Distributed Control of a Swarm of Buildings Connected to a Smart Grid

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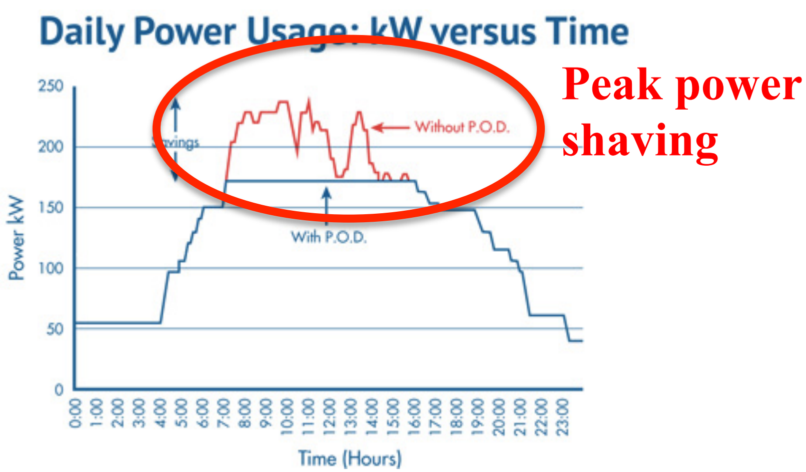
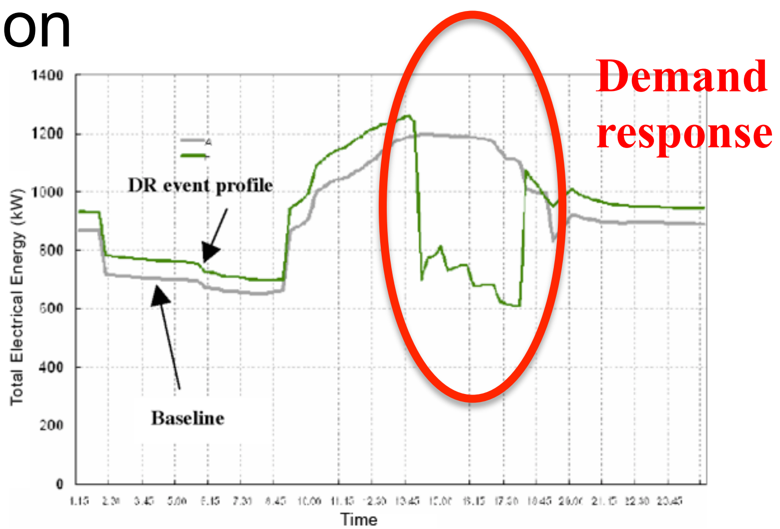
Building Energy Control

- Building energy management in smart grid has become an important research area
- Individual scenarios might include:
  - Demand response
  - Peak power management
  - Demand shifting based on time-of-use pricing and/or renewable energy generation

