

Modular and Extensible Systemic Simulation of Demand Response Networks

2008 CIGRÉ Canada Conference on Power Systems

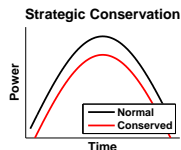
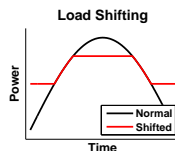
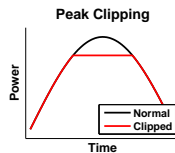
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Demand Response Background

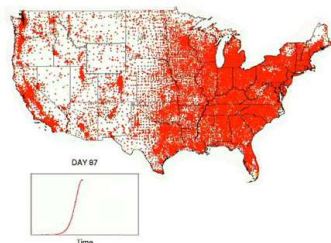
- DR Goal:
 - ▶ Manipulate power demand on the electrical distribution and generation system.
- DR Types [Bellarmine, 2000]:
 - ▶ Peak Clipping
 - ▶ Load Shifting
 - ▶ Strategic Conservation
- Reasons to use DR:
 - ▶ Avoid blackouts
 - ▶ Avoid peaker plants
- Examples Technologies:
 - ▶ Load Switches
 - ▶ Grid Friendly Appliances [Lu and Nguyen, 2006].
 - ▶ AutoDR [Watson et al., 2004].



Simulation Motivation

- **Goal:** Explore main DR controls issues
 - ▶ Systemic Control
 - ▶ Local Control
 - ▶ Disturbances
 - ▶ Customer Effects
- **Problem:** Difficult to safely vet algorithms
 - ▶ Equipment is *costly*
 - ▶ Experiments take *time*
 - ▶ Failure could be *catastrophic*
- **Solution:** Simulations make life easy
 - ▶ *Cheap*
 - ▶ *Quick*
 - ▶ *Safe*

Avian Flu Pandemic [Milner, 2006]



(Thankfully, just a simulation)

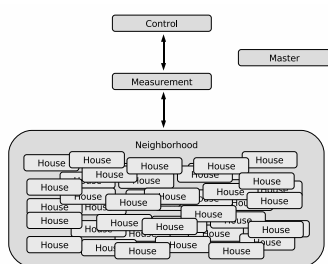
Simulation Approach

- Restricted scope
 - ▶ Residential HVAC (Easily Expanded)
 - ▶ Inexpensive Equipment (PCT)
- Approach
 - 1 Thermal Simulation of Individual Houses
 - 2 Simulate PCT in Each House
 - 3 Randomize House/PCT Parameters
 - 4 Examine Aggregate Response
- Major Contribution – Extensible Throughout
 - ▶ Thermal Simulation: random houses easy to create
 - ▶ Thermostat: easy to change local control
 - ▶ Systemic Control: try different global control algorithms

Systemic Simulation Overview

- Uses Strict Task/State Architecture
- Constructed using TranRunC
- 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 Task Diagram



Systemic Simulation – House Object

- Reduced Complexity Model

- ▶ 5 state dynamic model
- ▶ Modifiable state parameters
Randomly generated

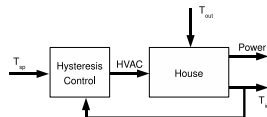
- PCT Controlled

- ▶ Strict Task/State Architecture
8 Tasks per house
- ▶ Hysteresis Control

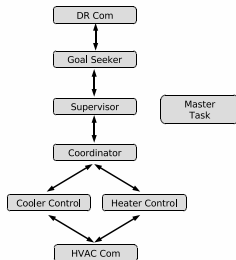
```
e = T_s - T_air
if u_{AC} == TRUE and e >= C_c - C_a
  then u_AC = FALSE
if u_{AC} == FALSE and e <= -C_h
  then u_AC = TRUE
```

- ▶ Set-point tables
Randomly generated
- ▶ DR Communications

House Block Diagram



PCT Task Diagram



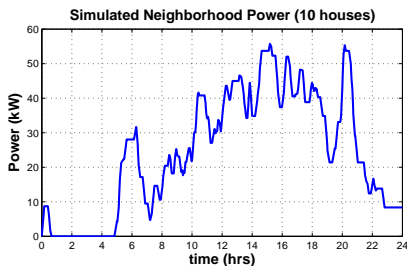
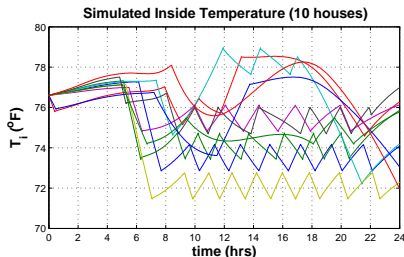
Systemic Simulation – Example Response

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	



Individual House Demand Response

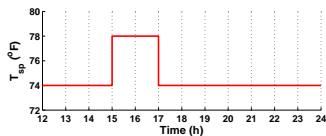
- Different local control strategies easily tested
 - ▶ Each house has independent control
 - ▶ Local Control Task extensible
- Example control strategies
 - ▶ Setback DR
 - DR command states thermostat setback
 - Allows temporally different setbacks – ramps, random times, etc
 - ▶ Cost Ratio DR
 - Learn past duty cycle/cost
 - Limit current power
 - DR Signal = price ratio
 - e.g., '4.5' means 'Power costs 4.5 x normal price.'
 - Each house has a price tolerance
 - e.g., '1.5' means 'I will tolerate 1.5 x normal cost.'

