Conservation Voltage Reduction Econometric Impact Analysis

Presented to

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Presented by

Sanem Sergici, The Brattle Group

(in collaboration with Pepco MD team led by Steve Sunderhauf and Basil Allison)

ASSOCIATION OF ENERGY SERVICES PROFESSIONALS

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Agenda

Background

Data Overview

Methodology

- Selecting Control Groups
- Conservation Analysis
- Peak Analysis

Results

- Conservation Analysis
- Peak Analysis

Background: What is Conservation Voltage Reduction?

- Conservation Voltage Reduction (CVR) is a reduction in feeder voltage which results in a reduction in energy consumption
- Key engineering principal: Voltage can be kept on lower end of American National Standard Institute standard voltage band of 114-126 volts
- Pepco Maryland's implementation of Advanced Metering Infrastructure has enabled Pepco to monitor and vary voltage levels while remaining within specified standards

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Background and Objectives

- Pepco MD initiated the CVR pilot program on August 1, 2013. It encompasses 7 substations
  - Approximately 45,000 residential customers
  - Approximately 4,000 non-residential customers
- The voltage levels were reduced by 1.5% at those substations participating in the pilot
- The objective of our study was to:
  - Quantify the conservation impact of the CVR program for residential and non-residential customers
  - Quantify the peak demand impact of the CVR program for residential and non-residential customers

Background
Overview of Previous Research- I

- Most studies have been engineering studies as opposed to econometric analysis, and have not estimated a peak demand vs energy conservation impact, or a residential vs non-residential impact
- Several studies have demonstrated that the implementation of CVR leads to decreased consumption, but there is no consensus for a “CVR factor” (energy reduction / voltage reduction)
  - Studies indicate a relatively wide range of CVR factors, generally ranging from .5 to 1

Background
Overview of Previous Research- II

- Residential and non-residential load may respond differently the CVR as non-residential load generally has a larger share of motor load, which may mitigate the effect of CVR
- CVR as an idea has been around for decades, but has recently gained more attention as it is becoming more cost-effective and also easier to control/monitor due to the deployment of AMI

Background
Review of Select Previous Studies- I

- **West Penn Power Company (2014)**
  - Study reduced voltage by 1.5% doing a "on for a day, off for a day" approach
  - Similar to Pepco MD study in that it uses difference-in-differences methodology
  - Range of CVR factors but average is 0.86
- **Indianapolis Power & Light Company (2013)**
  - Study turned "on" CVR for a few short periods in 2012 and 2013, and compared drop in usage during those periods to predict an impact
  - Study estimated a CVR factor of 0.7-0.8

Background
Review of Select Previous Studies- II

- **Dominion Virginia Power (2012)**
  - Study compared baseline pre-CVR period to consumption during period after CVR was implemented
  - Impact calculate using a day-pairing method instead of difference-in-differences
  - Day-pairing method matches day from the pre-treatment period to days in the post-treatment period to calculate CVR impact
  - Study found a CVR factor of 0.92

Background
Review of Select Previous Studies- III

- **Pacific Northwest National Laboratory (2010)**
  - Estimated impact of CVR on 24 modeled feeders by running a one-year simulation of system and re-running with reduced voltage levels
  - Results were varied, but almost all feeders experienced some reduction in both peak demand and energy consumption
- **Northwest Energy Efficiency Alliance (2007)**
  - Study measured CVR impact by comparing 24 hours on and 24 hours off, instead of using a set control group
  - Study found CVR factors for peak demand ranging from 0.55-1.12 and for energy ranging from 0.3-0.86

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Data Overview

The following datasets were utilized for this analysis

- Billing data
- Hourly consumption
- Weather data (dew point and drybulb temperatures)
- Advanced metering infrastructure (AMI) activation date
- Participation in Demand Side Management programs
- Recipients of Opower Home Energy Reports
- Net energy metering (NEM) status

