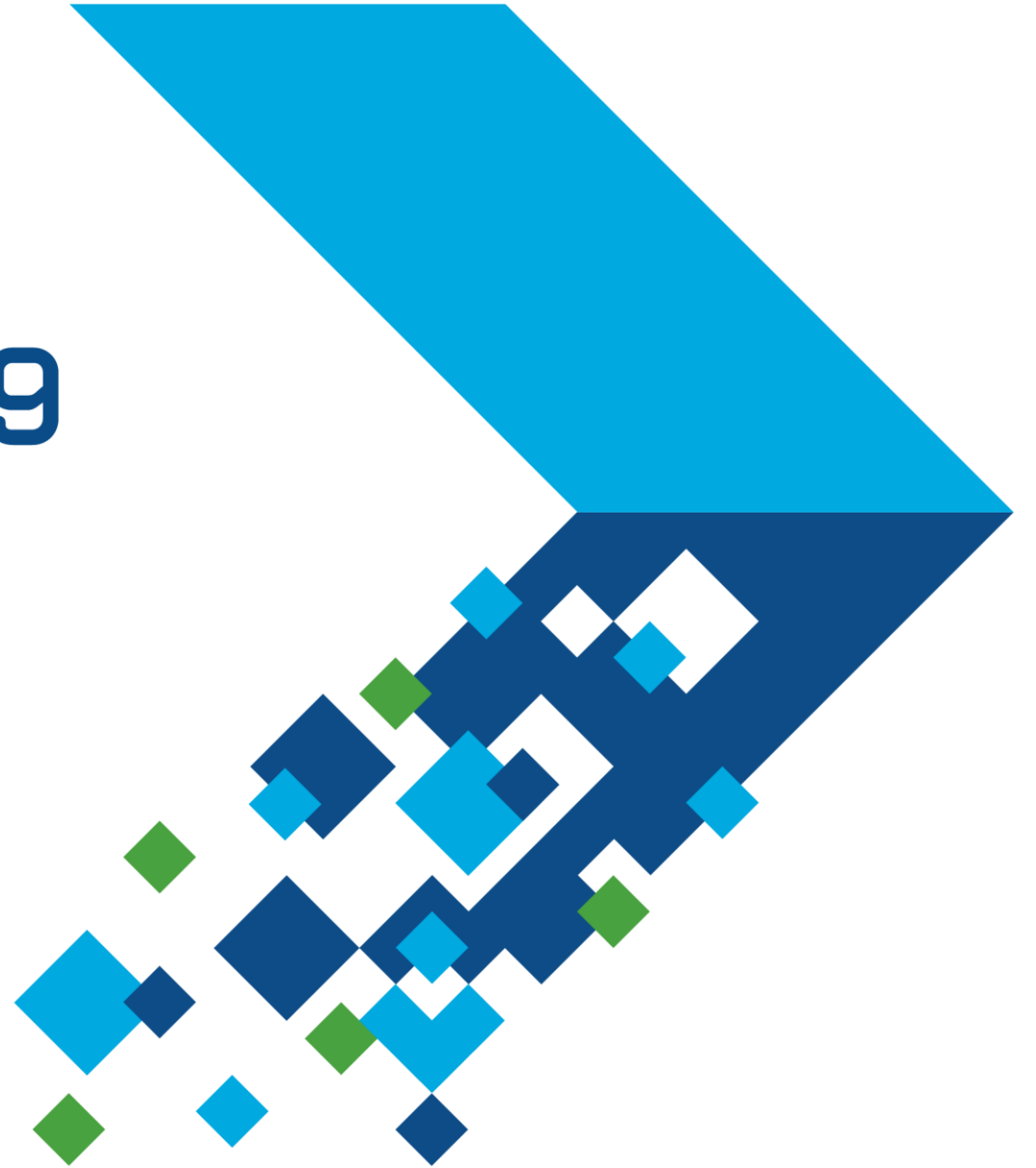


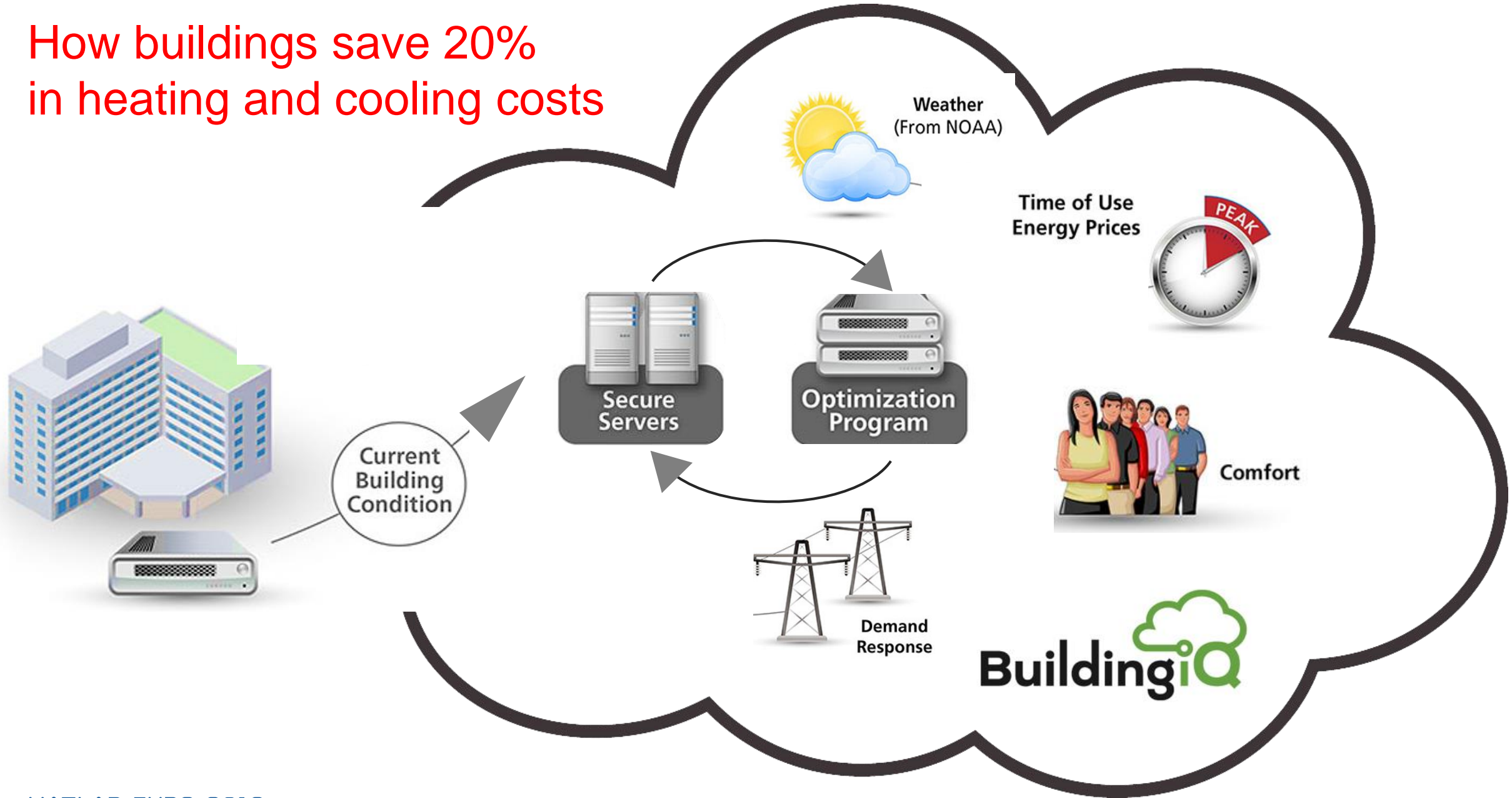
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Optimization in Energy
Management Systems

