PWM Synchronization for Intelligent Agent Scarce Resource Auction
DSCC2009-2689

ASME 2009 Dynamic Systems and Control Conference
Hollywood, California

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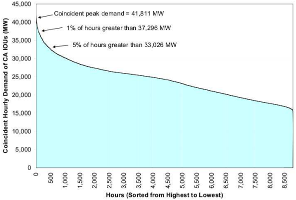
October 14, 2009

Introduction

We don't generate enough power!

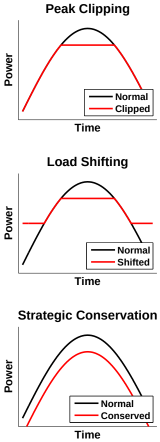
- Dirty and expensive peak power
  - Peaker Plants
  - Pollution
  - Carbon Emissions
- Coarse demand reduction
  - "Flex your power" Days
  - Brown-outs
  - Rolling blackouts
- Reduce the peak power



Load Management

Goal: Manipulate Electricity Demand

- LM Types (Bellarmine, 2000)
  - Peak Clipping
  - Load Shifting
  - Strategic Conservation
- Reasons to use LM
  - Avoid blackouts
  - Avoid peaker plants
- Examples Technologies
  - Load Switches (Navid-Azarbaijani & Banakar, 1996)
  - Thermostat Set-Point Adjustment (Katipamula & Lu, 2006), (Herter, McAuliffe, & Rosenfeld, 2007)
  - Grid Friendly Appliances (Lu & Nguyen, 2006)
  - Problem: Equity not considered



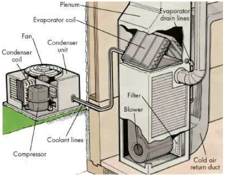
PCT and Smart Grid

Programmable Communicating Thermostat

- AC contributes heavily to summer peak
- Low cost $\Rightarrow$ information poor
- Communications enable load management

Smart Grid

- Communication and control improve robustness
- Aggregate response of intelligent PCTs
- Provide ubiquitous and robust load management



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Research Method

Goal

Develop a framework for distributing shared scarce resources amongst intelligent autonomous agents; specifically, distributing energy to residential home agents controlling HVAC equipment.

Proposed Method – Market Based Approach

- Auction *mechanism* takes bids and returns price
- Intelligent agents automatically respond to price

Previous Work

- Traditional controls approach to price response (Burke & Auslander, 2008b)
- Market based approaches (Akkermans, Ygge, & Gustavsson, 1996), (Gustavsson, 1999), (Kok et al., 2008)

Auction Mechanism

Use Tâtonnement Process (Codenotti & Varadarajan, 2007)

1. Auctioneer suggests a price
2. Bidders respond with expected energy
3. Process repeats with increasing price until objective met

Assumptions

- Normalized Price
  - $Price\ ratio = \frac{current\ price}{normal\ price}$
  - 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

Price Responsive Agents

Robustly Simple Design – Intelligent PCT

- Temperature control for comfort
- Power control for price response
- On-line system identification and prediction for bidding
- Computable demand function for cost to comfort decisions

Low Cost Agent Hardware

- Inexpensive processor
- No additional sensing (T_{inside} only)
- Two-way communications only luxury

Temperature Control Problem

Traditional Hysteresis Control

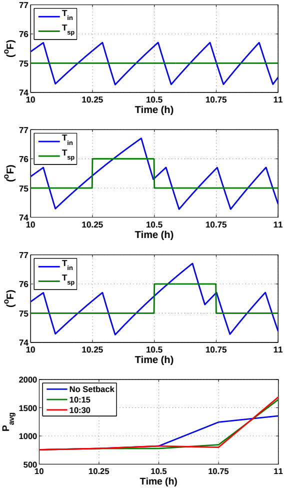
- Robust simple design
- Non-linear
- Difficult to modulate power

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!