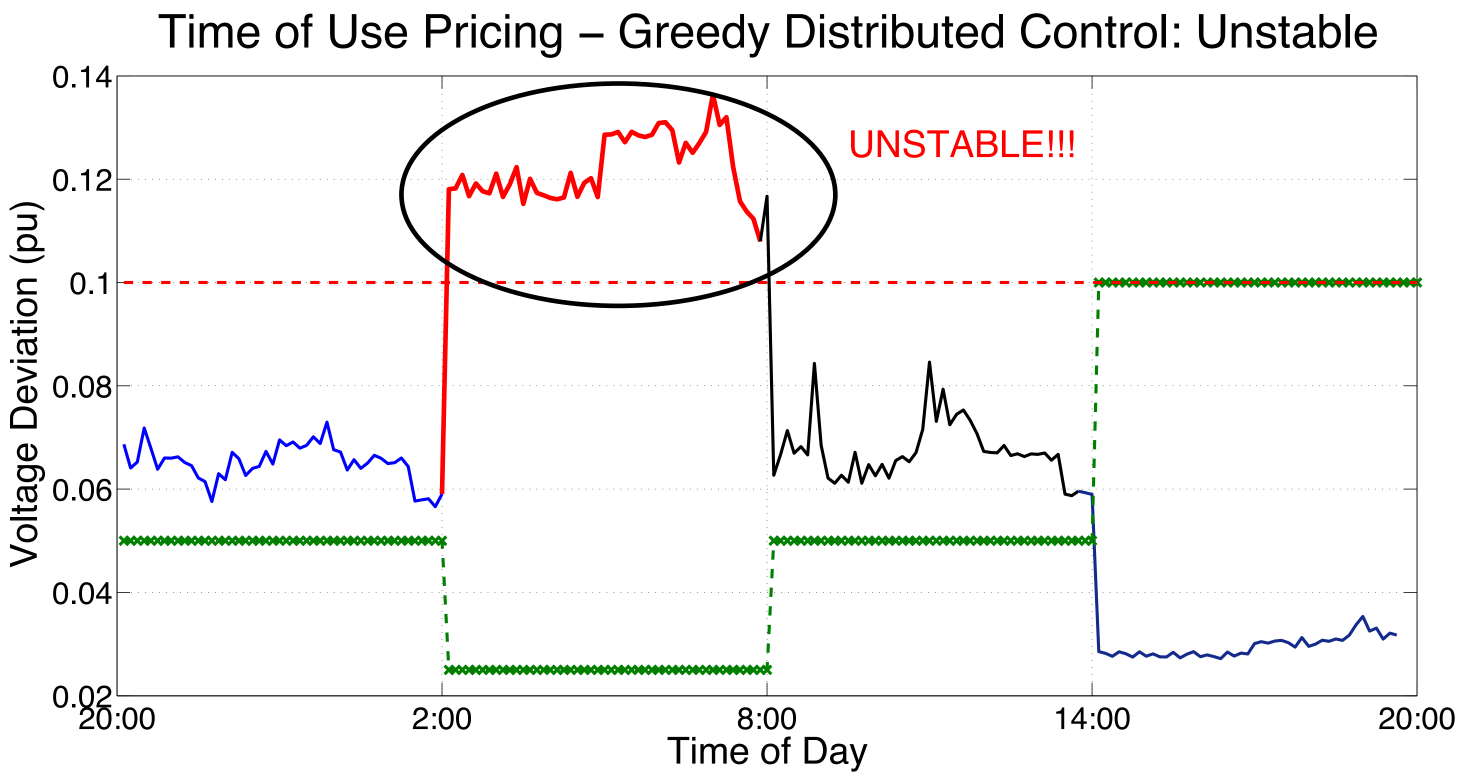




Distributed Building Control

- Each controller focuses on a single building
- These **individual** “optimal” controllers create a greedy **distributed** system.
- This can generate:
  - New peak spikes at non-peak hours
  - Supply-demand imbalances
  - Voltage/frequency instability

Distributed Control Issues

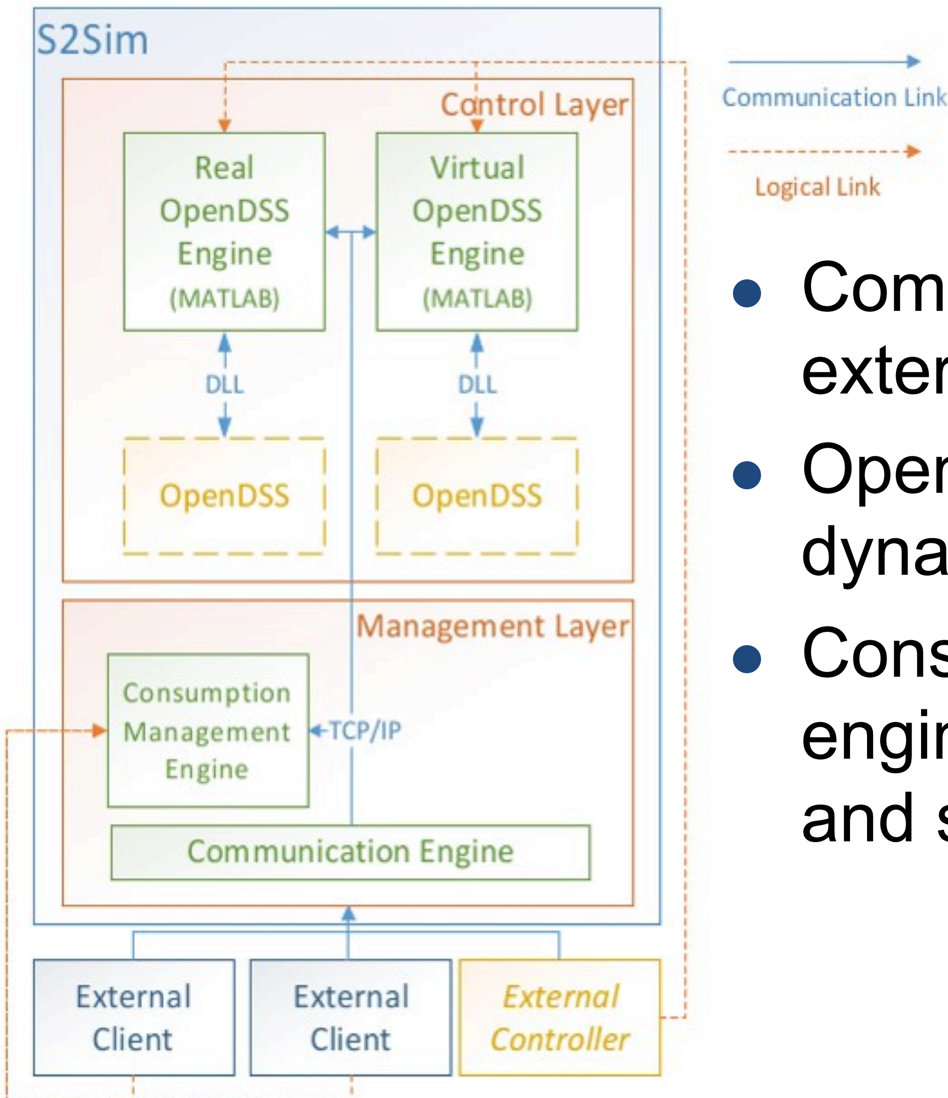


- We need to monitor the system in a holistic way
- Observe and eliminate the discrepancies