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Data Overview

- For the peak analysis, the primary dataset was hourly data from AMI for June-August 2013 and 2014, hours-ending 15-19

- For the conservation analysis, the primary dataset was monthly billing data from September 2012 through August 2014
  - Monthly data used because hourly data was only available for summer before CVR implementation as AMI activation started in early 2012 but was not completed until mid-2013

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- **Selecting Control Groups**
- **Conservation Analysis**
- **Peak Analysis**

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Methodology
Selecting Control Groups

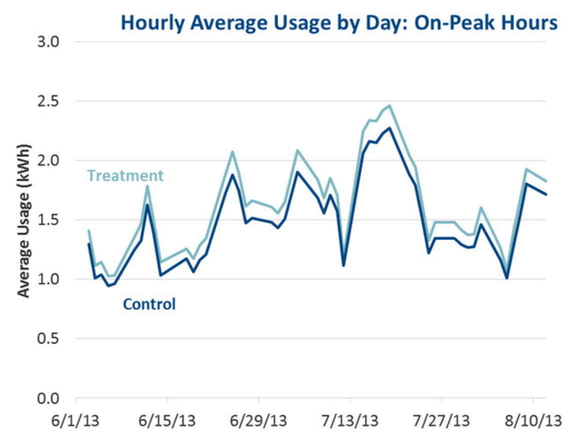
- Pepco MD’s CVR program was not designed as a randomized control trial
- Pepco Maryland engineering and load experts matched each substation which received CVR treatment with a control substation which did not receive CVR treatment
- To match treatment and control substations, the experts considered customer and load characteristics and ensured that treatment and control pairings are generally adjacent
- All pairings are in a single jurisdiction, many factors which affect consumption (e.g., economic factors and weather) are similar between pairings

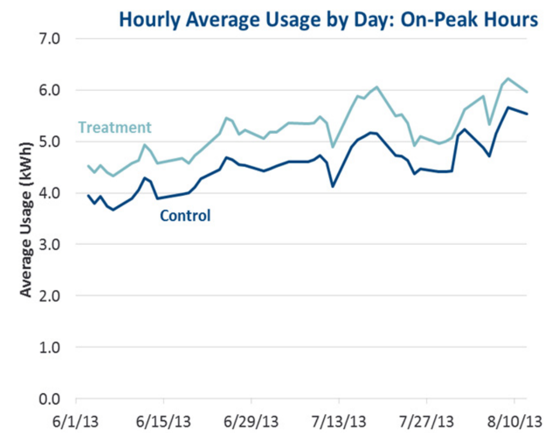
Methodology
Substation Pairings

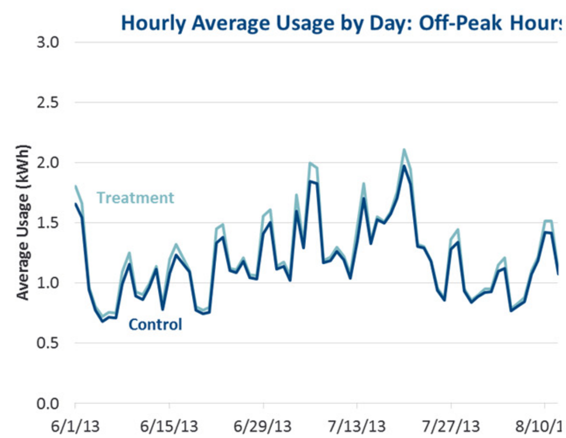
Treatment Substations	Control Substations
Kensington Sub. 193	Linden Sub. 156
Longwood Sub. 192	Wood Acres Sub. 154
Montgomery Village Sub. 56	Gaithersburg Sub. 31
Branchville Sub. 69	Greenbelt Toaping Castle Sub. 173
Riverdale Sub. 4	Bladensburg Sub. 175
Camp Springs Sub. 72	St. Barnabas Rd. Sub. 59
Wildercroft Sub. 178	Lanham Sub. 149

