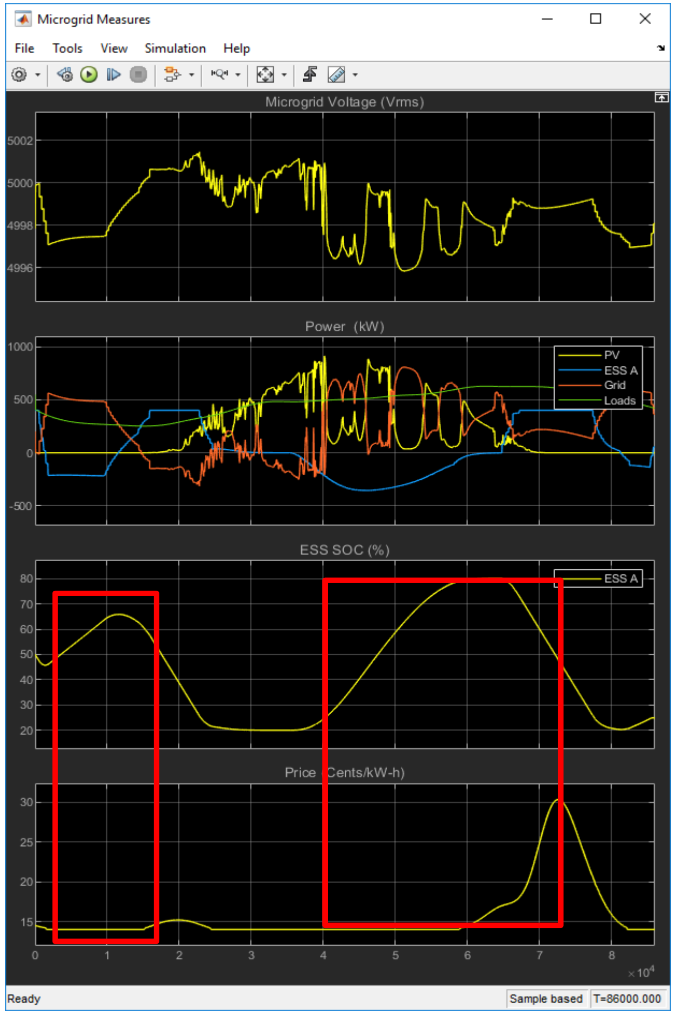
State of Charge

Price

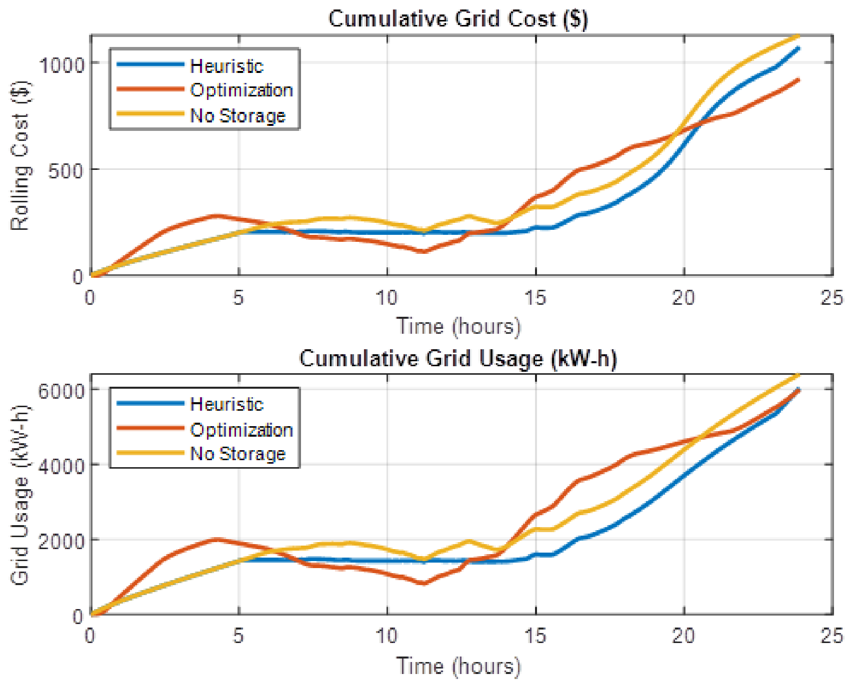
Heuristic



Optimized



Comparison



14% lower cost with optimization

Optimization Example: Community EMS with PV and Battery

minimize $\sum_{t=1}^{N} \delta c_t G_t - w E_N + \sum_{t=1}^{N-1} g_t$

subject to

$$E_1 = E_{initial}$$