Smart Grid Swarm Simulator (S^2Sim)

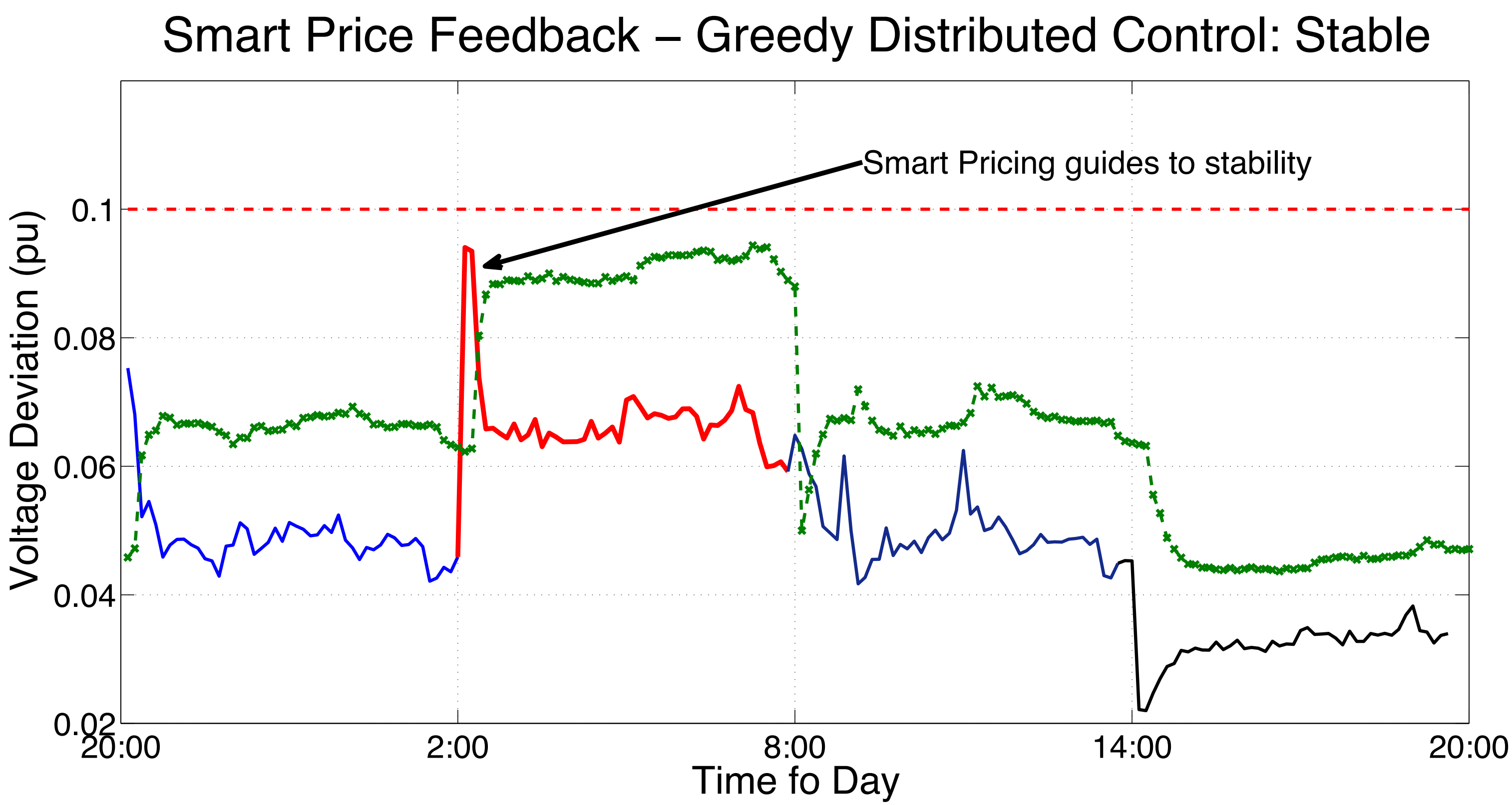
- OpenDSS based grid simulator
- Simulates grid dynamics: power, voltage
- Evaluates and quantifies grid stability
- Enables evaluation of the quality of distributed control of smart buildings
  - Treats each building as a black box
  - Allows co-simulation of individual controllers or data feeds from real-time sensor/actuator systems

