Conservation Voltage Reduction: What Are the Savings?

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ABSTRACT

PECO Energy Company is conducting a conservation voltage reduction (CVR) program throughout its service territory. This program offers the potential to provide substantial energy and demand savings at relatively little cost. Utilities across North America are increasingly looking at CVR programs and these programs are likely to play an increasing role in demand-side management and smart grids. It is important to develop and apply methods for evaluating these programs that provide utility management and regulators with confidence in the impacts achieved. CVR programs have seen limited analysis by the energy program evaluation community. This paper presents the methods used and results of such an evaluation.

The CVR program involves a physical adjustment in transformer settings governing voltage at the substation. By adjusting substation voltage, the program impacts hourly energy flows and capacity, including demand coincident with the system peak period(s). The evaluation of the PECO program used hourly data from a sample of substations combined with appropriate statistical methods. The evaluation had to select an appropriate sample, take into account weather factors, and ensure accurate measurement at each substation. The analysis found substantial savings.

Introduction

Conservation voltage reduction (CVR) is the long-term practice of controlling distribution voltage levels in the lower range of acceptable levels (as defined in American National Standards Institute 1995) to reduce demand and energy consumption. PECO Energy Company has implemented a CVR program in its service territory. PECO is the largest electric and natural gas utility in Pennsylvania, serving approximately 1.6 million electric customers and 494,000 natural gas customers in southeastern Pennsylvania. PECO's program is a key element of its portfolio of programs to meet its legislatively mandated requirements for energy efficiency (EE) and demand response. As required by regulators, PECO has sponsored an evaluation of the savings from this program. This paper presents a history of CVR, a description of the PECO program, the approach to estimating savings, a summary of the analysis, and the energy savings results.

CVR History

CVR has a long history. In the 1980s, the California Public Utilities Commission (CPUC) required that utilities lower voltages to conserve energy. Key CVR activities include the following (Fletcher 2009):

- » California utilities performed CVR research in 1970s.
    - o 5% voltage reduction ~ 5% reduction in energy usage and demand
- » CPUC directed utilities to lower voltage in 1976.
    - o Modify service voltage to 120 +0/-5% = 114–120 V

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- In the early 1980s, the Electric Power Research Institute conducted CVR tests with Project 1419.
  - Detroit Edison and TESCO (1982), Tennessee Valley Authority (2008)
- Northwest (NW) utilities conducted CVR tests in the late 1980s.
  - Seattle City Light, Pacific Power, and Snohomish
- The Northwest Energy Efficiency Alliance (NEEA) conducted utility distribution system efficiency research in 2003–2007.
  - Load research and pilot demonstrations with 13 Northwest utilities
- Current NW CVR applications
  - Snohomish, Clark, Lakeview L&P, Eatonville, Tacoma, and Idaho Power

The NEEA conducted a major study on the effects of CVR, known as the NEEA Distribution Efficiency Initiative (R.W. Beck 2007). The results of the study conclusively showed that operating a utility distribution system in the lower half of the acceptable voltage range (120–114 volts) saves energy, reduces demand, and reduces reactive power requirements without negatively impacting the customer.

A national study of the potential for CVR found that a complete deployment of CVR, on 100% of feeders, could provide a 3.0% reduction in annual energy consumption (Schneider 2010).

With the implementation of smart grids, capability is developing for utilities to practice dynamic voltage reduction, or volt/volt-ampere reactive optimization. Dominion Voltage Inc. (DVI) has recently been awarded a patent for its EDGE® CVR technology. EDGE® platform enables the utility to optimize the voltage delivered to the customer toward the lower end, while still complying with customer equipment performance requirements. DVI claims that EDGE® can result in reducing the customer's electric bill by 3–5%, with no change in the customer's behavior (PR Newswire 2013).

The PECO CVR Program

PECO initiated its CVR program as part of its Act 129 filed Energy Efficiency and Conservation Plan (PECO 2009) in July 2009. Act 129 required that PECO and other electric distribution companies in Pennsylvania reduce their load during the 100 highest demand hours by 4.5% by May 31, 2013. The CVR program is part of a portfolio of EE and demand response (DR) programs.

PECO's CVR program involves a static voltage reduction of approximately 1% across a significant portion of PECO's electrical distribution system. This type of CVR program, which is known as voltage fixed reduction, requires that the distribution substation voltage regulator and line regulators voltages be lowered by a fixed amount (e.g., 1% to 3%). This change involves a physical adjustment in transformer settings governing voltage at the substation. By adjusting substation voltage, the program impacts hourly energy flows and capacity, including demand coincident with the system peak period(s), including the top 100 (peak demand) hours on the system load duration curve.

Upon review of its current voltage setting thresholds, PECO determined that permanent voltage reductions could be made across the 13-kilovolt (kV) and 34-kV distribution systems, which account for an estimated 98% of PECO's overall system load. Upon acceptance of the plan, and completion of preliminary testing to ensure there would be no unforeseen customer consequences, PECO embarked on a schedule that commenced in February 2010 and ended in May of the same year, to manually reduce the voltage at the load tap changers, as shown in

Figure 1

~~Figure 1~~. This involved 87 substations, which were comprised of 249 distribution transformers.

