The Electricity Journal 30 (2017) 60–65

Contents lists available at ScienceDirect

The Electricity Journal

journal homepage: www.elsevier.com/locate/electr

The impact of AMI-enabled conservation voltage reduction on energy consumption and peak demand☆

Ahmad Faruqui*, Kevin Arritt, Sanem Sergici

The Brattle Group, United States

ARTICLE INFO

Article history:
Available online 19 March 2017

Keywords:
Conservation voltage reduction (CVR)
Advanced metering infrastructure (AMI)
Peak demand
Energy conservation
Demand side management
Distribution substation
Voltage reduction

ABSTRACT

Conservation voltage reduction reduces energy consumption and peak demand by lowering the voltage at which power is delivered to customers, without any loss of comfort to customers. CVR has been around for a long time but the inability to verify the drop in voltage at the customer's premise has prevented its wide-scale implementation. The adoption of advanced metering infrastructure, now deployed in half the country, finally is making feasible the rapid deployment of CVR.

1. Introduction

In this article, we introduce a novel approach to promoting energy conservation and reducing peak demand. Unlike other approaches, this one does not require changes in customer behavior nor does it require customers to acquire more-efficient appliances or light bulbs. It is called conservation voltage reduction (CVR).

CVR involves careful management of the voltage at which power is supplied to customers. The idea of reducing voltage levels as a means to reduce overall energy consumption has been well known to engineers and has been around for decades. However, without the modernization of energy meters through the implementation of advanced metering infrastructure (AMI), utilities have been hesitant to implement CVR. They could not ensure that customers would not suffer brownouts as voltage dropped below acceptable levels.

We present a case study of a utility that used AMI to roll out CVR. The utility is Pepco Maryland, an operating company of Pepco Holdings. Pepco Maryland serves approximately 500,000 residential customers and 50,000 other customers in much of Prince George's and Montgomery counties.[1] In the spring of 2013, Pepco Maryland deployed AMI in its service territory. This allowed Pepco Maryland to implement a CVR pilot program in August 2013. The voltage levels were reduced by 1.5% at seven substations. Seven other comparable substations without CVR were selected to serve as a control group for comparative purposes.

To assess the impact of CVR on energy consumption and peak demand, we carried out an econometric analysis (Faruqui, 2016). We estimated impacts separately for residential and non-residential customer classes. In Section 2, we describe how CVR operates and summarize the existing research. In Section 3, we discuss our methodology and econometric model. In Section 4, we discuss the data used in our econometric analysis. In Section 5 we discuss our results. Our conclusions are listed in Section 6.

It should be noted that our findings on the effectiveness of CVR have broad implications on the national level. Assuming that widespread national deployment of CVR would yield a modest 1% reduction in residential energy consumption, it would lower

☆ The authors acknowledge comments from Steve Sunderhauf and his team at Pepco Holdings. However, the views in this article are those of the authors and not necessarily those of The Brattle Group nor Pepco Holdings.

* Corresponding author.
E-mail address: ahmad.faruqui@brattle.com (A. Faruqui).

[1] Statistics on Pepco Maryland customers reported in Pepco Maryland's FERC Form No. 1 filing, filed with the Maryland Public Service Commission in May 2016. http://webapp.psc.state.md.us/newIntranet/CaseNum/NewIndex3_VOpenFile.cfm?filepath=%5C%5CColdfusion%5CUtility%20Company%20Annual%20Report%5C%5CPotomac%20Electric%20Power%20Company%5C2015%20-%20Potomac%20Electric%20Power%20Company.pdf.

http://dx.doi.org/10.1016/j.tej.2017.01.014
1040-6190/

Table 1
Estimated annual impacts due to widespread implementation of AMI-enabled CVR (residential only).