Souvick Chatterjee, PhD



How buildings save 20% in heating and cooling costs



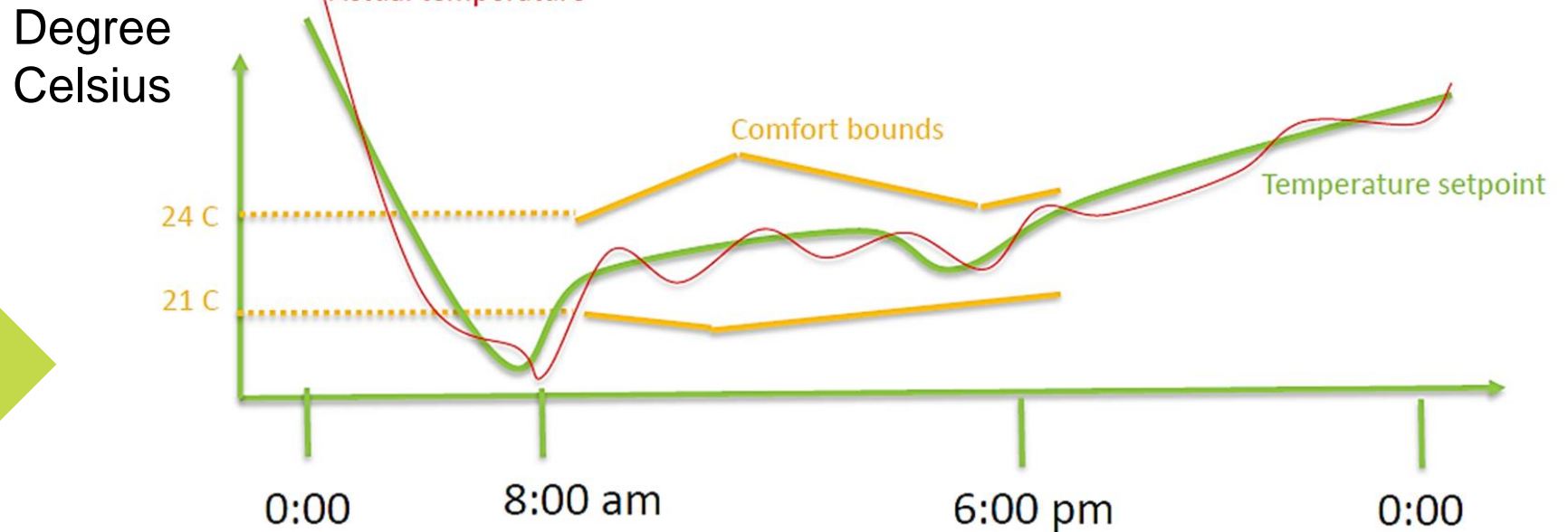
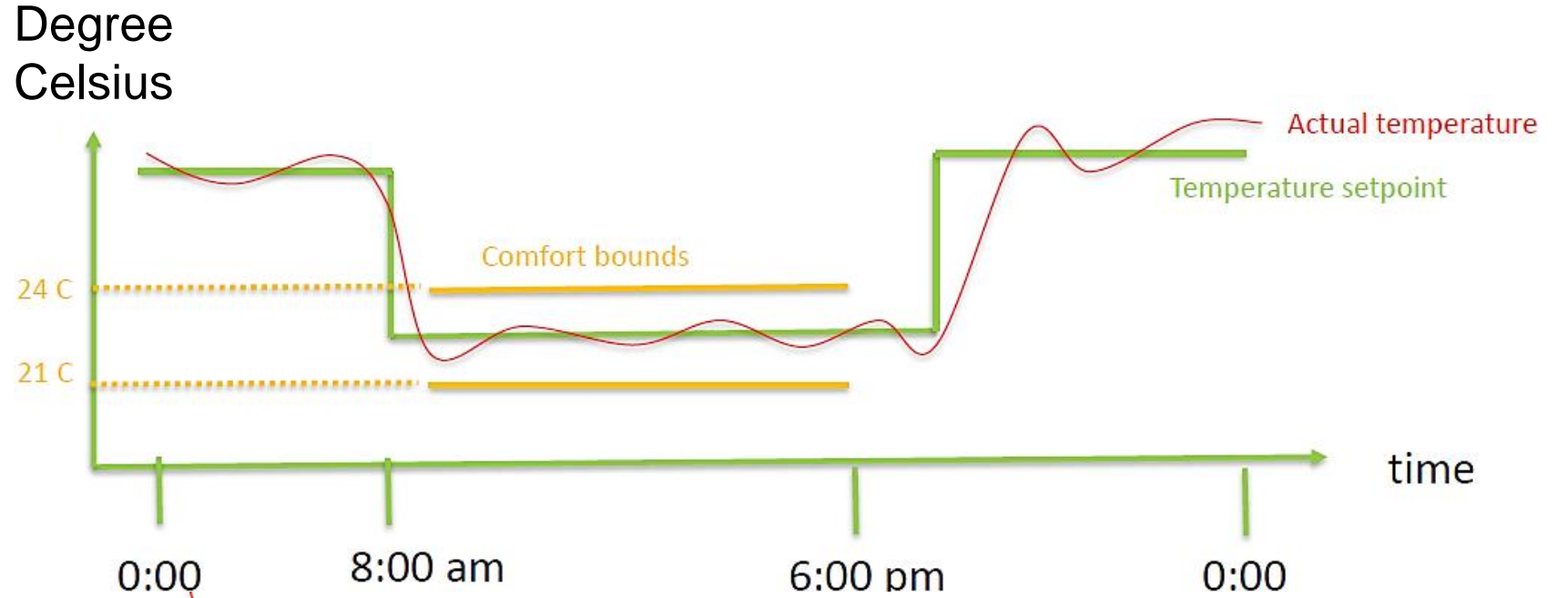


