Effects of Price-Responsive Residential Demand on Retail and Wholesale Power Market Operations

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Presentation Outline

• Overview of the Integrated Retail/Wholesale (IRW) project
• IRW test bed illustration
• Intelligent A/C controller
• Load aggregation
• Initial test case with illustrative findings
• Concluding remarks
IRW Project: Integrated Retail/Wholesale Power System Operation with Smart-Grid Functionality

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Meaning of “Smart Grid Functionality”? 

For our project purposes:

**Smart-grid functionality =**

Market design and resource enhancements permitting more responsiveness to the needs, preferences, and decisions of retail energy consumers.

**Examples:** Introduction of advanced metering and other technologies to support

- flexible dynamic-price contracting between suppliers (“Load-Serving Entities”) and retail energy consumers
- integration of distributed renewable energy resources, e.g., consumer-owned photovoltaic (PV) panels
IRW Test Bed Illustration

5-bus test system

AMES

Aggregate

MySQL

Modeling of Households

Load

Price

GridLAB-D

GridLAB-D

GridLAB-D

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New Energy Horizons
Opportunities and Challenges

Slide 5 of 21
Integrated Retail and Wholesale Effects of Price-Responsive Load

- Intelligent A/C Controller
- Aggregation of A/C Load
- Dynamic Feedback Loop
Intelligent A/C Controller

Forecast of environmental conditions

Retail price sequence

Scheduling (on remote or local server)

House Thermal Dynamics (ETP model)

(for A/C motor)

Ctrl

Estimator

for Mass Temp.

Air Temp.

On/Off

Environmental conditions

User-defined preferences

(entered via a user-friendly graphical interface)

Wall Control Unit

Comfort Cost

Price

User Preferences
ETP Model

\[
\frac{dT^a}{dt} = \frac{1}{C^a} \left[ (T^o - T^a) U^a + (T^m - T^a) U^m + \dot{Q} + \dot{Q}^a \right]
\]

\[
\frac{dT^m}{dt} = \frac{1}{C^m} \left[ (T^a - T^m) U^m + \dot{Q}^m \right]
\]

where

\[
\dot{Q}^a = f(\dot{Q}^s, \dot{Q}^i)
\]

\[
\dot{Q}^m = g(\dot{Q}^s, \dot{Q}^i)
\]

\(T^a, T^m\) and \(T^o\): Air mass, solid mass, and outside temperatures

\(\dot{Q}^s\) and \(\dot{Q}^i\): Solar and internal heat flow rates

\(C^a, C^m\) and \(U^a, U^m\): Heat capacity and thermal conductance
Forcing Terms

Outside Temperature ($^\circ F$)

Solar Heat Flow Rate ($kBTU/h$)

Internal Heat Flow Rate ($kBTU/h$)

Relative Humidity (%)
Home Resident Attributes

- Comfort function (utils) measuring home resident’s comfort level as a function of inside air temperature
- Bliss temperature = Inside air temperature at which the home resident achieves maximum comfort
- $\alpha$ = Parameter (utils/$\$$) measuring resident’s optimal trade-off between thermal comfort and electricity cost (higher $\alpha$ → higher concern for cost and less for comfort)
- Home-occupancy times of the home resident
Results: Resident at Home

Bliss Temperature: 74 °F
Results: Resident Not Home (8 am – 5 pm)

Bliss Temperature: 74 °F
Load Aggregation in a Distribution Feeder

- Non-price-responsive load (from GridLAB-D)
  - Household appliances
  - Lighting loads
- Intelligent A/C load
  - Traditional A/C systems replaced with intelligent A/C systems with differing attributes
Load Aggregation in a Distribution Feeder

Non-Price-Responsive Load

Intelligent A/C Load

Retail Price ($/MW\cdot h$)
Initial Test Case: Five-Bus Grid
**Initial Test Case: Five-Bus Grid**

- **Initial test-case assumption**: LSE’s DAM demand bid (load forecast) for day D is the LSE’s actual load realized on day D-2.
How Should an LSE Forecast Intelligent Load?

Illustration of how forecast errors can affect prices

Deviation between DAM and RTM Prices

Price Deviation ($/MWh)

Time (h)

Deviation between DAM and RTM Prices

Illustration of how forecast errors can affect prices

Price Deviation ($/MWh)

Time (h)
LSE’s Net Earnings for Hour H of Day D Resulting from LSE’s Cleared DAM Demand Bid on Day D-1

\[
\text{NetEarnings}(H, D) = [m + LMP_{H,D-1}^{DA}] \cdot \text{Load}_{H,D}^{RT}
\]

\[
- LMP_{H,D-1}^{DA} \cdot \text{Load}_{H,D-1}^{DA}
\]

\[
+ LMP_{H,D}^{RT} \cdot [\text{Load}_{H,D-1}^{DA} - \text{Load}_{H,D}^{RT}]
\]

\(LMP^{DA}\) and \(LMP^{RT}\) : DAM and RTM locational marginal prices (LMPs)

\(Load^{DA}\) : LSE’s cleared DAM demand bid

\(Load^{RT}\) : RTM actual load

\(m\) : Markup added by LSE to DAM LMP
DAM/RTM System Gives LSEs Incentive to Make Accurate Load Forecasts

\[
\text{NetEarnings}(H,D) = m \cdot \text{Load}_H^{RT} - \Delta \text{LMP}_H^{DA} \cdot \Delta \text{Load}_H^{DA} + [\text{LMP}^\text{DA}_{H,D-1} - \text{LMP}^\text{RT}_{H,D}] \cdot [\text{Load}^\text{RT}_{H,D} - \text{Load}^\text{DA}_{H,D-1}]
\]

This term will typically be positive, vanishing only if LSE’s DAM bid correctly forecasts actual RTM load, since price & load outcomes are positively correlated (high/high or low/low) all else equal.
Ongoing Research Topics

• Further investigation of the dynamic IRW feedback loop

• Improved ISO and LSE forecasting methods for handling price-responsive retail load

• Development of more realistic load aggregation methods
Thank You!