Price Responsive Loads – Simulation Results

William Burke (billstron@berkeley.edu)
Prof. David Auslander (dma@me.berkeley.edu)

Department of Mechanical Engineering
University of California
Berkeley, California 94720

December 14, 2009

Presentation Overview

- Motivation
- Simulation Overview
- Controls Background
- Local Control
- Systemic Control
- Conclusion
- Future Work

Research Motivation and Goals

Load Management

- Reasons to use
  - Avoid blackouts
  - Avoid peaker plants
- Examples Technologies
  - Load Switches
  - Thermostat Set-Point Adjustment
  - Grid Friendly Appliances

Goal: Explore Residential Load Management Controls Issues

- Local Control – individual unit response
- Systemic Control – aggregate response
- Customer Effects – comfort, cost, etc.

Simulation Motivation

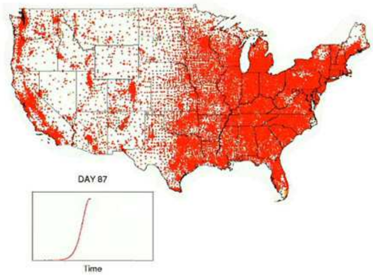
Problem: Difficult to safely vet algorithms

- Equipment is *costly*
- Experiments take *time*
- Failure could be *catastrophic*

Solution: Simulation makes life easy

- *Cheap*
- *Quick*
- *Safe*
- *Repeatable*

Avian Flu Pandemic (Milner, 2006)



(Thankfully, just a simulation)

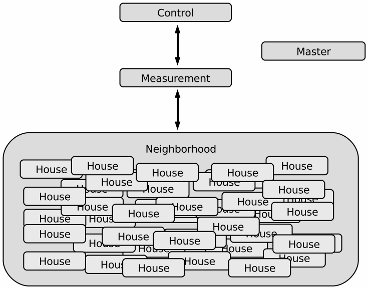
Simulation Overview

Constructed using TranRunC

- Object Oriented style
- Task/State Architecture

Consists of three *main* tasks

- Neighborhood Task
  - Array of independent houses
  - Coordinates timing and communications
- Measurement Task
  - Feeder station
  - Aggregates HVAC power
- Control Task
  - Sends DR messages
  - Flexible



Simulation – House Object

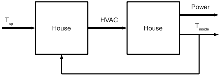
- Reduced Complexity Model
  - 5 state dynamic model
  - Modifiable state parameters

    Randomly generated
- PCT Controlled
  - Strict Task/State Architecture

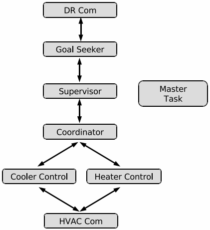
    8 Tasks per house
  - Temperature Control
  - Set-point tables

    Randomly generated
  - DR Communications

House Block Diagram



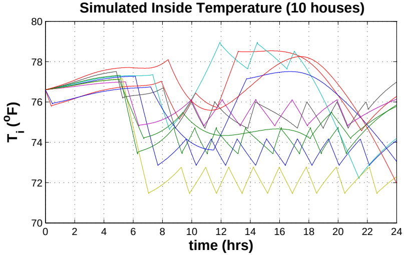
PCT Task Diagram



Simulation – Example Response

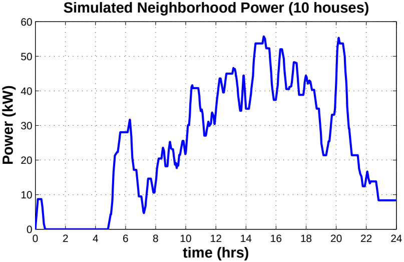
Simulation Construction

- 10 Houses
- Randomly generated parameters
- Randomly generated set-point tables



House Parameter Range

Parameter	Range	Scale
House Size (ft^2)	1661 - 3222	1x - 2x
AC Size (ton)	2 - 10	0.5x - 1.25x
Slab Construction	Y/N	