Traditional EMS

Smart EMS

25% cost reduction

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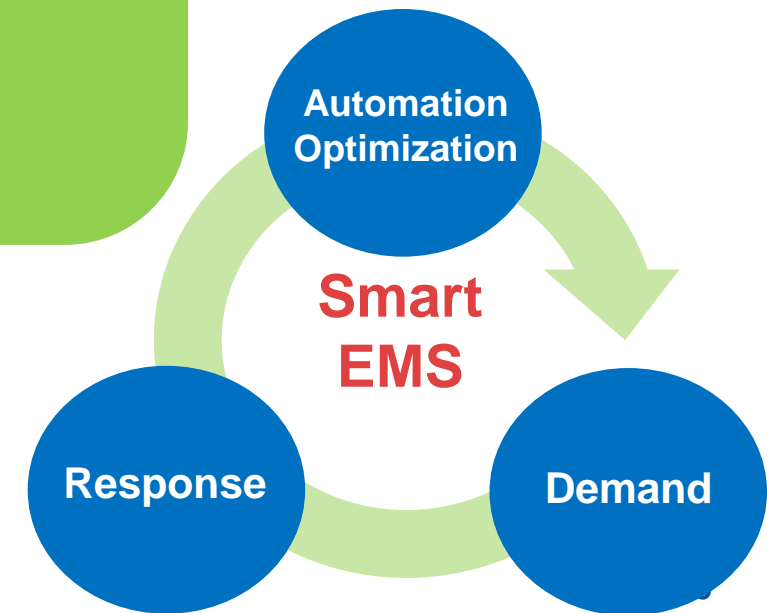
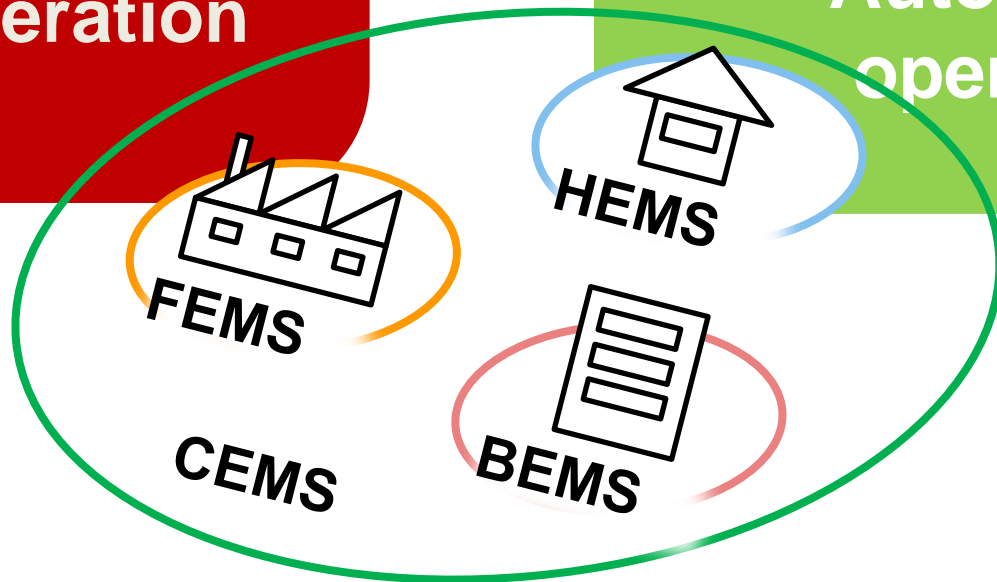


Energy Management Systems (EMS) are a MUST in a smart energy society

Static policies
+
Offline data
+
Manual operation



Dynamic policies
+
Realtime data
+
Automated operation



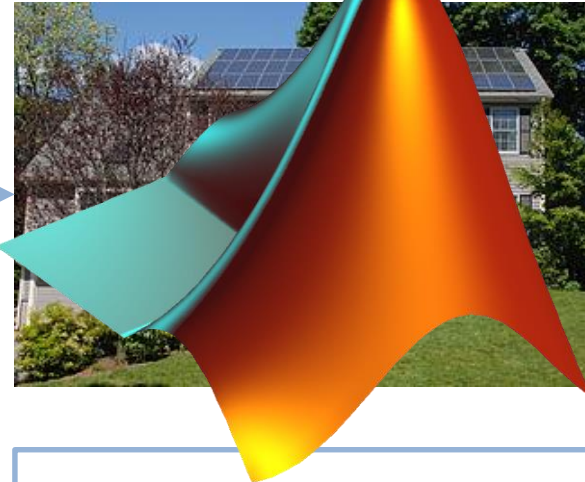
Community EMS

Using Model-Based Design and Optimization

CEMS example – *community with variable loads*

PV Panels:

- MPPT Control
- Power electronics

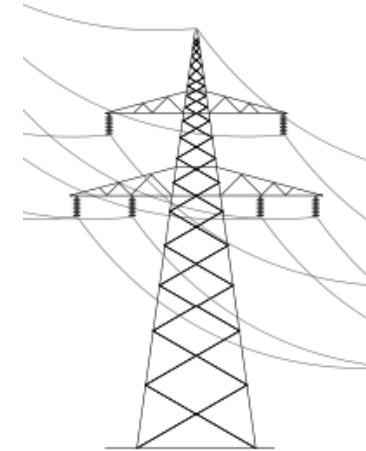


Decision Logic:

- Store/draw power
- Use external grid
- Optimize energy

Battery System:

- Charge controls
- Discharge controls
- Power electronics

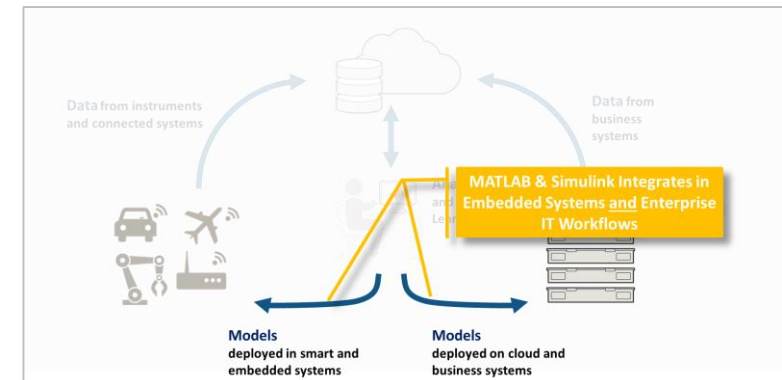
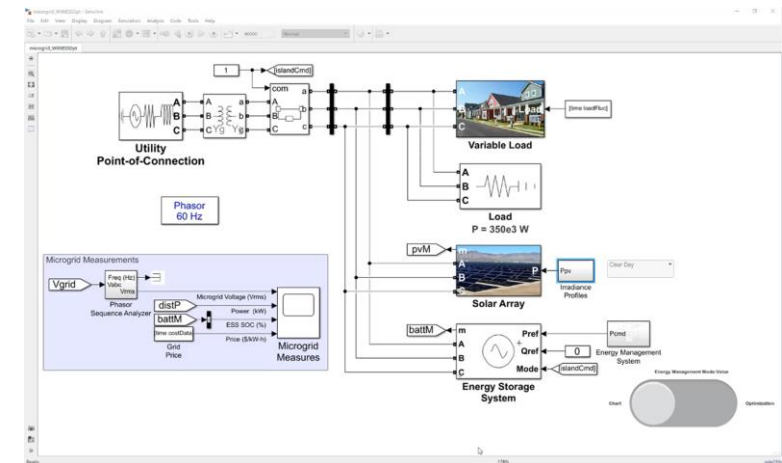


What do you need to build a smart EMS?