$$E_{t+1} = E_t - \delta B_t$$

$$\boxed{s_t + G_t + B_t = d_t}$$

$$G_{t+1} - G_t \leq g_t$$

$$G_t - G_{t+1} \leq g_t$$

G_t	Power from grid
$l_B \leq B_t \leq u_B$	Power from battery
$l_E \leq E_t \leq u_E$	Stored energy
g_t	Change in power from grid

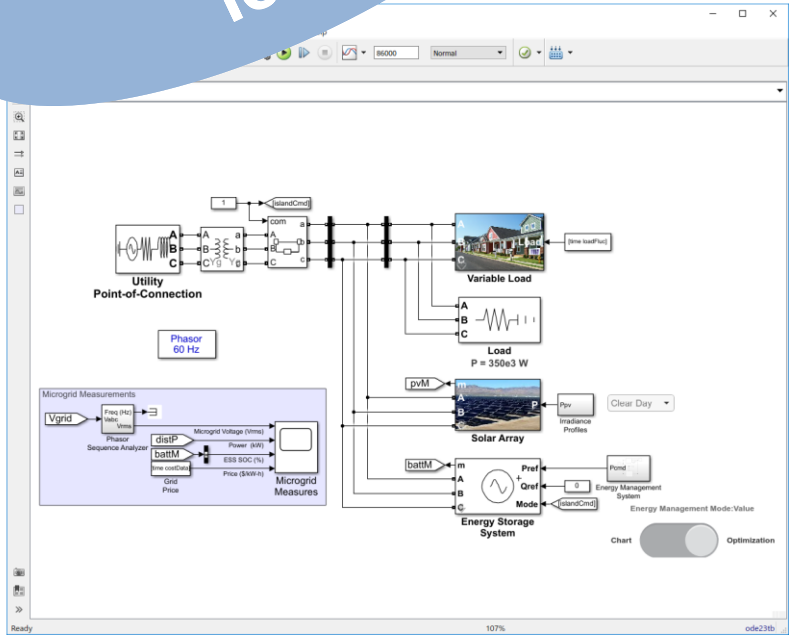
Editor - C:\Demos\Microgrid_EMS\battSolarOptimize.m