The program included proactive low-voltage mitigation, which involved augmenting of, or installation of, new capacitors, and where necessary, re-conductoring to maintain acceptable output voltages at customer meters.

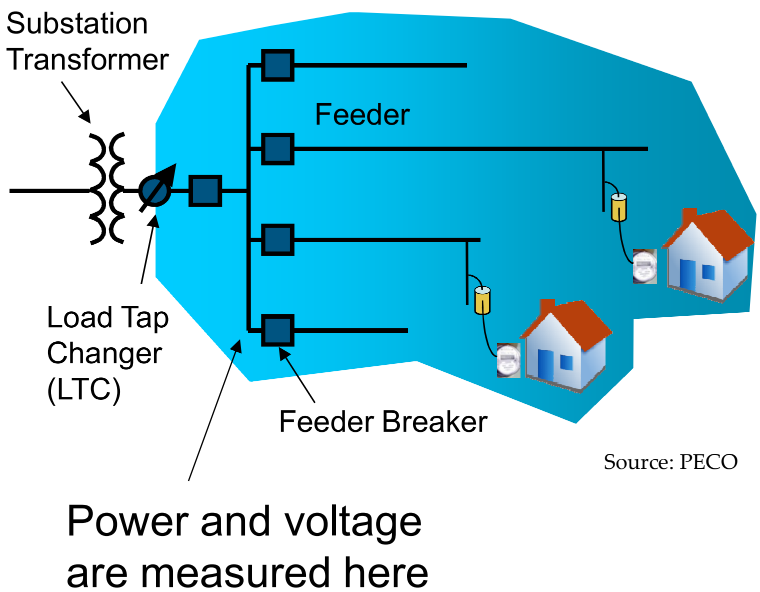

Figure 1. Overview of Distribution System

Approach to Estimating Savings

Energy and peak demand savings from CVR cannot be directly measured. Voltage settings can be measured; however, the relationship to energy and peak demand savings requires estimating the CVR factor (CVR_f). CVR_f is a dimensionless value that is a per-unit measure of how much per-unit energy conservation or demand reduction is obtained per unit voltage reduction, or $\Delta E / \Delta V$ (Wilson 2010). Results of field tests indicate a wide range for the CVR_f of 0.5 to 1.5 (Fletcher 2009). The variability in the factor depends on the nature of the load and temperature.

PECO initially explored a formulaic CVR protocol developed in collaboration with the NEEA and the Bonneville Power Administration, referred to going forward as the NEEA CVR Protocol (PCS Utilidata 2004). The NEEA CVR protocol was based on substantial evaluation of changes in voltage, and the corresponding energy savings and demand reduction within several of the participating energy distribution companies (EDCs) located in the Pacific Northwest. In addition, this protocol developed a series of look-up tables to establish CVR values for participating utilities. However, after extensive evaluation, it was determined that this data would not accurately characterize PECO's distribution system given the substantial differences in load and weather conditions between the Pacific Northwest and the Mid-Atlantic regions.

PECO formed a CVR working group consisting of PECO personnel, their evaluation, measurement, and verification (EM&V) contractor, Navigant Consulting, Inc. (Navigant), and representation from the State-Wide Evaluator to develop a protocol applicable to not only PECO, but other EDCs that may elect to implement similar programs in the future. The CVR working group developed research and data collection methodologies, performed statistical sampling, and engaged objective reviewers in comparing the data with the research study findings in development of enhanced versions of the NEEA CVR protocol, adapted for use at PECO for energy and demand savings. The working group estimated separate protocols for energy and demand savings. This paper presents findings of the energy savings analysis.

A key component of this collaborative effort was the identification of evaluation parameters that could be treated as deemed within the protocol. These deemed savings parameters were identified to include the following:

» The CVRf measuring the relationship between changes in energy (megawatt-hours [MWh]) in response to changes in voltage effected under the CVR program
» The measured change in average hourly voltage (Delta V) resulting from CVR
» Average hourly system losses (line loss factor) reflecting energy lost in the delivery of power from substations to metered end-use customers

Toward this goal, the evaluation team conducted a detailed study of the likely energy impacts of a 1% reduction in voltage levels at substations under PECO's CVR program, using substation and circuit-level hourly data for the late winter/early spring of 2010. The team developed an EM&V protocol that follows Option C as described in International Performance Measurement and Verification Protocol (Efficiency Valuation Organization 2007), where savings are determined by measuring energy use at the whole-facility or sub-facility level. Option C is likely to require a regression analysis to account for independent variables such as outdoor air temperature.

The evaluation team performed a statistical regression analysis study using hourly loads and voltage data collected for substation transformers and circuits treated under the CVR program. The data set available for this regression analysis included hourly loads and voltage readings for the week immediately prior to and the week after, the date on which voltages were changed over the program period—February through May 2010—for the entire census of stations/circuits treated in the program.