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

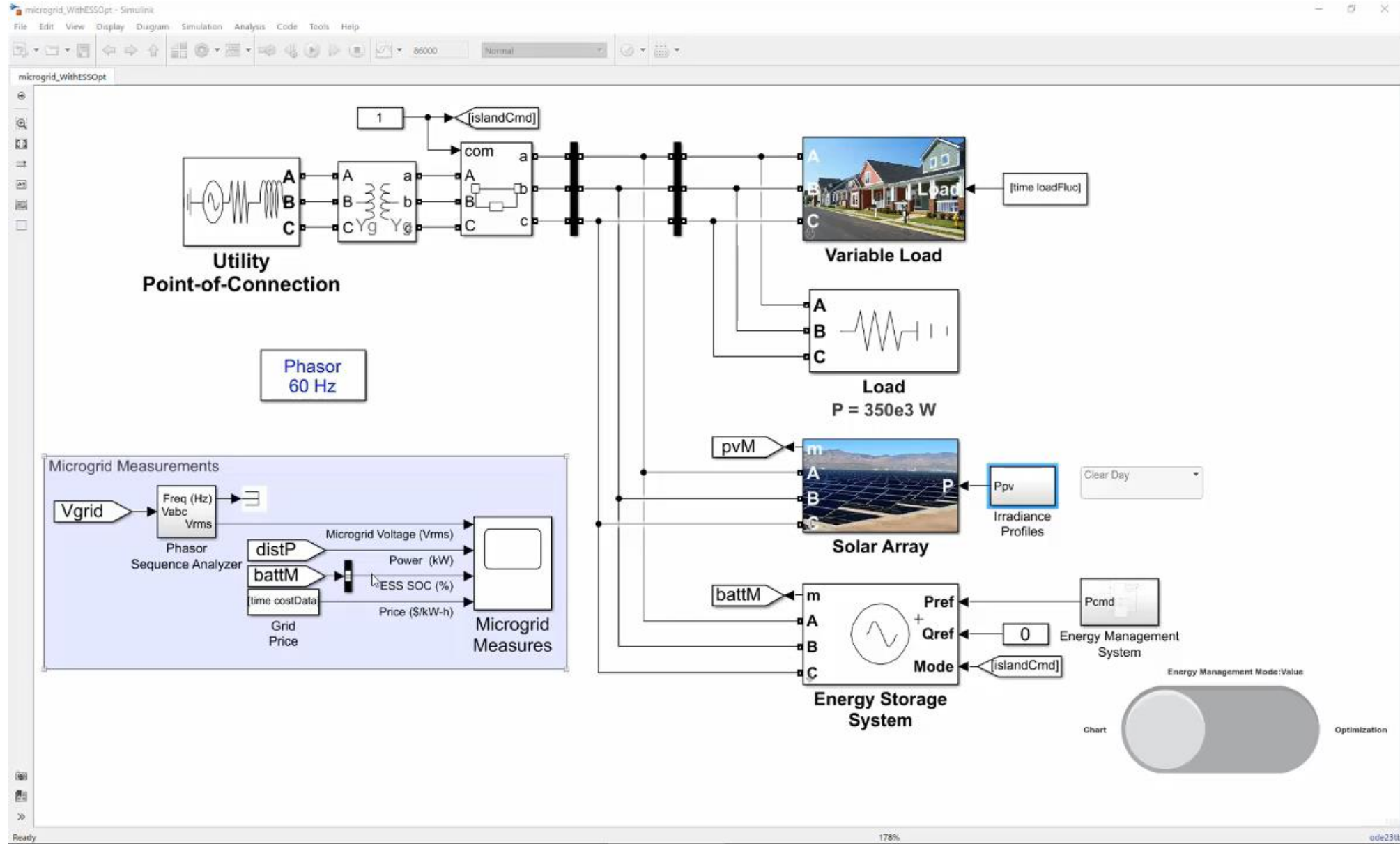
- Virtual prototyping

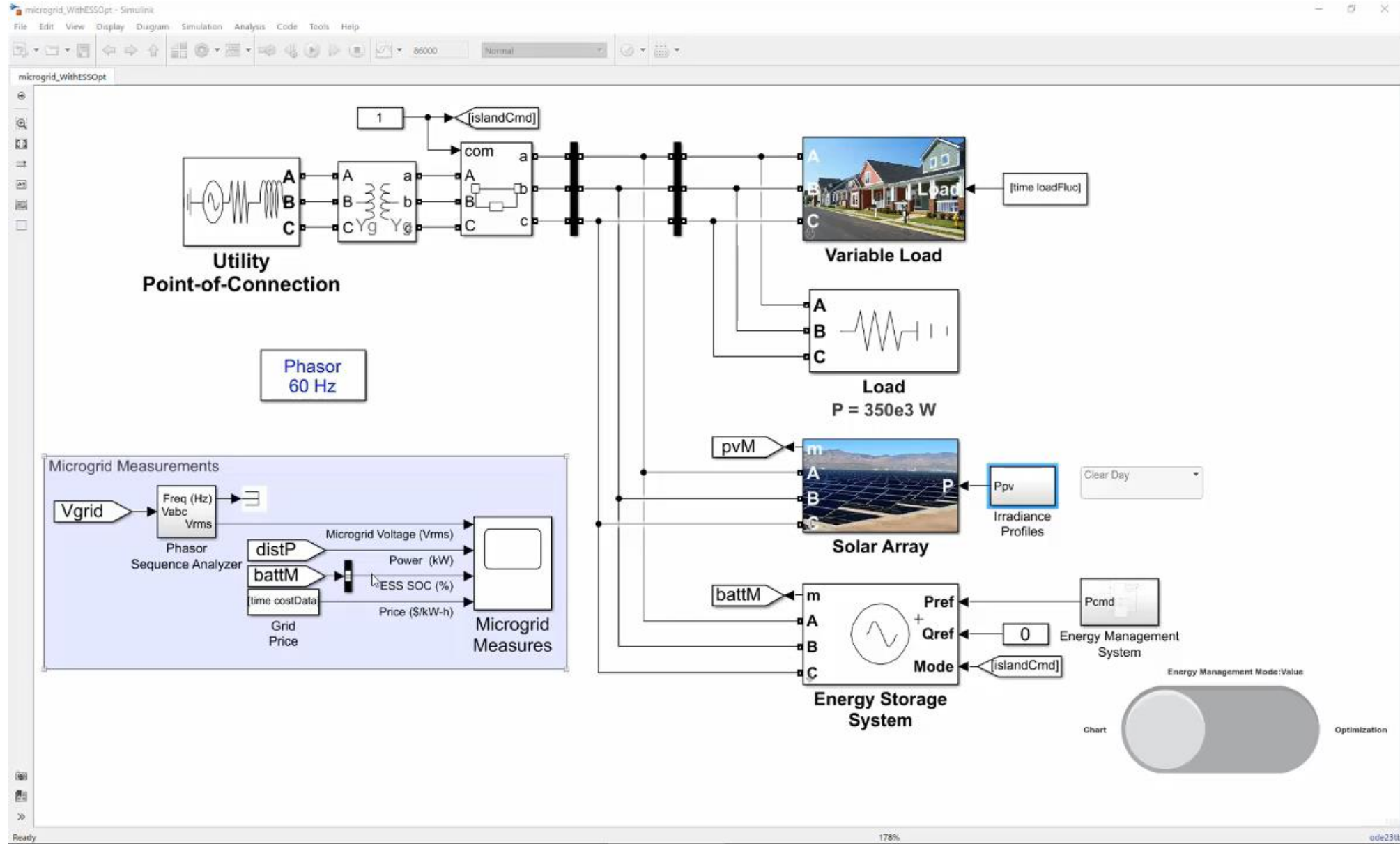
- Deployment options
 - Deploy to embedded systems
 - Deploy to enterprise systems