Set-point DR – Simple Event

Event Description

- 4°F Setback for 2 hours
- Each house responds simultaneously

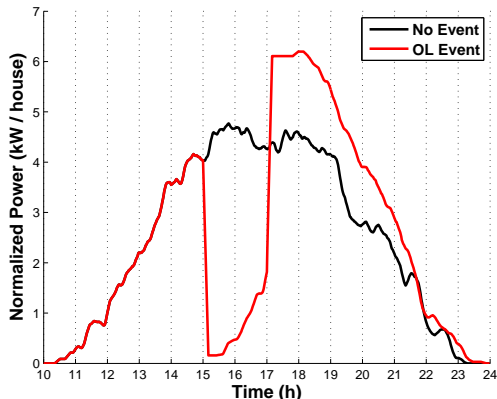
Simple Event Set-point Profile



Notice

- Large discontinuities
- Large payback

Simple Event Response

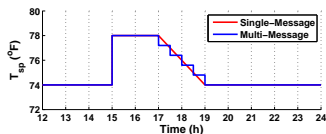


Set-point DR – Payback Mitigation

Ramp Types

- Multi-message ramp
- Single-message ramp

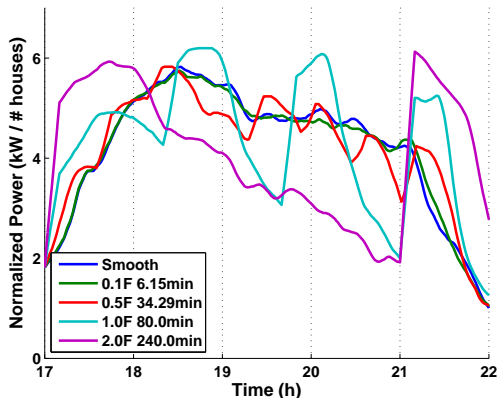
Ramped Event Set-point Profile



Notice

- Large spikes with multi-message
- Single Message better

Ramped Event Response



Cost Ratio DR – 2 Day Example

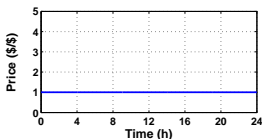
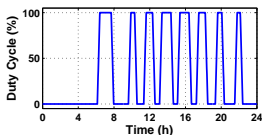
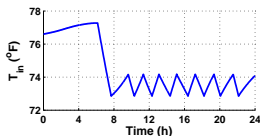
Simulation Parameters

- Neutral Factor: 2
- DR Event
 - ▶ Price Ratio 4
 - ▶ From 3-5pm

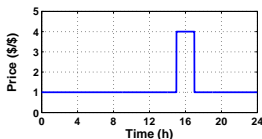
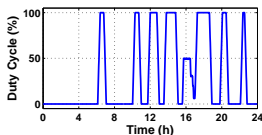
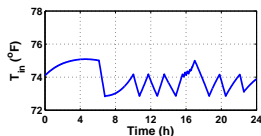
Notice

- Lower AC duty cycle during price increase
- Increased T_{in} during price increase

Day 1: No Price Change



Day 2: Price Increase



Cost Ratio DR – Systemic Response

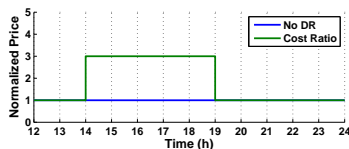
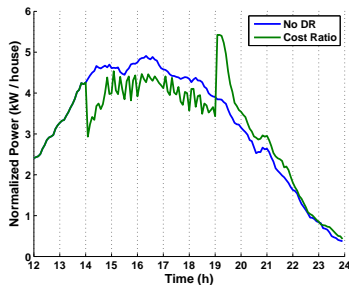
California CPP Event

- Price increase of 3x
- from 2-7pm

Notice

- Houses have random cost preferences
- Response still follows T_{out}
- Basis for closed loop control

Response to CPP Rate



Conclusions

Conclusions

- Demonstrated Systemic Simulation
 - ▶ Flexible
 - ▶ Extensible
- Demonstrated Different Control Strategies
 - ▶ Simple DR Events
 - ▶ Rebound Mitigation Techniques
 - ▶ Cost Ratio DR

Future Work

- Add residents to the model
 - ▶ Use stochastic state machine to model resident actions
 - ▶ Use the same random property assignment as used for physical properties
- Refine Cost Ratio DR Predictions
- Systemic Control
 - ▶ Closed Loop Control Strategies
 - ▶ Estimation methods for HVAC energy usage

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