Reduction in Energy Consumption								
50%	x	**1%**	x	**1.4 billion MWh**			=	**7 million MWh**
^		^		^				^
Share of U.S. with AMI		CVR Energy Conservation Impact		Residential Energy Load				CVR Residential Energy Reduction
Residential Customer Bill Savings								
$0.13/kWh	x	**7 million MWh**					=	**$910 million**
^		^						^
Avg. Rate		CVR Residential Energy Reduction						Residential Bill Savings due to CVR
Avoided Carbon Dioxide Emissions								
37.9%	x	**50%**	x	**1%**	x	**1925 million tonnes**	=	**3.65 million tonnes**
^		^		^		^		^
Residential Share of Sales		Share of U.S. with AMI		CVR Energy Conservation Impact		Electricity Sector Emissions		Avoided CO2 Emissions
Reduction in Peak Demand								
45.0%	x	**50%**	x	**0.5%**	x	**786,000 MW**	=	**884 MW**
^		^		^		^		^
Residential Share of Peak		Share of U.S. with AMI		CVR Peak Demand Impact		U.S. Peak Demand		CVR Residential Peak Demand Reduction

electricity usage by *7 million MWh*,[2] saving consumers some *$910 million* dollars annually in electricity bills.[3] It would also avoid *over 3.5 million metric tonnes* CO_2 emissions.[4] Furthermore, assuming CVR would yield a modest half-percent reduction in residential peak demand, CVR would reduce overall system peak demand by nearly 900 MW. The realized savings would likely be even greater than our estimates if CVR were also deployed to non-residential customers. These estimates are summarized in Table 1.

2. Conservation voltage reduction

The American National Standards Institute (ANSI) requires that the voltage at which power is delivered to customers lie in a band between 114 and 126 V. CVR, when coupled with AMI, can ensure that it is delivered at the lower end of the standard band (114–120 V).[5] This voltage reduction has the potential to produce considerable energy savings at low cost and without harm to customer equipment or loss of service quality. CVR as a conservation mechanism is entirely passive. Customers do not need to make any lifestyle changes or install new energy efficient equipment.

The main engineering concept is that lower voltage levels cause end users to consume less electricity. Electric loads are broadly classified into three categories: constant current load, constant resistance/impedance load, and constant power load. Constant current load varies directly with voltage, so a 1.5% decrease in voltage would result in a 1.5% decrease in electric consumption. Constant resistance/impedance load varies with the square of voltage, so a 1.5% decrease in voltage would yield more than a 1.5% decrease in electric consumption. Constant power load does not vary with voltage levels, as the load controls aim to maintain the same power output regardless of the voltage level.

The realized impact of CVR on electricity consumption is driven by the underlying load characteristics. Therefore, the CVR factor will differ between different classes of customers and different utilities. Non-residential electricity consumption may include a different mix of loads, and different loads may respond differently to a reduction in voltage. Peak demand and conservation impacts may also differ from each other because the mix of loads may differ by hour. For these reasons, we analyze the CVR impacts separately for residential and non-residential classes and for energy consumption and peak demand. An example of these loads and how they may differ between customers is illustrated in Fig. 1.

Several engineering studies have demonstrated that the implementation of CVR leads to decreased consumption at the customer meter, but there is no consensus on a "CVR factor," which is the quantity of energy that is reduced for a specific reduction in voltage. Specifically, the CVR factor is calculated as the percent reduction in consumption divided by the percent reduction in voltage.[6] For example, a CVR factor of 0.85 indicates that a 1% decrease in voltage would lead to a 0.85% decrease in consumption.

CVR as a mechanism for conservation has been around for decades but has recently gained more attention due to more utilities employing AMI technology (Carter, 1978). With CVR becoming more accessible, there have been many recent studies that have aimed to provide guidance on the actual effect of CVR on end-use consumption. Most previous studies have been engineering studies and not econometric studies. They have focused on simulating the impact of CVR on energy consumption, and not use

[2] Calculation assumes that 50% of the U.S. has AMI, which is the current estimate. Calculation assumes total U.S. residential energy consumption to be 1.4 billion MWh, which represents residential daily consumption (3.84 billion kWh) as reported by EIA, multiplied by the number of days in the year (365). The data is from EIA's Short-Term Energy Outlook. https://www.eia.gov/forecasts/steo/report/electricity.cfm.

[3] Calculation assumes an average rate of 13 cents per kWh.

[4] Calculation assumes that 50% of the U.S. has AMI and that the residential sector is responsible for 45% of peak demand. Calculation assumes annual peak demand of 786,000 MW. U.S peak demand is reported by the EIA at How much electric supply capacity is needed to keep U.S. electricity grids reliable? https://www.eia.gov/todayinenergy/detail.php?id=9671.

[5] COMAR at 20.50.07.02 specifies the required Maryland voltage delivery levels.

[6] In economics, the CVR factor would be called the voltage-reduction elasticity of consumption.