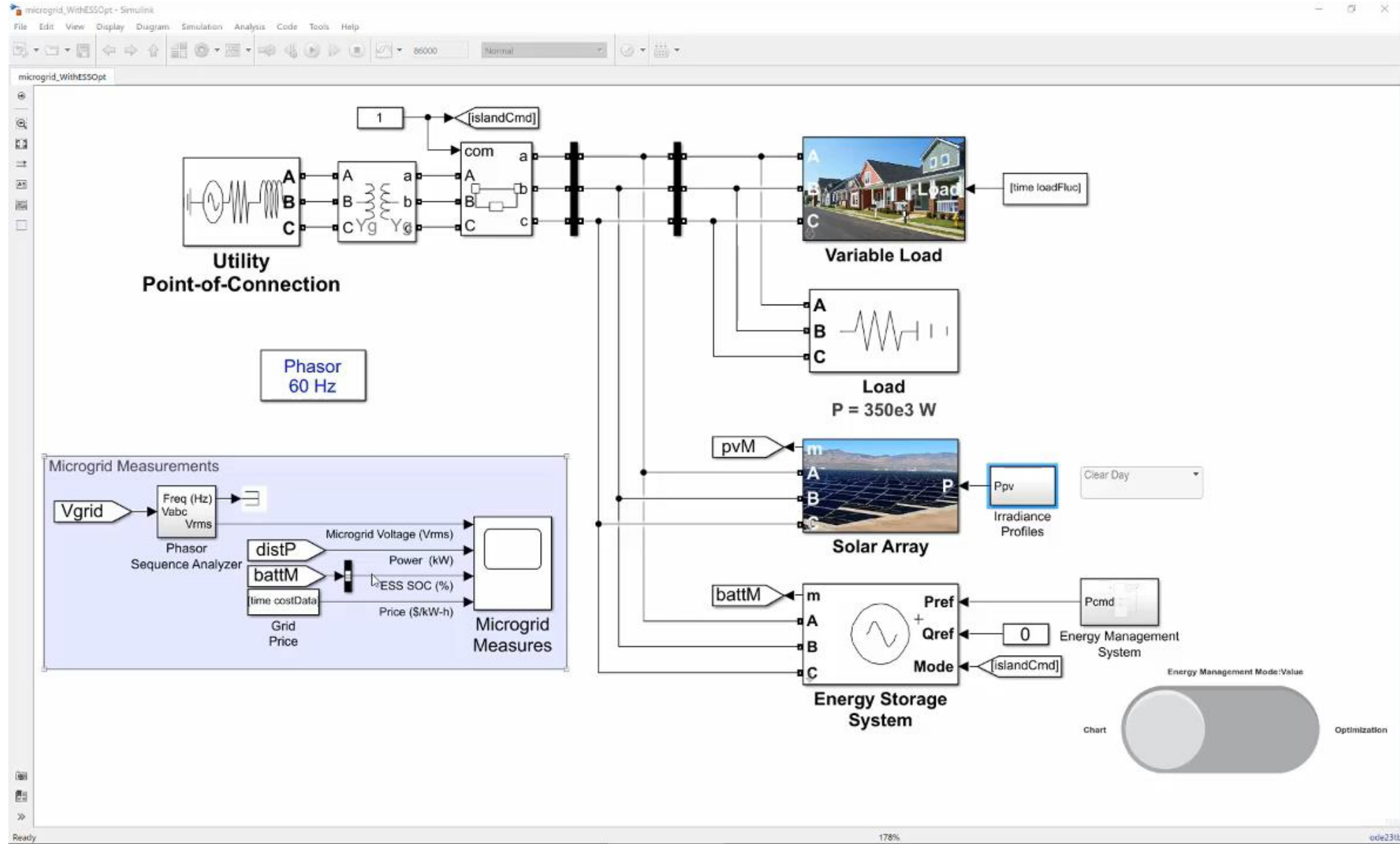


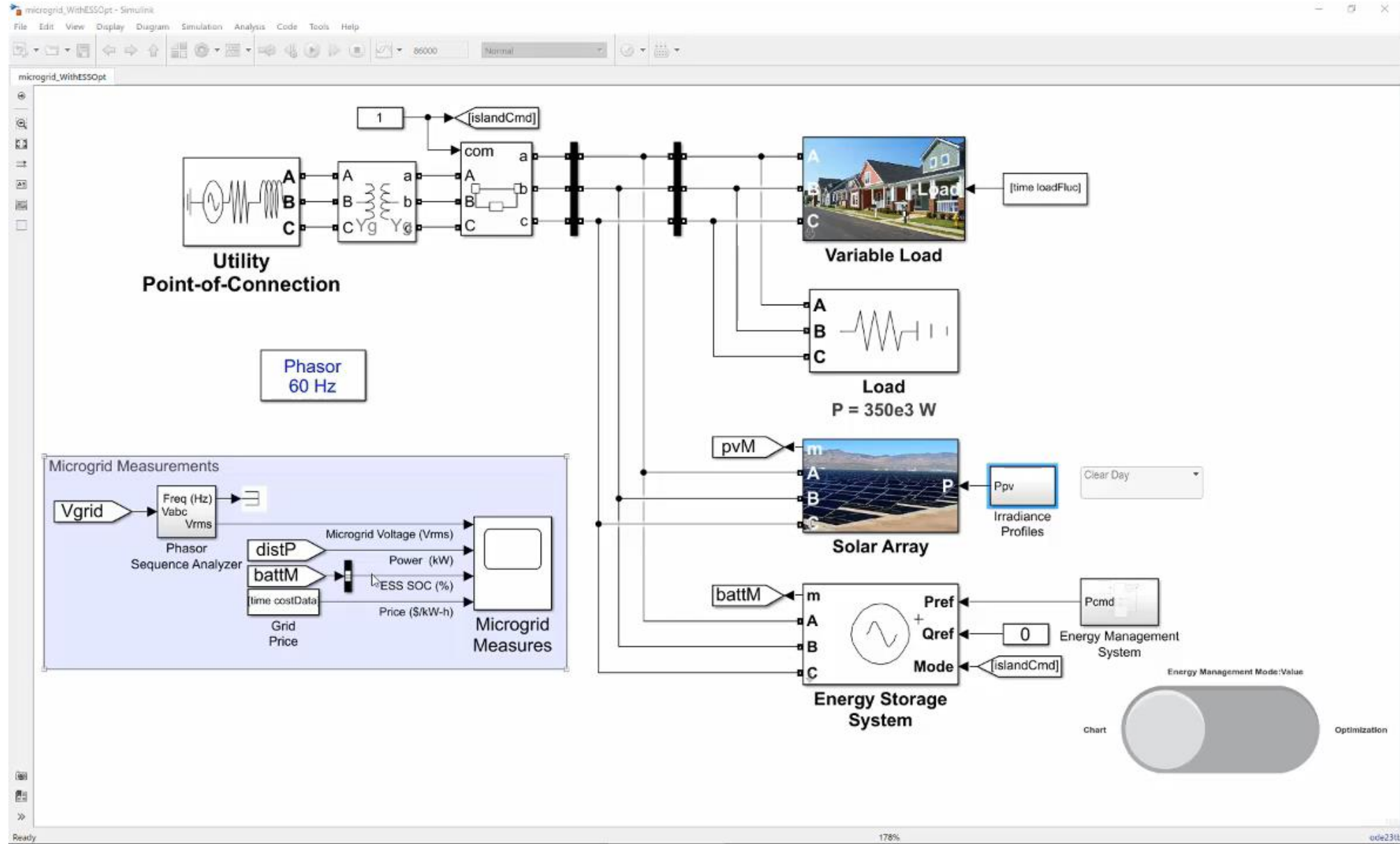
Challenges

- 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





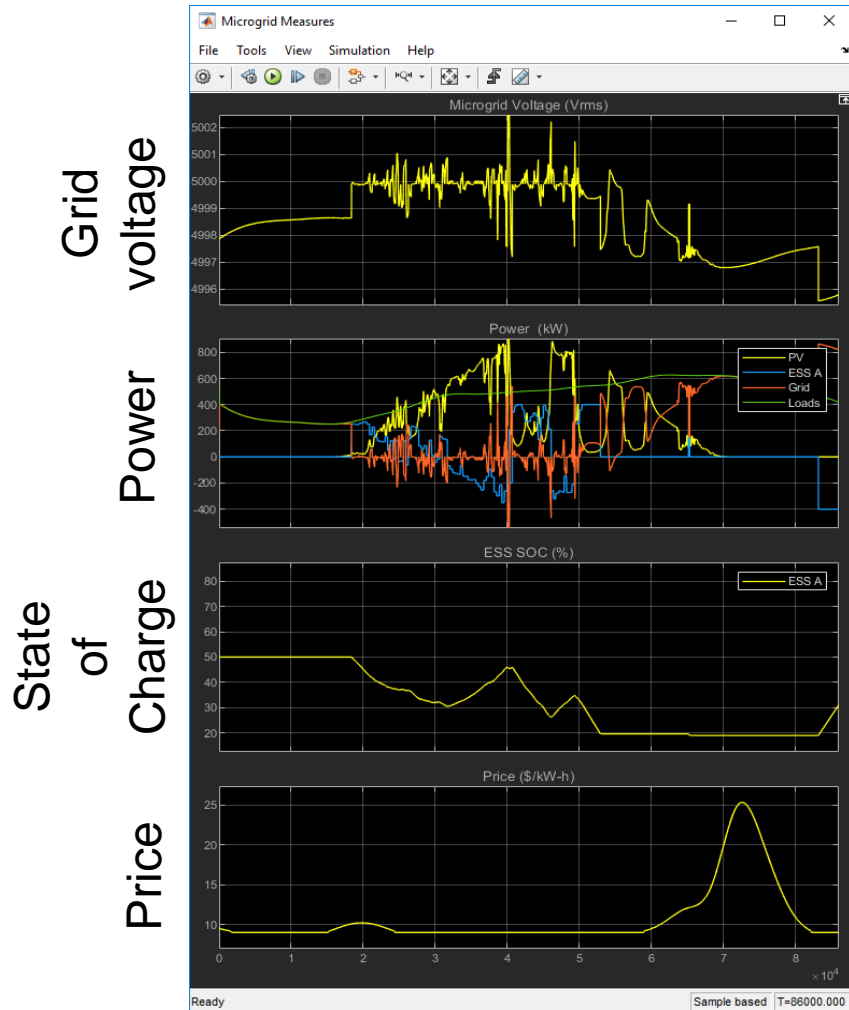




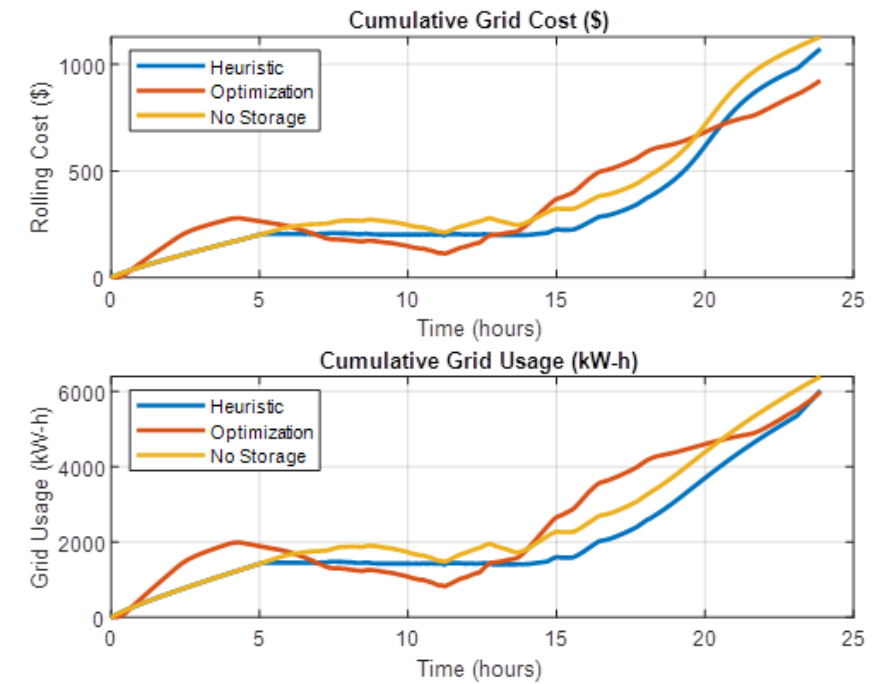
Policy Comparison - Cloudy Day

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

$$E_1 = E_{initial}$$

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

$$s_t + G_t + B_t = d_t$$

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

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

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  x  +
1  function [Pgrid,Pbatt,Ebatt] = battSolarOptimize(N,dt,Ppv,Pload,Einit,Cost,FinalWeight,batteryMinMax)
2
3  % Minimize the cost of power from the grid while meeting load with power
4  % from PV, battery and grid
5
6  prob = optimproblem;
7
8  % Decision variables
9  PgridV = optimvar('PgridV',N);
10 PbattV = optimvar('PbattV',N,'LowerBound',batteryMinMax.Pmin,'UpperBound',batteryMinMax.Pmax);
11 EbattV = optimvar('EbattV',N,'LowerBound',batteryMinMax.Emin,'UpperBound',batteryMinMax.Emax);
12 PgridDelta = optimvar('gridDelta',N-1);
13
14 % Minimize cost of electricity from the grid
