Analysis of Dynamic Retail Electricity Rates and Domestic Demand Response Programs

Taylor VanderKley
Ahlmahz Negash, Daniel Kirschen
7-25-2014

IEEE Conference on Sustainable Technology
Overview

• Background
• Modified Real Time Price (mRTP)
• Rate Comparisons
  – Case Study 1: House Categorization
  – Case Study 2: Yearly Savings Analysis
• Findings
• Further Exploration
Background
State of Residential DR in the U.S.

• Advanced Metering Infrastructure (AMI) penetration increased from 4.8 % in 2008 to 23.9 % in 2012

• However only 2.1 million (~1.68 %) US residential customers reported TOU participation in 2012

• The proposed rate design, “Modified Real Time Price” (mRTP) attempts to solve the issue of participation

Modified Real Time Price (mRTP)
California ISO (CAISO)
Grid Condition RTP

• Customers receive a signal updating them on grid conditions

• Scale from 0-10, matching the grid condition to a certain multiple of the off or on peak average price
CAISO Grid Condition Index

<table>
<thead>
<tr>
<th>Visual Cue</th>
<th>Grid State</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>0</td>
<td>n/a</td>
<td>&lt;= $-30/MWh</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>&gt; $-30/MWh</td>
<td>&lt;= $0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>&gt; $0</td>
<td>&lt; off-peak average</td>
</tr>
<tr>
<td>Green</td>
<td>3</td>
<td>&gt;= off-peak average</td>
<td>&lt; on-peak average</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>&gt;= on-peak average</td>
<td>&lt; 1.1 * on-peak average</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>&gt;= 1.1 * on-peak average</td>
<td>&lt; 1.33 * on-peak average</td>
</tr>
<tr>
<td>Yellow</td>
<td>6</td>
<td>&gt;= 1.33 * on-peak average</td>
<td>&lt; 1.67 * on-peak average</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>&gt;= 1.67 * on-peak average</td>
<td>&lt; 2 * on-peak average</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>&gt;= 2 * on-peak average</td>
<td>&lt; 3 * on-peak average</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>&gt;= 3 * on-peak average</td>
<td>&lt; 10 * on-peak average</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>&gt;= 10 * on-peak average</td>
<td>n/a</td>
</tr>
</tbody>
</table>

- **Blue**: Use Now
- **Green**: Use Freely
- **Yellow**: Use Cautiously, Defer Tasks if Possible
- **Red**: Use Sparingly, Shut Down Low Priority Devices

mRTP

- Uses the CAISO Grid Condition Index
- Gives customers several rate options rather than one flat rate
- Includes a real time component and a flat rate component

\[ B \times G + R_{min} = mRTP \]

\( R_{min} \) is the minimum rate, \( B \) is the customer chosen risk factor, \( G \) is the CAISO grid index.
Daily Example: Comparison of Rates

![Graph showing comparison of rates](image)
Rate Comparisons
Case Study 1: House Categories

• Smart meter data from nine houses were analyzed.

• Houses fell into one of three categories
  – Houses that benefit from mRTP (Houses 6-9)
  – Houses that benefit from the flat rate (Houses 1, 2 & 4)
  – Houses that are indifferent to rate design (Houses 3 & 5)
Average Daily Loads: Houses 6-9

Average Daily Load of Homes that Benefit from mRTP

Time of Day (hr)

Average Load (kW)
Average Daily Loads: Houses 1, 2 & 4

Average Daily Load of Homes that Benefit from Flat Rate

Hour of Day (hr)

Average Load (kW)
Average Daily Loads: Houses 3 & 5

Average Daily Load of Homes that are Indifferent to Rate Design

- **House 3**
- **House 5**

Hour of Day (hr)

Average Load (kW)
Case Study 2: Yearly Savings Analysis

• Goals:
  – Determine the amount of potential savings of each household ($\Delta$), & pick a representative for each category
  – Differentiate between savings due to switching to mRTP and the savings due to shifting/reducing load
  – Determine who service providers should focus their attention
Assumptions

• When households participate, they shift their load without reducing

• Household shift behavior is the same
  – Dependent on two factors:
    • $n$, the # of hours participated daily
    • $s$, the overall amount of shifted load in kW
Quantifying DR Participation

• Two metrics to quantify DR: Frequency ($F$) & Magnitude ($M$)
  – Frequency is measured in percent of hours where shifting occurs
  – Magnitude is measured in percent of load shifted at each instance of participation
  – $F$ and $M$ are both broken into 4 subsets
Quantifying DR Participation (cont.)