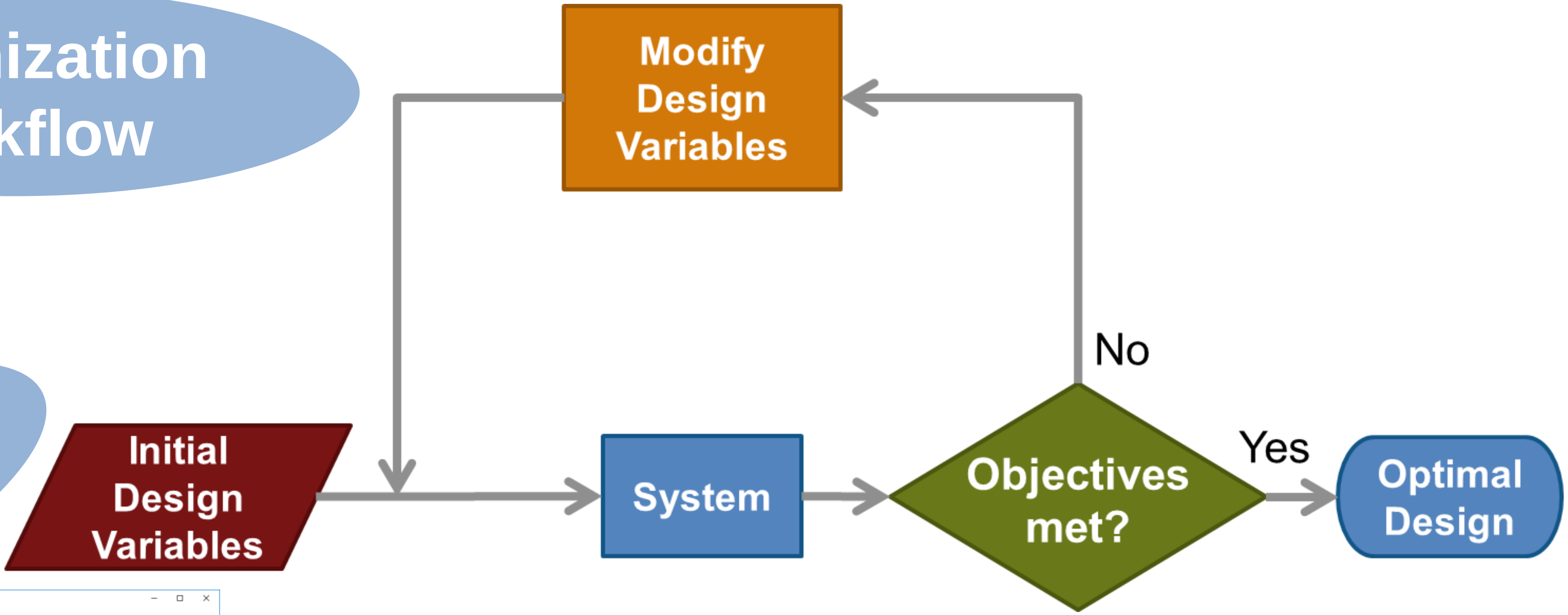
battSolarOptimize.m

```
function [Pgrid,Pbatt,Ebatt] = battSolarOptimize(N,dt,Ppv,Pload,Einit,Cost,FinalWeight,batteryMinMax)

% Minimize the cost of power from the grid while meeting load with power
% from PV, battery and grid

prob = optimproblem;

% Decision variables
PgridV = optimvar('PgridV',N);
PbattV = optimvar('PbattV',N,'LowerBound',batteryMinMax.Pmin,'UpperBound',batteryMinMax.Pmax);
EbattV = optimvar('EbattV',N,'LowerBound',batteryMinMax.Emin,'UpperBound',batteryMinMax.Emax);
PgridDelta = optimvar('gridDelta',N-1);

% Minimize cost of electricity from the grid
% - Account for final battery storage
% - Smooth period-to-period changes with a penalty
prob.ObjectiveSense = 'minimize';
prob.Objective = dt*Cost'*PgridV - FinalWeight*EbattV(N) + sum(PgridDelta);

% Power input/output to battery
prob.Constraints.energyBalance = optimconstr(N);
prob.Constraints.energyBalance(1) = EbattV(1) == Einit;
prob.Constraints.energyBalance(2:N) = EbattV(2:N) == EbattV(1:N-1) - PbattV(1:N-1)*dt;

% Satisfy power load with power from PV, grid and battery
prob.Constraints.loadBalance = Ppv + PgridV + PbattV == Pload;

% Track change from period to period in electricity from the grid
prob.Constraints.deltaPlus = PgridV(2:N) - PgridV(1:N-1) <= PgridDelta;
prob.Constraints.deltaMinus = PgridV(1:N-1) - PgridV(2:N) <= PgridDelta;

% Solve the linear program
options = optimoptions(prob.optimoptions,'Display','none');
[values,~,exitflag] = solve(prob,'Options',options);

% Parse optmization results
if exitflag <= 0
    Pgrid = zeros(N,1);
    Pbatt = zeros(N,1);
    Ebatt = zeros(N,1);
else
    Pgrid = values.PgridV;
    Pbatt = values.PbattV;
    Ebatt = values.EbattV;
end
```