S²Sim Design Overview



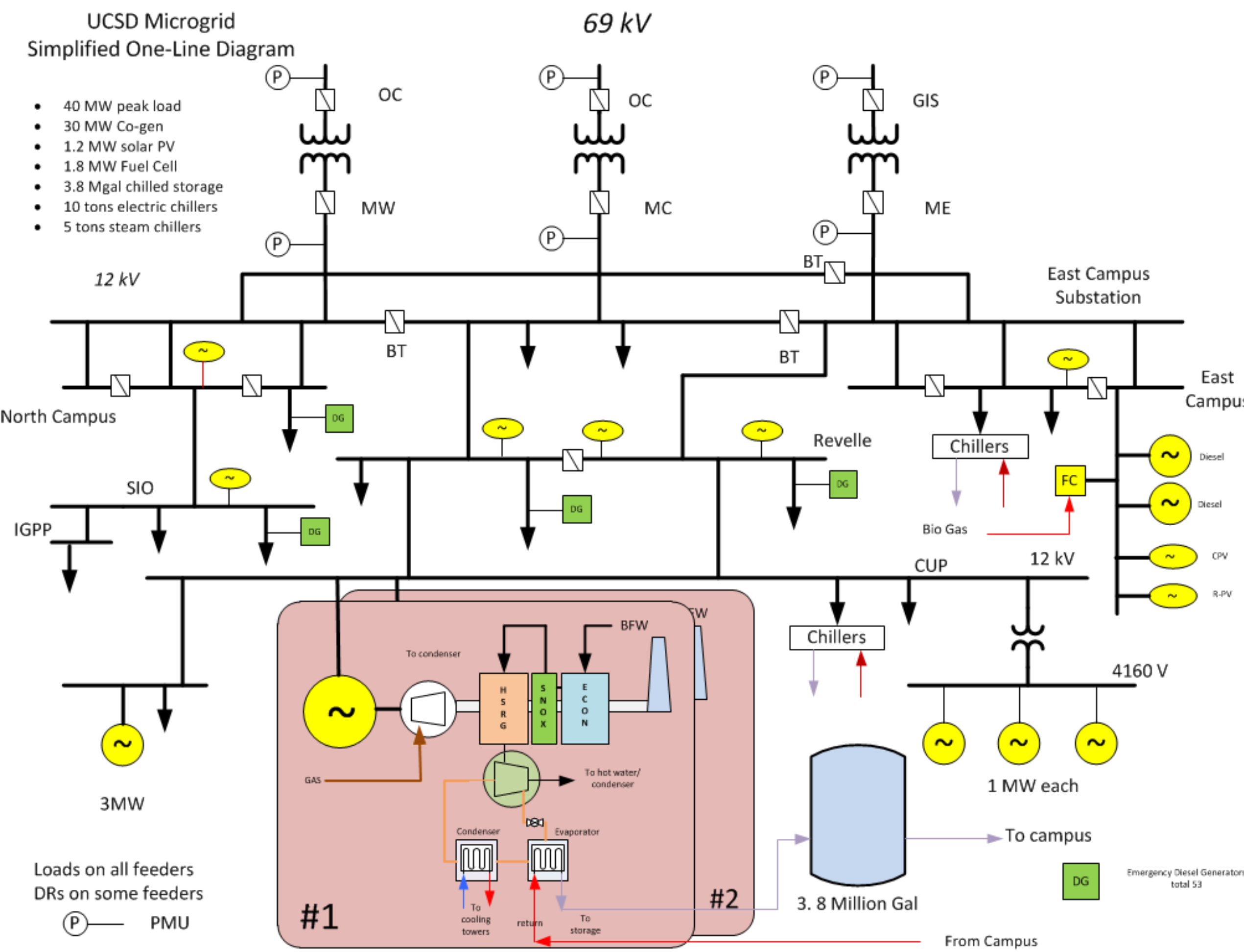
- Communication engine manages external client connections
- OpenDSS engine calculates grid dynamics
- Consumption management engine evaluates power values and sends price feedback