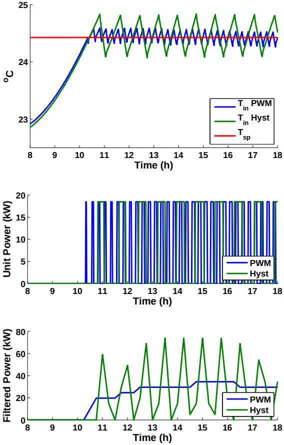
PWM Synchronization and Control

Low-Frequency PWM (Burke & Auslander, 2009a)

- 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



System Identification and Prediction

Estimate Power Consumption

- PWM simplifies this at PWM period
- Outside temperature from communications
- Estimate from PWM and SEER

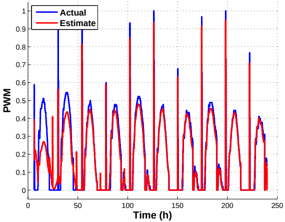
System Identification not *Easy*

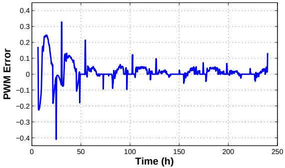
- Saturation present
- Actual system is of large order
- Many unmodeled inputs (e.g. solar)

Non-Linear Least-Squares Like ID

- Parameter Vectors ψ and θ
- ψ_j based on time of day (15min)

$$\hat{P}(k+1) = \psi_j + (T_{out}(k+1) - \theta_2)\theta_1 + (T_{in}(k) - T_{sp}(k))\theta_3 \quad (1)$$





Demand Function

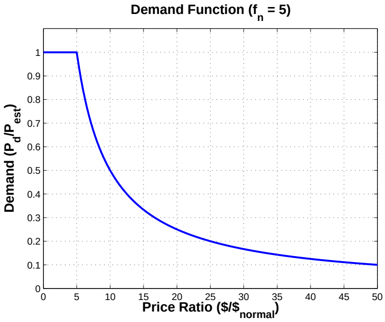
Possibly Conflicting Goals

- Maintain comfort
- Reduct cost

Cost Limiting Demand Function

- Cost limited demand – P_d
- Estimated power – P_{est}
- User input neutral factor – f_n
- Energy price ratio – p_r

$$P_d = \min\left\{\frac{P_{est} f_n}{p_r}, P_{est}\right\} \quad (2)$$



Results

Results Based On Systemic Control Simulation

- Software-in-the-loop simulation
- Independent houses
- Randomly chosen house properties
- Randomly chosen neutral factor
- Previously detailed in (Burke & Auslander, 2008a)

Simulation Advantages

- Low cost
- Fast 72 simulated hours = 2 real minutes
- Different experiments with identical days / populations

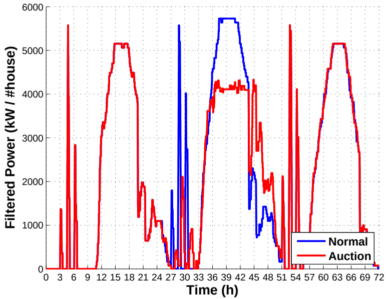
Results – Aggregate Power

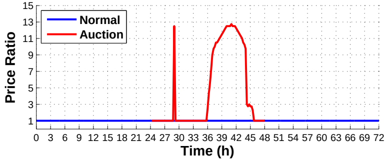
3 House Simulation

- 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





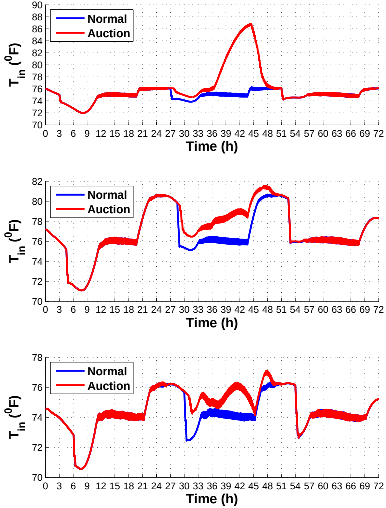
Results – Inside Temperature

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



Discussion

Intelligent Agent Scarce Resource Auction

- Use auction to generate electricity price
- Synchronized PWM simplifies agent power prediction and modulation
- Cost limiting demand curve enables price response

Open Controls Issues

- Refinement of system identification?
- Refinement of the start time randomization

Open Market Design Issues

- We need a better market design
- CLOSED: Soft Budget Constraint Mechanism solves this problem (Burke & Auslander, 2009b)

Acknowledgment

Thanks for Excellent Advice and Encouragement

- Ron Hofmann
- Joseph Eto

Funding Award

- California Energy Commission
- California Institute for Energy and the Environment
- Project number C08019

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Thank You

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