Optimization workflow

System level





Effect of parameters can be easily visualized

Model can be extended with additional components

System Simulation Example: HEMS with PV and Batteries

Simulation platform
Simulink

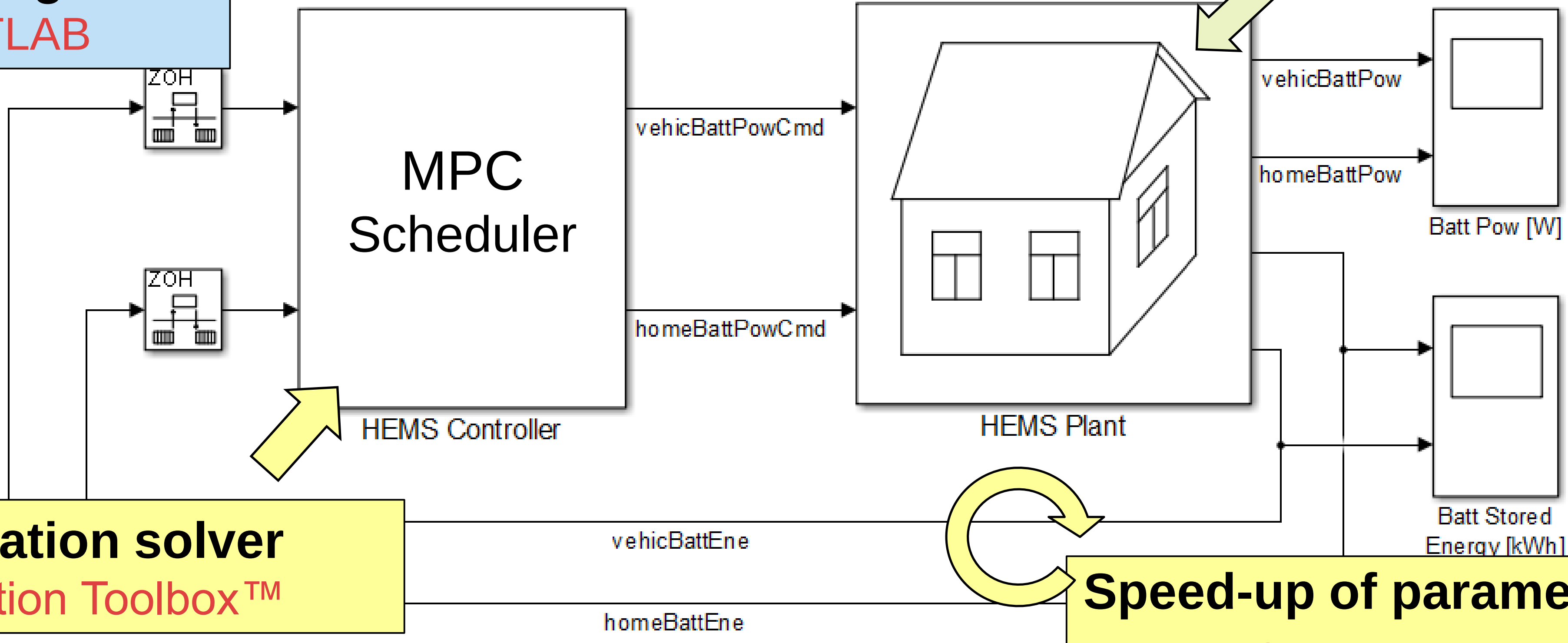
MPC modeling
Simulink, MATLAB

System simulation model

HEMS Controller
Block Diagram

Plant
Circuit Diagram

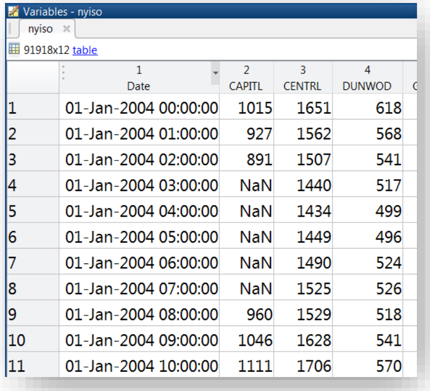
1D physical modeling
Simscape Electrical™