Smart Price Feedback Mechanism

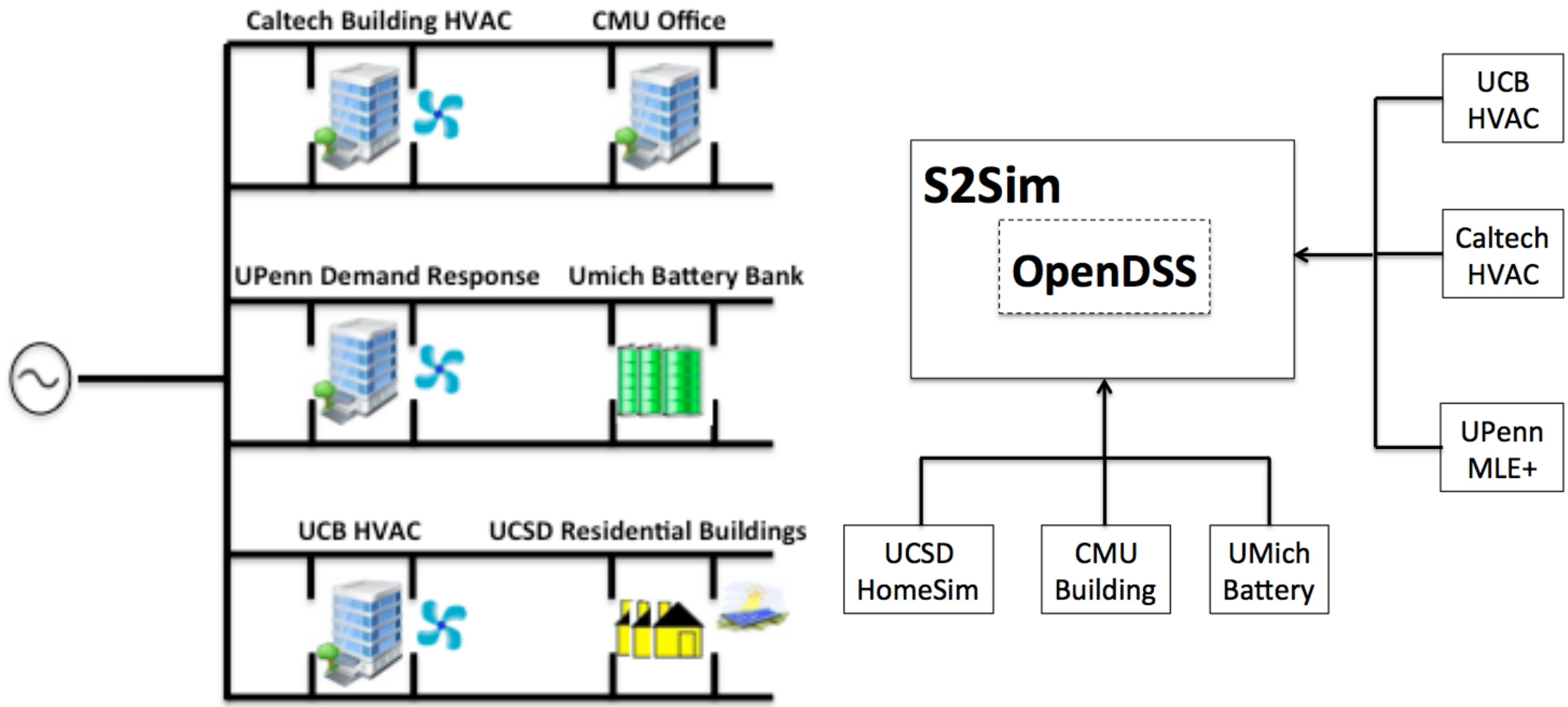


- S^2Sim calculates a price for each client
- Higher deviation → Higher price
- Clients reduce their consumption to avoid high prices

Base Model: UCSD Microgrid



Current System

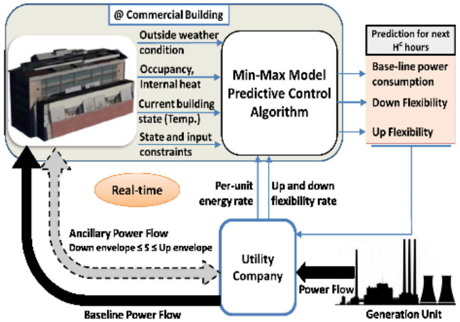


- Current circuit can support up to 12MW, corresponding to a town with approx. 10000 residents
- A joint effort of six universities

Individual Clients
UCSD/UCB/UPenn/CMU/UMich/Caltech

UCB HVAC

- Flexibility of commercial buildings HVAC system is a significant regulation resource.
- Defined and quantified flexibility of building HVAC systems.

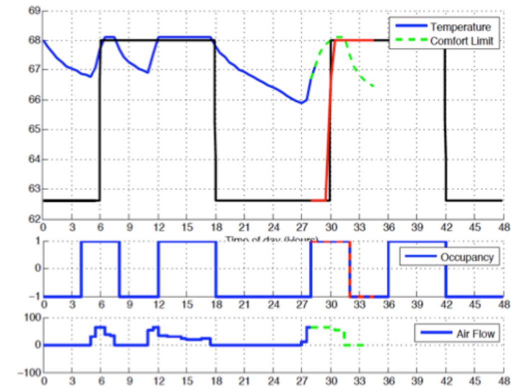


- Designed robust model predictive control framework to guarantee:
  1. Building climate control
  2. Grid flexibility requirements
- Implemented *contractual framework* for costs and benefits to building and grid.