15 % - Account for final battery storage
16 % - Smooth period-to-period changes with a penalty
17 prob.ObjectiveSense = 'minimize';
18 prob.Objective = dt*Cost'*PgridV - FinalWeight*EbattV(N) + sum(PgridDelta);
19
20 % Power input/output to battery
21 prob.Constraints.energyBalance = optimconstr(N);
22 prob.Constraints.energyBalance(1) = EbattV(1) == Einit;
23 prob.Constraints.energyBalance(2:N) = EbattV(2:N) == EbattV(1:N-1) - PbattV(1:N-1)*dt;
24
25 % Satisfy power load with power from PV, grid and battery
26 prob.Constraints.loadBalance = Ppv + PgridV + PbattV == Pload;
27
28 % Track change from period to period in electricity from the grid
29 prob.Constraints.deltaPlus = PgridV(2:N) - PgridV(1:N-1) <= PgridDelta;
30 prob.Constraints.deltaMinus = PgridV(1:N-1) - PgridV(2:N) <= PgridDelta;
31
32 % Solve the linear program
33 options = optimoptions(prob,'Display','none');
34 [values,~,exitflag] = solve(prob,'Options',options);
35
36 % Parse optimization results
37 if exitflag <= 0
38     Pgrid = zeros(N,1);
39     Pbatt = zeros(N,1);
40     Ebatt = zeros(N,1);
41 else
42     Pgrid = values.PgridV;
43     Pbatt = values.PbattV;
44     Ebatt = values.EbattV;
45 end
    