<table>
<thead>
<tr>
<th>Frequency Participation</th>
<th>F (%)</th>
<th>Participation Threshold (G)</th>
<th>Actual # of Active Hours (for 2011 PJM Load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Frequent</td>
<td>&gt;10</td>
<td>&gt;=4</td>
<td>1198</td>
</tr>
<tr>
<td>Frequent</td>
<td>~5-10</td>
<td>&gt;=5</td>
<td>755</td>
</tr>
<tr>
<td>Occasional</td>
<td>~2-5</td>
<td>&gt;=6</td>
<td>319</td>
</tr>
<tr>
<td>Rare</td>
<td>&lt;2</td>
<td>&gt;=7</td>
<td>118</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Magnitude Participation</th>
<th>M (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>~10</td>
</tr>
<tr>
<td>Moderate</td>
<td>~25</td>
</tr>
<tr>
<td>High</td>
<td>~33</td>
</tr>
<tr>
<td>Very High</td>
<td>~50</td>
</tr>
</tbody>
</table>

Breakdown of the Four Different Frequency Participation Levels

Breakdown of the Four Different Magnitude Participation Levels
Yearly Savings Analysis (cont.)

• One household was selected for each category
  – House 8: Benefits from mRTP, $\Delta = +6.87\%/\text{yr}$
  – House 4: Benefits from the flat rate, $\Delta = -3.52\%/\text{yr}$
  – House 3: Indifferent to rate design, $\Delta = 0.03\%\text{/yr}$
Yearly Savings: Benefits from mRTP

Yearly Savings as a Function of Participation Level: House 8

- Rare-Very High
- Occasional-Very High
- Frequent-Very High
- Very Frequent-Very High
- Rare-High
- Occasional-High
- Frequent-High
- Very Frequent-High
- Rare-Moderate
- Occasional-Moderate
- Frequent-Moderate
- Very Frequent-Moderate
- Rare-Low
- Occasional-Low
- Frequent-Low
- Very Frequent-Low

Yearly Change in Bill (%)
Component of Yearly Savings Due to Shifting Load: Benefits from mRTP

Yearly Savings as a Function of Participation Level: House 8

- Risk 10 Shifted Component
- Risk 1 Shifted Component

Participation (Frequency-Magnitude): Rare-Very High, Occasional-Very High, Frequent-Very High, Very Frequent-Very High, Rare-High, Occasional-High, Frequent-High, Very Frequent-High, Rare-Moderate, Occasional-Moderate, Frequent-Moderate, Very Frequent-Moderate, Rare-Low, Occasional-Low, Frequent-Low, Very Frequent-Low

Yearly Change in Bill (%): 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5
Yearly Savings: Benefits from Flat Rate

Yearly Savings as a Function of Participation Level: House 4

- Rare-Very High
- Occasional-Very High
- Frequent-Very High
- Very Frequent-Very High
- Rare-High
- Occasional-High
- Frequent-High
- Very Frequent-High
- Rare-Moderate
- Occasional-Moderate
- Frequent-Moderate
- Very Frequent-Moderate
- Rare-Low
- Occasional-Low
- Frequent-Low
- Very Frequent-Low

Change In Yearly Bill (%)
Component of Yearly Savings Due to Shifting Load: Benefits from Flat Rate

Yearly Savings as a Function of Participation Level: House 4

- Risk 10 Shifted Component
- Risk 1 Shifted Component

- Rare-Very High
- Occasional- Very High
- Frequent- Very High
- Very Frequent- Very High
- Rare- High
- Occasional- High
- Frequent- High
- Very Frequent- High
- Rare- Moderate
- Occasional- Moderate
- Frequent- Moderate
- Very Frequent- Moderate
- Rare- Low
- Occasional- Low
- Frequent- Low
- Very Frequent- Low

Change in Yearly Bill (%)
Yearly Savings: Indifferent from Rate Design

Yearly Savings as a Function of Participation Level: House 3

- Risk 10 vs. Flat Rate
- Risk 1 vs. Flat Rate

- Rare-Very High
- Occasional-Very High
- Frequent-Very High
- Very Frequent-Very High
- Rare-High
- Occasional-High
- Frequent-High
- Very Frequent-High
- Rare-Moderate
- Occasional-Moderate
- Frequent-Moderate
- Very Frequent-Moderate
- Rare-Low
- Occasional-Low
- Frequent-Low
- Very Frequent-Low

Yearly Change in Bill (%)
Component of Yearly Savings Due to Shifting Load: Indifferent to Rate Design

Yearly Savings as a Function of Participation Level: House 3

Risk 10 Shifted Component
Risk 1 Shifted Component

Rare-Very High
Occasional- Very High
Frequent- Very High
Very Frequent- Very High

Rare-High
Occasional- High
Frequent- High
Very Frequent- High

Rare-Moderate
Occasional- Moderate
Frequent- Moderate
Very Frequent- Moderate

Rare-Low
Occasional- Low
Frequent- Low
Very Frequent- Low

Yearly Change in Bill (%)

-1 0 1 2 3 4 5 6
Households with average load profiles like the indifferent category, have the most incentive to participate in DR with mRTP.
Further Exploration

• Customer behavior is not ideal: Developing a model with random customer behavior
• Exploration of mRTP in different regions of the United States
• Quantifying the effect of grid condition indexing (incentivizing participation on the front end)
Questions?