Caltech HVAC

- Resistor-capacitor network to model heat transfer
- MPC to satisfy formal specifications in Signal Temporal Logic

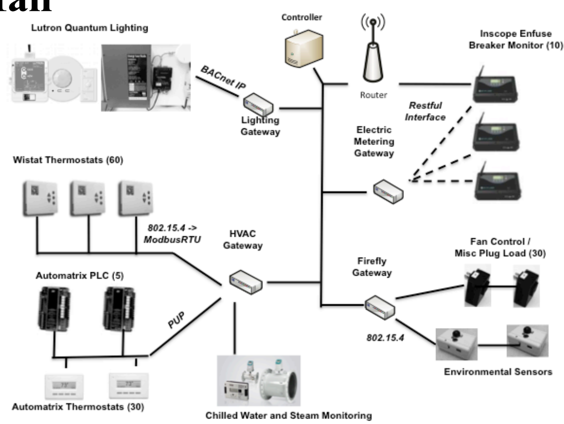
$$\varphi = \Box((\mathrm{occ}_t > 0) \Rightarrow (T_t > T_t^{\mathrm{comf}}))$$



CMU Scaife Hall

40,000 sq ft, 5 story, 140 room, built in 1962 with classrooms, auditorium, offices and labs

- Sensing and control from 6 building automation systems
- Live data streaming into S^2Sim
- Load shedding based on S^2Sim pricing signals

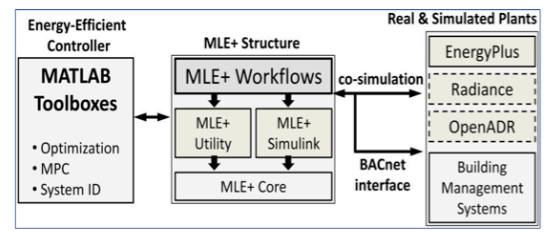


UPenn MLE+

Use price signals for Demand response

Matlab Toolbox for Integrated Modeling and Controls for Energy-Efficient Buildings.

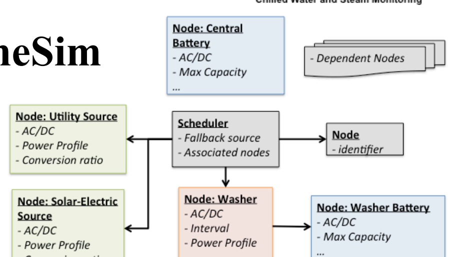
Co-simulate with realistic EnergyPlus buildings



Graphical front-end for workflow from modeling to controller synthesis and deployment

UCSD HomeSim

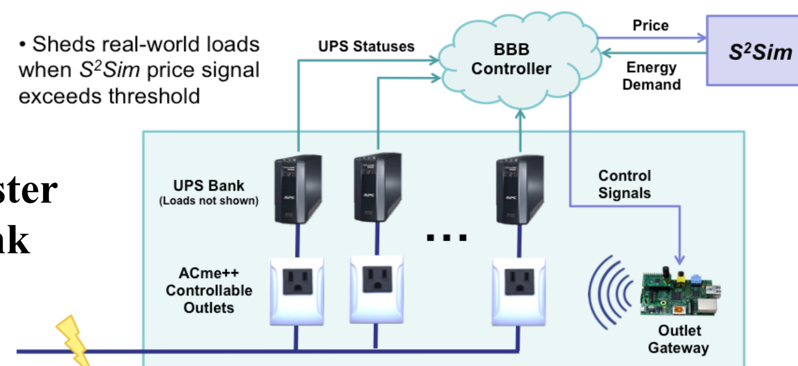
- Residential energy simulation platform
- Can emulate neighborhoods
- Replicated and connected to *S^2Sim*



- Pricing feedback from *S^2Sim* based on consumption, affects *appliance rescheduling, battery charge/discharge periods, matching solar energy with demand*

UMich Beyster Battery Bank

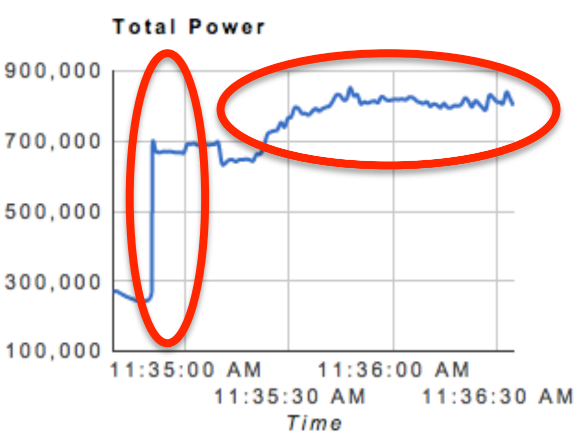
- Sheds real-world loads when *S^2Sim* price signal exceeds threshold