```

Optimization workflow

System level

Initial Design Variables

Modify Design Variables

System

Objectives met?

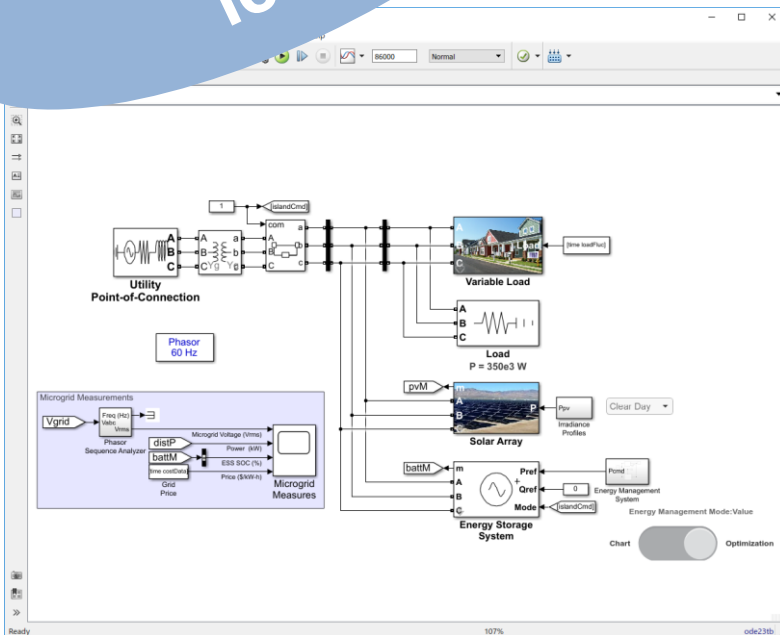
Optimal Design

No

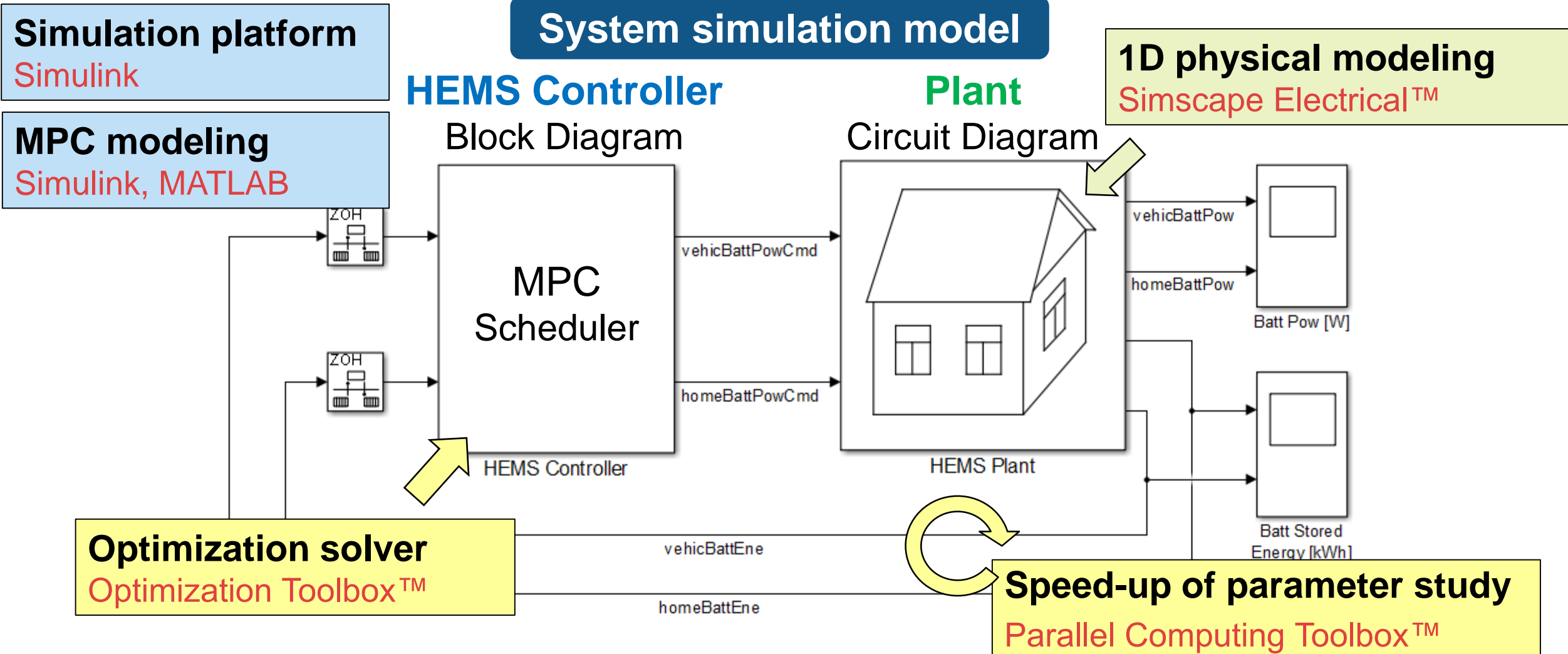
Yes

Effect of parameters can be easily visualized

Model can be extended with additional components

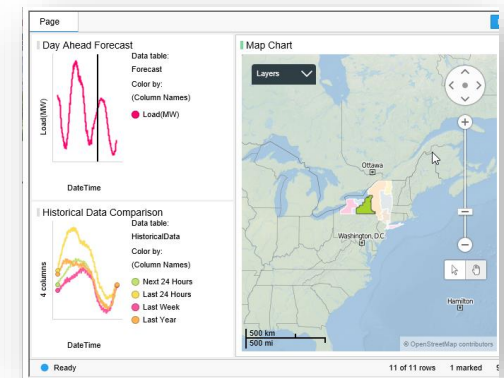
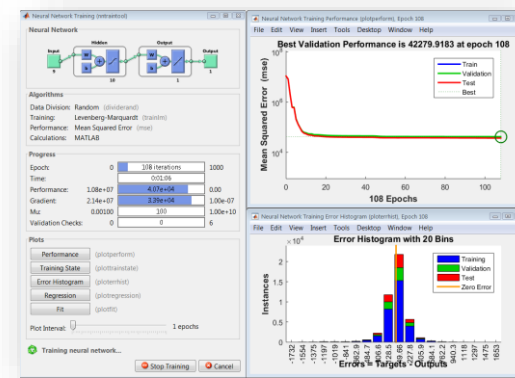
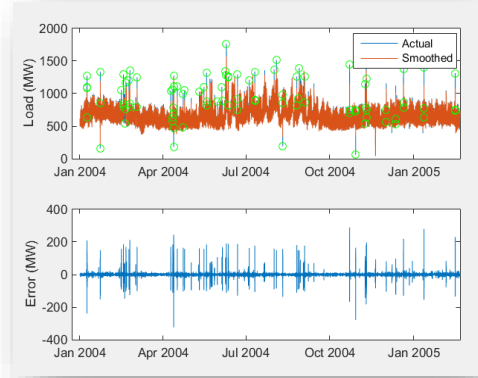


System Simulation Example: HEMS with PV and Batteries



End-to-end Workflow

	1	2	3	4
	Date	CAPITL	CENTRL	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