Optimization solver
Optimization Toolbox™

Speed-up of parameter study
Parallel Computing Toolbox™

End-to-end Workflow

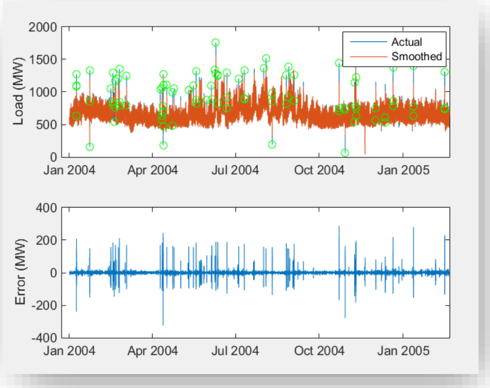


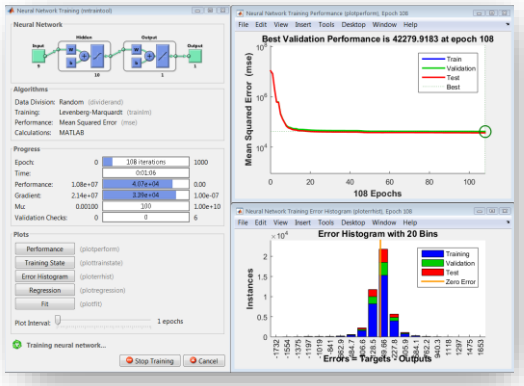
Variables - nyiso

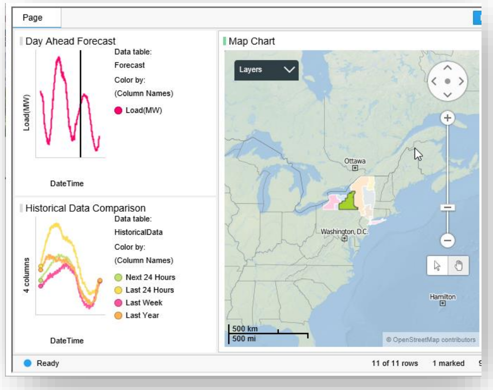
nyiso

91918x12 table

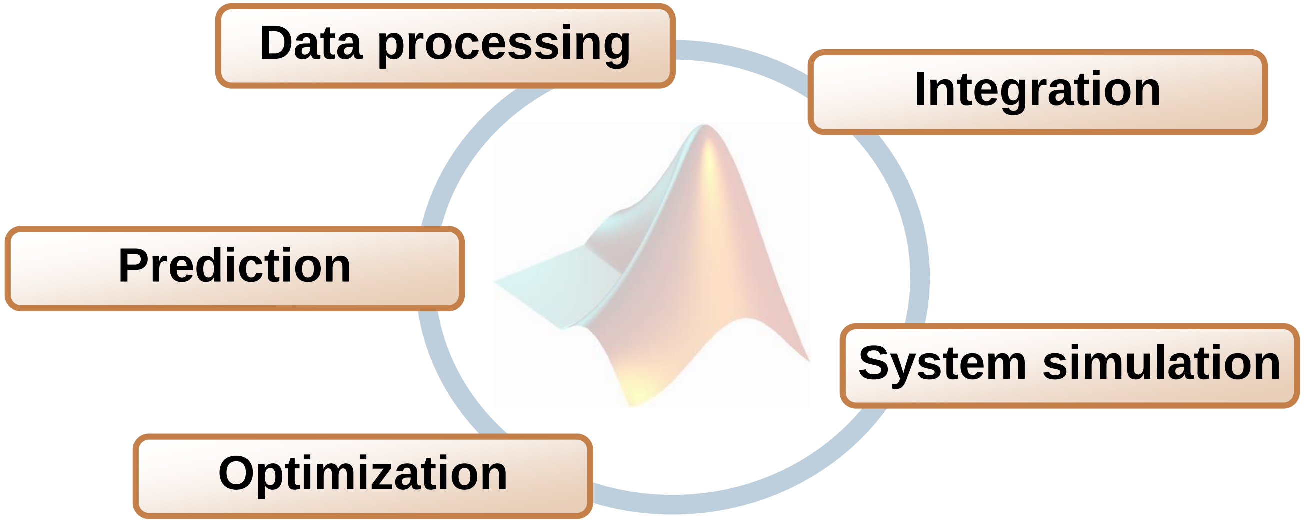
	1 Date	2 CAPITL	3 CENTRL	4 DUNWOD
1	01-Jan-2004 00:00:00	1015	1651	618
2	01-Jan-2004 01:00:00	927	1562	568
3	01-Jan-2004 02:00:00	891	1507	541
4	01-Jan-2004 03:00:00	NaN	1440	517
5	01-Jan-2004 04:00:00	NaN	1434	499
6	01-Jan-2004 05:00:00	NaN	1449	496
7	01-Jan-2004 06:00:00	NaN	1490	524
8	01-Jan-2004 07:00:00	NaN	1525	526
9	01-Jan-2004 08:00:00	960	1529	518
10	01-Jan-2004 09:00:00	1046	1628	541
11	01-Jan-2004 10:00:00	1111	1706	570