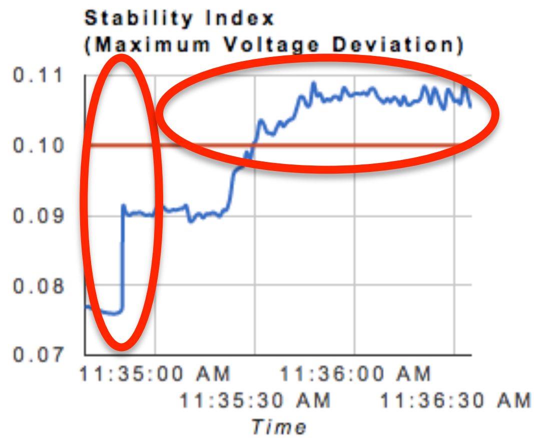


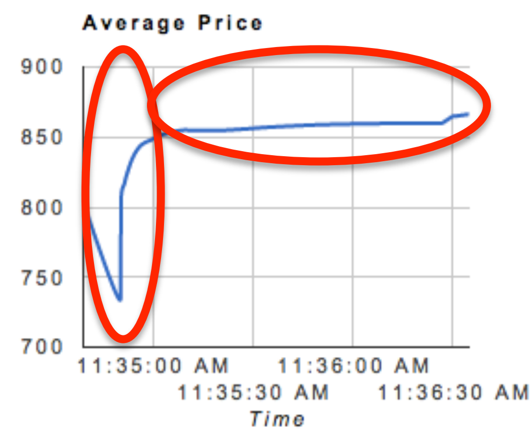
Example Scenario
Step 1: Voltage deviation occurs

Client Id	Client Name	Client Description
118	UCB1	UCB-CALTECH HVAC Controller
117	UCSD2	UCSD Medical Facility
115	UMICH1	Battery Bank Controller
119	UCB2	UCB SDH Hall - Office Building Controller
116	UCSD1	UCSD Campus Dormitory
120	UPENN1	MLE+ HVAC Controller

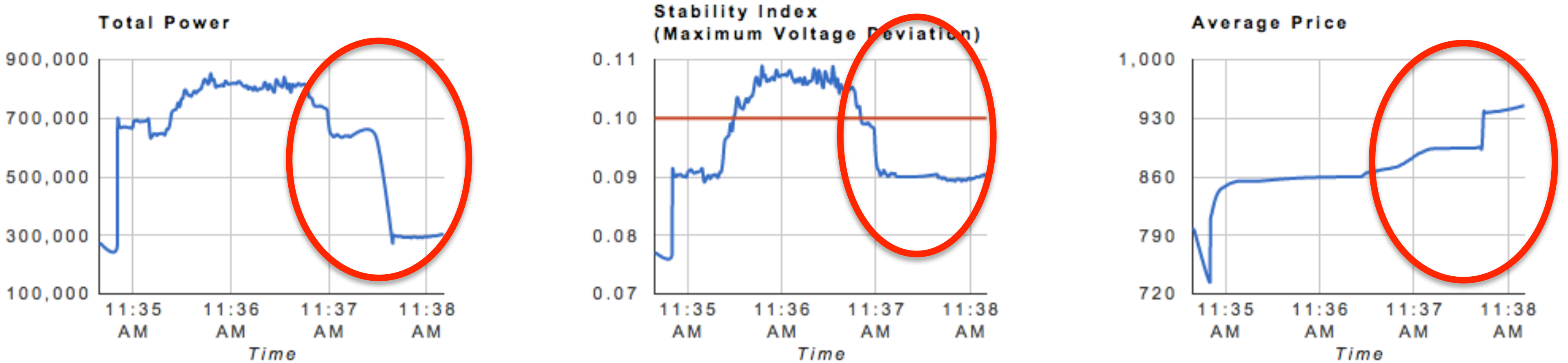
- Six individual *smart* building controller
- Sudden power spikes can increase stability, hence price
- Gradual power spikes result in gradual price increase