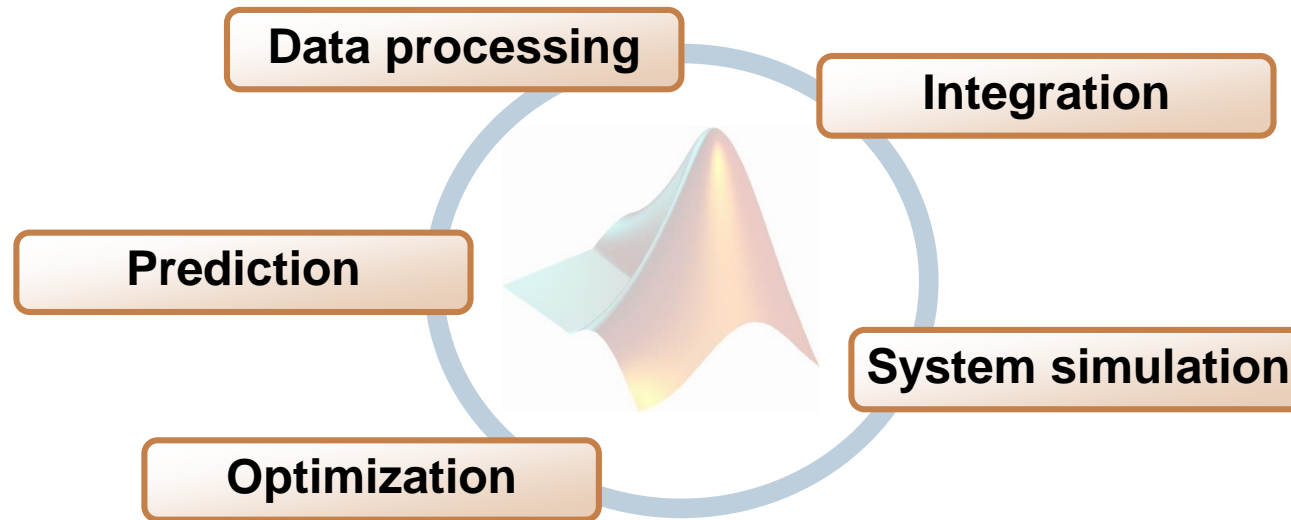


Access Data

Analyze Data

Develop

Deploy



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

Challenge

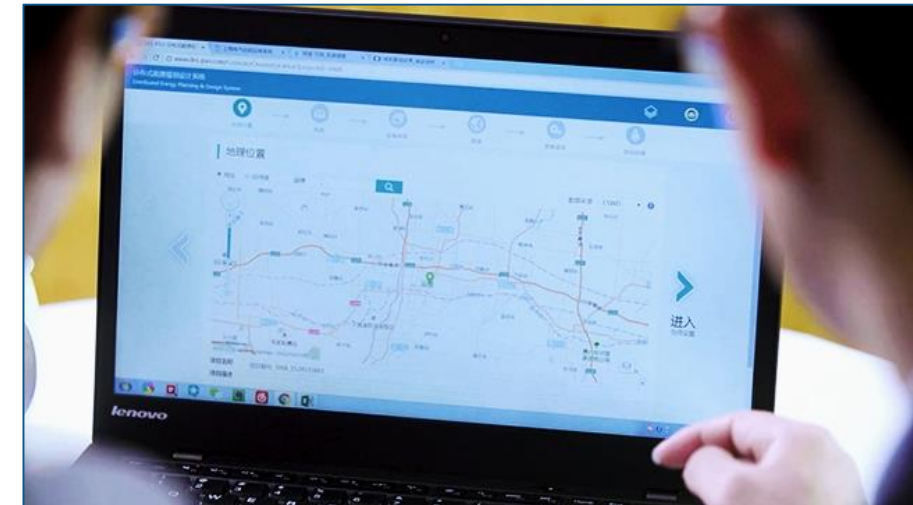
Develop web-accessible software for planning and designing distributed energy systems

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

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

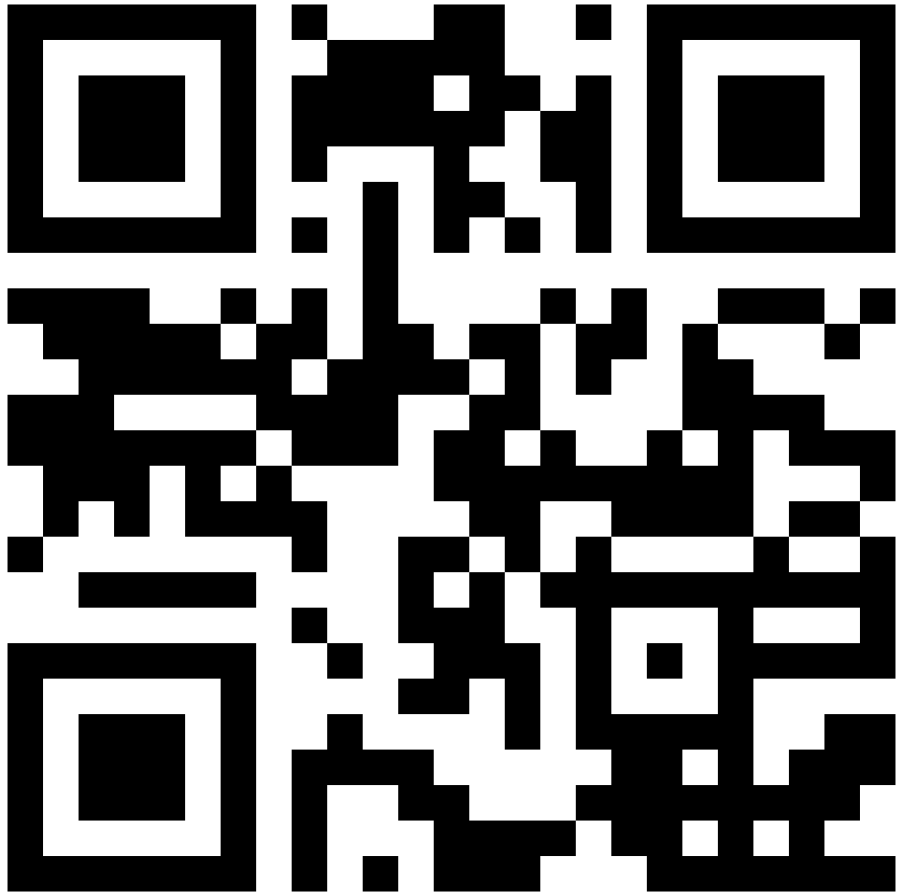
Products in demo:

**MATLAB
Simulink**

**Simscape
Simscape Electrical**

**Stateflow
Optimization Toolbox**

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