Access Data | **Analyze Data** | **Develop** | **Deploy**



Shanghai Electric Builds and Deploys Cost-Saving Enterprise Software for Planning and Designing Distributed Energy Systems

Challenge

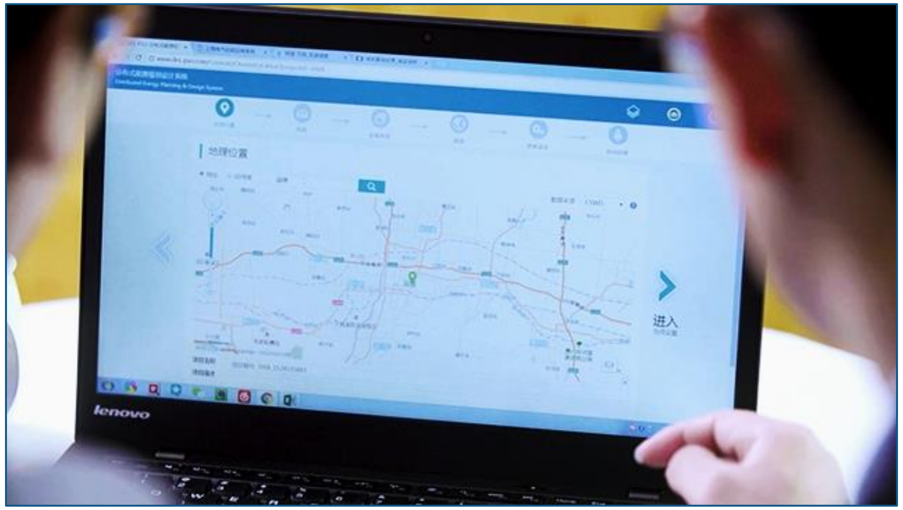
Develop web-accessible software for planning and designing distributed energy systems

Solution

Use MATLAB to develop algorithms that compute investment return based on models of energy production subsystems, loads, and grids, and then use MATLAB Production Server to deploy the algorithms in a production IT system

Results

- Delivery time reduced by six months
- 2 million Chinese yuan saved on a single project
- Updates deployed immediately and without IT assistance



DES-PSO web user interface

"My team's expertise is in energy modeling or algorithm development, not in deploying software into production. MATLAB saved us months of development time on the models and algorithms, and then made it easy to deploy them as part of a stable, reliable web application without recoding."

- Yunjiao Gu, Shanghai Electric

Link to user story

Learn More

Web resources:

- Microgrid System Development and Analysis - video series
- Data Analytics with MATLAB – webinar
- Linear and Mixed-Integer Linear Programming in MATLAB - webinar

Products in demo:

MATLAB
Simulink

Simscape
Simscape Electrical

Stateflow
Optimization Toolbox

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Speaker Details:

Email: schatter@mathworks.com

LinkedIn:

https://www.linkedin.com/in/souvick-chatterjee-1649b927/