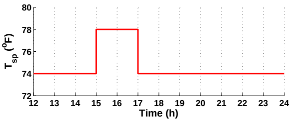


Controls Background – Motivation

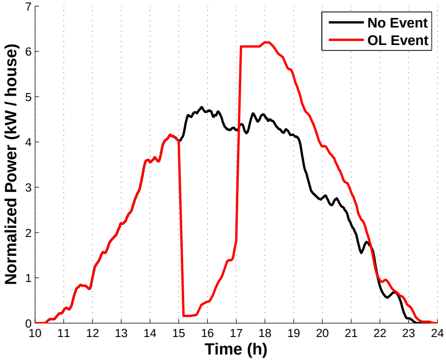
Setback Events

- $4^o F$ Setback for 2 hours
- Each house responds simultaneously

Simple Event Set-point Profile



Simple Event Response



Problem – Not Robust

- Not scalable
- Large discontinuities
- Large payback
- Not equitable

Controls Background – Temperature Control Problem

Traditional Hysteresis Control

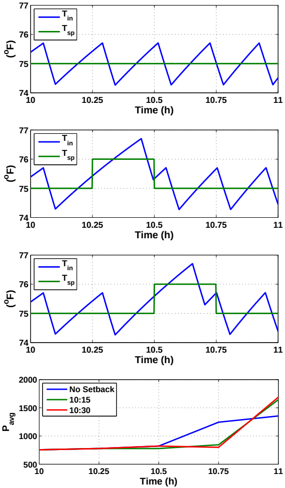
- Robust simple design
- Non-linear
- Difficult to modulate power

Unreliable Setback Power Response

- Difficult to predict output
- Not same for different houses

Unreliable Setback Example

- Three simulations with identical houses
- First – no setback
- Second – 1^oF at 10:15
- Third – 1^oF at 10:30
- Second and third have similar power!



Controls Background – Overview

Open-Loop Control Is Coarse

- Set-point is *not* the same as power
- Not equitable – each house responds differently
- Payback hard to control

Intelligent Control Can Help

- Systemic control
  - Choose meaningful control variable, e.g. price
  - Use feedback (communications or measurements) to gain robustness
  - Apply different techniques – feedback controls, real-time auctions, etc
- Local control
  - Each house responds independently
  - Individual comfort/cost optimization

Systemic Control – Real-Time Auction

Use Auction Mechanism

1. *Bid Call:* At predefined time before, the units submit bids, bids = {expected consumption, price willing to pay}.
2. *Clearing:* Compute clearing price
3. *Auction Period:* Units charged the clearing price for their consumption

Assumptions

- Normalized Price
  - *Price ratio* = $\frac{\textit{current price}}{\textit{normal price}}$
  - Price = 4 means: electricity cost 4 *times* "normal" price
- Market Operation: 15 Minute Period
  - Normal Period – price is a predefined value, i.e. 1
  - Control Period – price is time varying
- Resource is scarce, i.e. agents want more than exists

Systemic Control – Soft Cost Constraints

Possibly Conflicting Goals

- Maintain comfort
- Reduct cost

Cost Limiting Demand Function

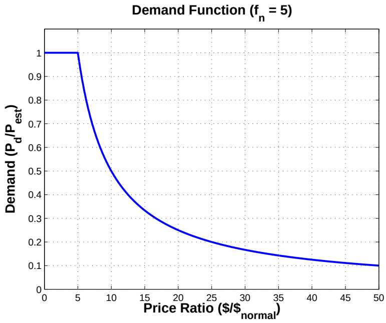
$$P_d = \min\left\{\frac{P_{est} f_n}{p_r}, P_{est}\right\} \quad (1)$$

Cost limited demand – P_d

Estimated power – P_{est}

User input neutral factor – f_n

Energy price ratio – p_r



Systemic Control – Clearing Mechanism

Soft Budget Constrained Mechanism

1. Order the bids in ascending order
2. Iterate on a "function" until the clearing price is between two bids.
3. Compute the allocations

Theorem

The Soft Budget Constraint Mechanism is policy-consistent when the bidders have soft budget constraints.