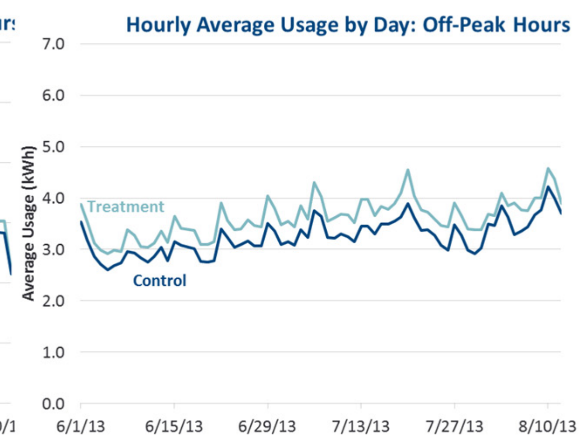
Methodology
Validating Control Group

- We carried-out after-the-fact comparison of Pepco Maryland's control-treatment pairings to validate the control group
- Below are comparisons of control and treatment consumption using hourly AMI data for the peak analysis









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Methodology
Validating Control Group

- We find that the residential customer load profiles are very similar to each other in terms of their shape and level for the treatment and control groups
  - This implies that the residential control group customers represent the but-for usage of the residential treatment customers fairly well
- For the non-residential customer load profiles, we find that they are very similar to each other in terms of their shape but they differ in terms of the level of usage between the treatment and control groups
  - Treatment customers are slightly larger than the control group customers, on average. This difference will be accounted for by the fixed effects estimation routine

Methodology: Difference-in-Differences through Panel Data Analysis

We carried out a Difference-in Differences (DID) analysis through a panel data regression analysis to estimate the CVR impact

- Regression model compares the usage of the treatment and control group customers before and after the CVR treatment, while accounting for other factors that could potentially confound the estimated impact such as weather conditions, DSM program participation, AMI activation, and calendar dummies
- The Fixed Effects (FE) estimation routine was used to ensure that the estimated coefficients from the resulting model are unbiased. FE estimation assumes that the unobservable factor in the error term is related to one or more of the model's independent variables. Therefore, it removes the unobserved effect from the error term prior to model estimation using a data transformation process

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Methodology
CVR Impacts estimated in this Study

Impact	Dataset	Analysis Variable	Pre-treatment Period (*)	Post-treatment Period
Peak	Hourly AMI Dataset	Hourly Usage	June – August 2013	June – August 2014
Conservation	Monthly Billing Data	Average Daily Usage	Sept. 2012 – August 2013	Sept. 2013 – May 2014

(*) The CVR program has begun on August 1st, however the CVR activation for the last treatment substation was on August 12, which is the effective start date of the CVR program for our analysis. For that reason, August 2013 is partially a pre-treatment month

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Methodology
Conservation Model Specification

Conservation model measures average energy savings from CVR

$$\boldsymbol{ln(kWh_{it}) = \beta_{0i} + \beta_1 * TreatPeriod_i + \beta_2 * CVR_{it} + \beta_3 * THI_{t_0} + \beta_4 * AMI_{it_0}}$$
$$\boldsymbol{+ \sum_{m=1}^{12} (\beta_{4m} * monthm_t + \beta_{5m} * monthm_t * THI_{it}) + \beta_6 * DSM_{it} + v_i + \varepsilon_{it}}$$

Where:

kWh_{it}	Average hourly consumption for household i in day t.
$TreatPeriod$	Flag indicating that the start of the treatment period
CVR_{it}	Flag indicating that the customer has received the CVR treatment
THI_t	Impact of Temperature Humidity Index on usage
AMI	Flag indicating that a customer's AMI meter has been activated
$monthm_t$	Month specific impact common to all households
$monthm_t * thi_{it}$	Month specific impact of the Temperature Humidity Index
DSM_{it}	Indicator that a customer is participating in DSM program
v_i	Customer fixed effect
ε_{it}	iid error term, clustered by household