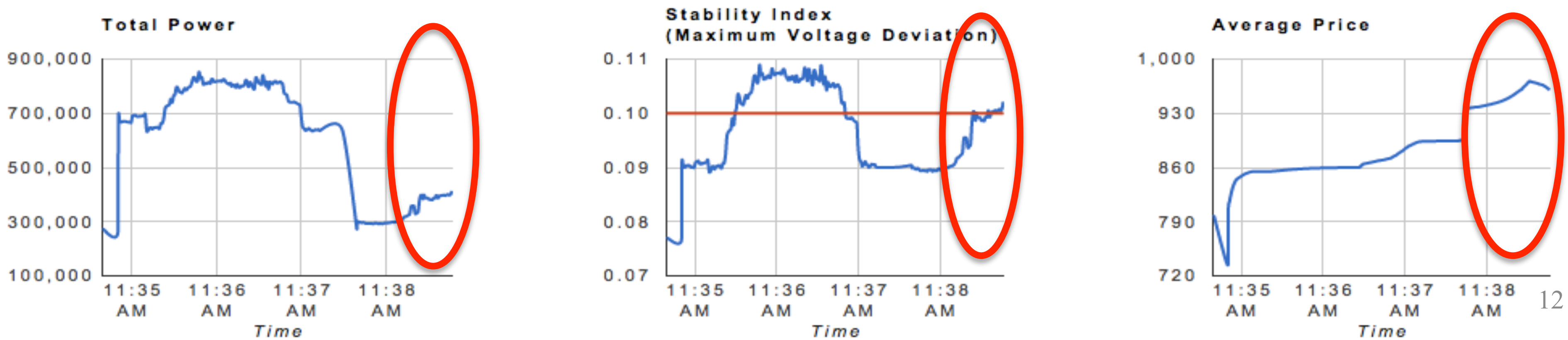




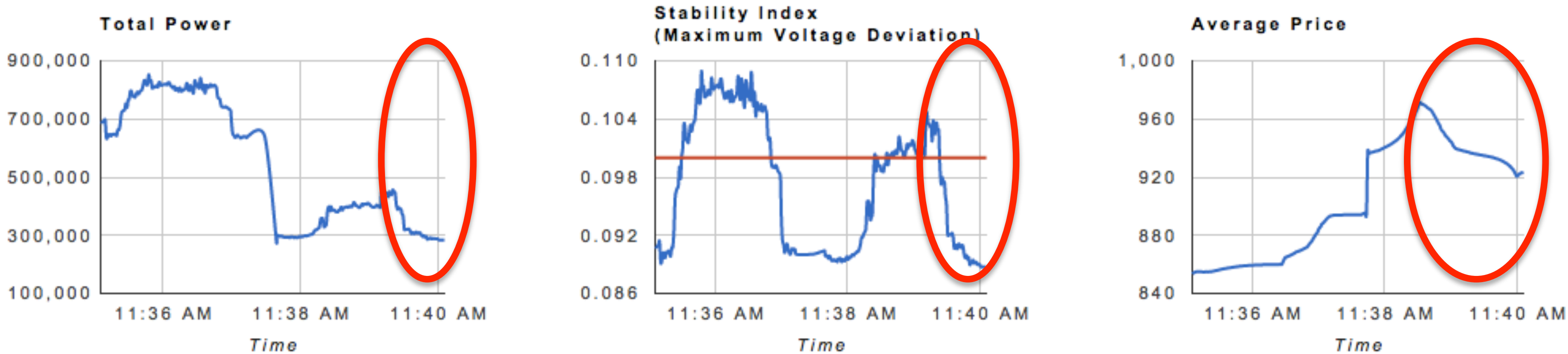
Example Scenario
Step 2: Stability is restored



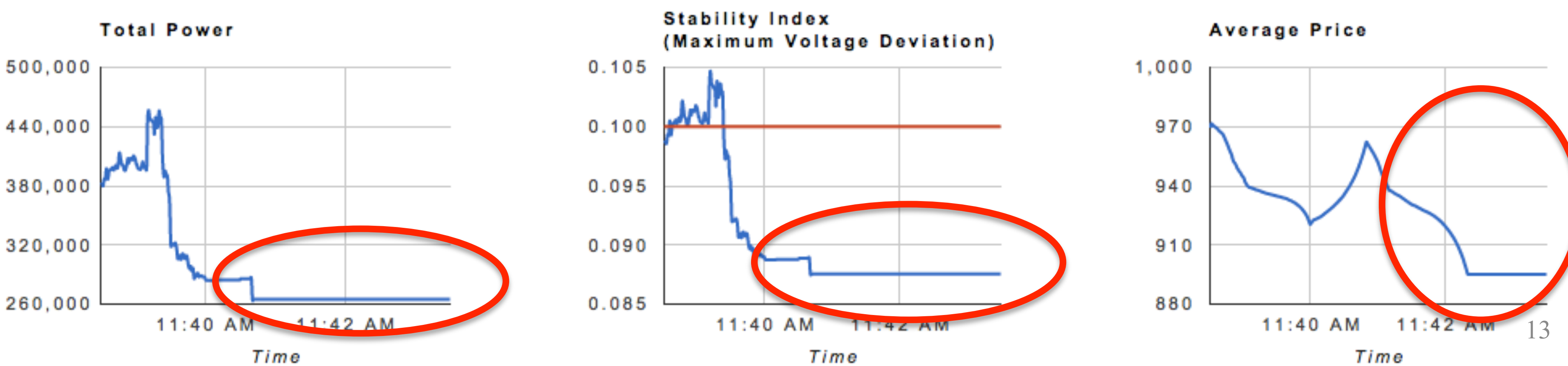
- When consumption decreases, stability is restored
- The price keeps increasing due to high deviation
- After consumption increases again, voltage/price increases



Example Scenario
Step 3: Price reduces



- After a while price starts to reduce
- At the end, the price stabilizes



Next Steps

- Consider the system ***twofold***:
  - ***Building controllers:*** Revise the individual building controllers to account for the grid dynamics
  - ***Grid:*** Smart grid control instead of individual greedy distributed control

- ***Combine*** these separate parts to create an optimal close-loop feedback system
  - ***Joint optimization*** of building savings and grid operation

Summary

- Smart grid energy management is an important topic
  - Residential (house) energy management
  - Building energy management – HVAC in office and commercial buildings
  - Uncoordinated individual control mechanisms can endanger the grid stability
- Distributed energy management in a smart grid
  - **S^2Sim:** Simulates grid dynamics; evaluates and quantifies grid stability
  - Created a realistic grid model, corresponding to a small town
  - Monitor and prevent instability events
  - Devised a smart price feedback mechanism