Benefits

- Game Proof!
- Fast – Computable in polynomial time
- Communication Efficient – only one message per bidder

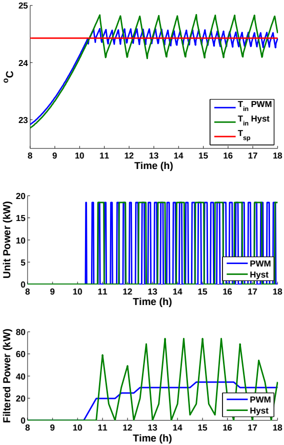
Local Control – PWM Synchronization and Control

Low-Frequency PWM

- On/off HVAC operated proportionally
- Use any control method (PI for example)
- *Simple power modulation using tunable saturation*

PWM Synchronization

- Synchronize PWM period with auction
- Prediction much easier (1 step look-ahead)
- Force load diversity – random start times



Local Control – PWM and Power Control

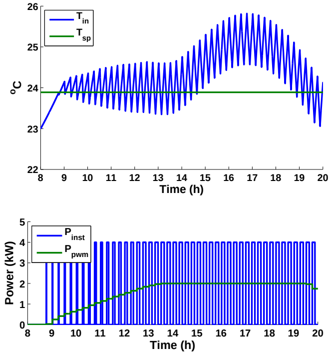
Control with Low-Freq PWM

- Controller directly modulates power
- Controllable saturation limits

Direct Load Control (DLC)

- Radio operated switch
- Cuts power from compressor for specified time
- Variable effect on power
- Adaptive switches

PWM Control with Tunable Saturation



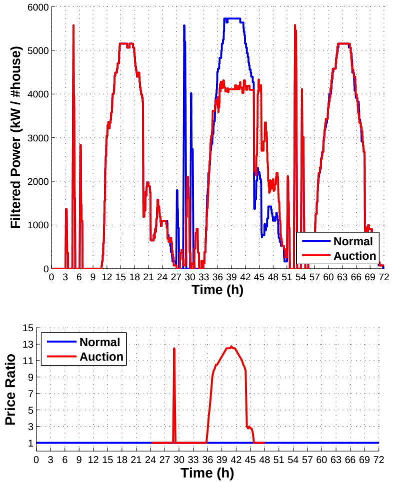
Results – Aggregate Power

3 House Simulation

- Plotting 3 days for visualization purposes
- 7 days to ID house
- Day 8, control begins
- Day 9, no control
- Goal: keep average power below 4kW

Aggregate Power Response

- Price increase at hour 36
- Average power follows 4kW
  - Mismatch due to poor local power estimate



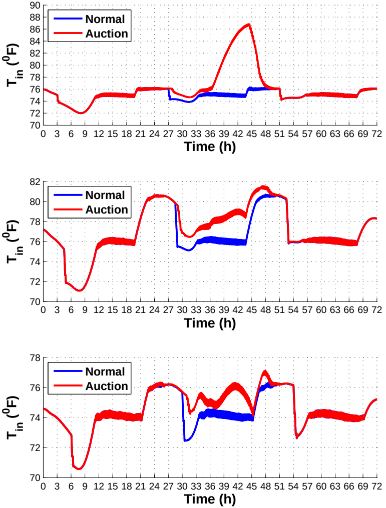
Results – Inside Temperature

3 House Simulation Results

- Same simulation as previous
- Each figure shows inside temperature for one house
- Comparison with and without auction

Inside Temperature Comparison

- Different responses due to different neutral factor
- Inside temperature deviates before price change
  - Mainly due to inaccurate power estimate



Conclusion

Systemic Control Results

- Cost limiting demand curve enables price response
- Cost Constraint Mechanism is fast, efficient, and game proof

Local Control Results

- Low-Frequency PWM simplifies power control
- Synchronization allows for systemic control

Future Work

- Vehicle-to-Grid
- Decentralized Control
- Micro-Grids with Responsive Loads
- Electricity Hedging for "Real" Real-Time Pricing

For More Information

Project
http://response.berkeley.edu

William Burke
billstron@berkeley.edu
http://billstron.com

Bibliography

Milner, J. (2006). *Avian flu pandemic simulation.* (http://jeffmilner.com/index.php/2006/04/08/avian-flu-pandemic-simulation/)