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Methodology
Peak Impact Model

- Peak impact model measures peak demand savings from CVR
- As the peak impact analysis is focused on quantifying the savings during system peak conditions, we undertake our analysis using data on the hottest days of the year
  - We define peak as hours ending 15-19 (using PJM's capacity market peak definition for summer)
  - We define hottest days as those with average peak THIs greater than 77, which equates to roughly 85 °F)
- We run the peak impact model for weekdays, weekends and all days to gauge whether the peak impact varies due to different peak load characteristics during these days

Methodology
Peak Impact Model Specification

$$\begin{aligned} \boldsymbol{ln(kWh_{it})} &= \boldsymbol{\beta_{0i} + \beta_1 * TreatPeriod_i + \beta_2 * CVR_{it} + \beta_3 * THI_t} \\ &+ \boldsymbol{\sum_{m=6}^{10}(\beta_{4m} * monthm_t + \beta_{5m} * monthm_t * THI_{it})} \\ &+ \boldsymbol{\beta_6 * DSM_{it} + \beta_6 * v_i + \varepsilon_{it}} \end{aligned}$$

Where:

kWh_{it}	Average hourly consumption for household i in day t
$TreatPeriod$	Flag indicating the start of the treatment period
CVR_{it}	Flag indicating that the customer has received the CVR treatment
THI_t	Impact of Temperature Humidity Index on usage
$monthm_t$	Month specific impact common to all households
$monthm_t * thi_{it}$	Month specific impact of the Temperature Humidity Index
DSM_{it}	Indicator that a customer is participating in DSM program group k
v_i	Customer fixed effect
ε_{it}	iid error term, clustered by household

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Results
Conservation Impact

Residential Customers

A 1.5% reduction in voltage is estimated to result in a 1.4% reduction in consumption

- Significant at the 1% level
- Implied CVR factor of .93 which is within range suggested by previous studies

Results
Conservation Impact

Non-Residential Customers

1.5% reduction in voltage is estimated to result in a 0.9% reduction in consumption

- Not statistically significant, though still an unbiased estimate of the mean impact
- Implied CVR factor of 0.6 which is within range suggested by previous studies
- Insignificant result likely driven by smaller sample size and also heterogeneity of customers

Results
Peak Impact

Residential Customers

A 1.5% reduction in voltage is estimated to result in a 1.1% reduction in peak consumption

- Significant at the 1% level
- Implied CVR factor of .73 which is within range suggested by previous studies

Results
Peak Impact

Non-Residential Customers

1.5% reduction in voltage is estimated to result in a 2.5% reduction in peak consumption

- Significant at the 1% level
- Implied CVR factor greater than 1 is beyond expected range for CVR impact
- High impact implies that there are other unobservable effects which we were not able to capture in this analysis, likely due to heterogeneity of non-residential customers

Results
Peak Impact

Residential peak results are robust across days and hours

Hour Ending	All Days *(% Impact)*	Weekends & Holidays Only *(% Impact)*	Weekdays *(% Impact)*
Hour 15	-1.13%	-1.67%	-0.90%
Hour 16	-1.02%	-1.23%	-0.90%
Hour 17	-1.02%	-1.08%	-1.00%
Hour 18	-1.21%	-1.16%	-1.20%
Hour 19	-1.17%	-1.10%	-1.20%
15-19 Pooled	**-1.11%**	**-1.28%**	**-1.08%**

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Results
Conclusion

Residential impact is robust

- Pepco Maryland's CVR pilot program has been successful in leading to a decrease in residential consumption during peak hours and also year-round
- The results are stable across multiple econometric models

Non-Residential impact is more difficult to quantify using econometric methods due to heterogeneity and sample size issues

- In the future, larger datasets with larger sample size may result in statistically significant results