The team used the data set to statistically estimate an average, system-wide CVRf for use in calculating gross energy savings across all substations/circuits treated under the program. The regression used to calculate this factor was the following:

$$Eq.1: \; Log(Hourly\ MW) = B0 + B1*[Hourly\ HDD\_65] + B2*[Hourly\ CDD\_65] \\ \mathbf{B3}*Log[Metered\ Voltage]$$

where ***B3*** is the CVR_f for energy measuring the average percentage change in MWh, for every one-percentage change in voltage over all hours on the PECO system.

The Hourly MW post-cut-over and Hourly MW pre-cut-over do not include two hours of dead band immediately after the cut-over time when the voltage was set up and when it was set down. Note that this equation also includes average hourly heating and cooling degree days to control for weather-related influences on change in hourly energy consumption.

Several alternative model specifications were tested using the data set in Equation 1, including different segmentations of this data, to test for the robustness of the CVR_f calculated in Equation 1 above. Based on a review of these alternative models, the results from Equation 1 were determined to provide a statistically reliable measure of CVR_f.

Calculation of the Measured Percentage Change in Voltage [%ΔV]

The following equation was used in the calculation of the measured (%) change in voltage:

$$\text{Eq. 2:} \quad \%\Delta V = \frac{[Avg\ Hrly\ kV\ post\text{-}cut\text{-}over - Avg\ Hrly\ kV\ pre\text{-}cut\text{-}over]}{[Avg\ Hrly\ kV\ pre\text{-}cut\text{-}over]}$$

The calculation of Avg Hrly kV post-cut-over and Avg Hrly kV pre-cut-over does not include two hours of dead band immediately after the cut-over time when the voltage was set up and when it was set down.

Deemed Parameter Value for Average Hourly Line Losses

Line losses for energy are also represented as an average percentage or proportional value, and treated as a deemed value in the custom protocol for CVR. This value was obtained from company studies filed with the Pennsylvania Public Utility Commission, and approved for use in the studies of EE and DR program impacts on the PECO system.

Table 1. Summary of Deemed Savings Parameters for Gross Energy Savings from CVR

Energy Factors	Deemed Values:	Source(s):	Discussion:
CVR Factor:	**1.08**	Regression Study	Estimated from census of all CVR substations/circuits in winter/spring
Delta Volts (in %):	**0.76%**	Analysis of System Impacts	Measured change in volts in PY2009
System Loss Factor:	**4.9%**	Approved Parameter	PECO loss factor

The evaluation team used the above set of deemed parameter values in the following equation to calculate gross energy savings (MWh) for CVR:

$$Eq.\_3:\ Gross\ EE_{Saved} = (\text{Energy}_{\text{Test Period}}) \text{ x } [(\Delta V) \text{ x } [CVRf] \text{ x } (1\text{-line loss})]$$

Where ($\text{Energy}_{\text{Test Period}}$) represents systemwide energy use (MWh) on a monthly, quarterly or annual basis, depending on PECO reporting requirements. The overall impact of the program was substantial—320 gigawatt-hours/year.

Process Evaluation

The evaluation team completed a telephone survey of residential and commercial customers to assess the effect of the CVR program on customer satisfaction. This was done by comparing the experiences of both residential and commercial customers subject to CVR to the small population of those who are not.

For the residential survey, the sample was pulled proportionally to the disposition of CVR customers within the income segments for both CVR and non-CVR customers. For the commercial survey, the sample was designed to oversample the larger energy-using customers, but was still pulled to get the same number of CVR and non-CVR customers.

The survey indicated that in general the CVR program is not noticeable to PECO customers. Few customers reported any complaints about electrical service and there was not a significant difference between the customers affected by CVR and those who are not. Eighty to 90% of customers did not notice any change (good or bad) in their electrical service over the past one to two years. Only 4% of commercial CVR customers have noticed a change in service; in the question that followed, they all reported the change they noticed was an improvement in service. On the other hand, 12% of non-CVR commercial customers reported noticing a change in service (but only two of which reported a decline in service). Very few residential customers reported noticing a change in service as well. Only 12% of non-CVR and 10% of CVR customers noticed a change in service and only two non-CVR and one CVR customer noted that the change they noticed was a decline in service.

Benefit-Cost Analysis

Because of the large energy savings and since the implementation costs were relatively minimal—$1.5 million—the benefit-cost ratio using the Total Resource Cost test was a substantial 262, with net benefits of $398 million (PECO 2011).

Conclusion

The results of this evaluation are being used to verify energy and peak savings to comply with state requirements for energy efficiency and demand response. The program has been highly cost effective for PECO, with substantial energy and demand savings and benefit-cost ratios of over 200. Customers reported no significant changes in service. This paper demonstrates methods and techniques used to produce energy and peak impact estimates for use in meeting regulatory requirements. It provides a benchmark approach for conducting CVR program evaluations.

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