Voltage and Power Optimization Saves Energy and Reduces Peak Power

Successes from the Smart Grid Demonstration Projects

Introduction

The smart grid brings increased operating efficiencies to the distribution grid. This is being proven in the Smart Grid Demonstration projects conducted by American Electric Power (AEP) Ohio, Battelle Memorial Institute, Kansas City Power and Light (KCP&L), and the National Rural Electric Cooperative Association (NRECA), which provided a rare opportunity to do controlled experiments of the benefits of enhanced voltage control on the grid. . Power quality and reliability is improved by voltage optimization. Energy efficiency applications such as conservation voltage reduction (CVR) can then be safely implemented.[1]

What is Voltage Optimization?

Voltage optimization consists of two steps, control of power quality and voltage extremes by putting capacitors and voltage regulators (transformer load tap changers regulate voltage also) on a line; and using reduced voltages to conserve energy. By controlling power factor and voltages, the utility can deliver energy more efficiently, but this also allows the utility to exercise finer control over voltages, to a smaller range at the bottom of the American National Standards Institute (ANSI) allowed range. This can also save money, via reduced electricity charges for consumers. By lowering peak power generation, it is also possible for utilities to defer generation capacity investments. The five challenges leading utilities to choose to invest in these technologies are summarized in Table 1[2].

Challenge	*Motivation*
Power Factor financial penalties	Charge for load requiring excessively leading or lagging power
Resistive Line Losses	Higher currents associated with higher I^2R losses
Lost Capacity	Extra inductive current wastes conductor and transformer capacity
Voltage Drop	Excess current results in excess voltage drop along line
Preparation for Conservation Voltage Reduction (CVR)	End of line voltage must have sufficient margin to allow reduction

Table 1. Challenges and Motivations for Voltage Optimization

Costs and Benefits of Voltage Optimization

Voltage Optimization provides the benefits of higher reliability, improved power quality, and, via CVR, lower energy costs to consumers. However, these benefits are obtained by deployment of equipment and monitoring of its operation, with associated costs for communications.

[1] Willoughby, R. and Warner, K., Conservation Voltage Regulation: An Energy Efficiency Resource, IEEE, April, 2013, http://smartgrid.ieee.org/april-2013/842-conservation-voltage-regulation-an-energy-efficiency-resource, accessed 4/2/15

[2] Jim Weikert for NRECA, The Why of Voltage Optimization, https://www.nreca.coop/wp-content/uploads/2013/08/TS_Volt_VAR_January2013.pdf, accessed 2/17/15

AEP Ohio describes the energy efficiency methods and benefits of their Volt-Var management technology in the following passage, describing the subset of CVR in particular:

> Applying technology on our distribution system through monitoring and controlling voltage reduces the amount of energy that must be produced and delivered to customers to meet demand. Known as Volt Var Optimization (VVO), this technology has proven its technical viability and energy efficiency potential. Typically, customers receive electricity at a voltage between 114 and 126 volts. Using the full range of voltage is common practice in our industry. *Studies and recent experience are showing that optimizing voltage – delivering voltages that more closely match the voltage level customers' equipment was designed for – benefits customers and the grid*. Customers continue to receive the electricity they need while reducing their demand from the grid and lowering their consumption. This contributes to energy efficiency at the customer's location and makes for more efficient use of the distribution system (emphasis added). [3]

A typical conservative, simple, estimate of investment payback is five years, given an investment of $20,000 on a feeder and savings of $4,000 a year. Jim Weikert of NRECA says "Regardless of the motivation, the programs outlined here often justify themselves financially, having a relatively short payback period. The equipment cost can range from $5,000 to $20,000 per feeder and savings in the range of $3,000 to $5,000 per year. Together, these programs can be referred to as integrated Volt/VAR control (IVVC).[4]"

Project Scopes

The project funding and regional characteristics are listed below:

AEP Ohio's first phase of its gridSMART® demonstration project deployed a comprehensive suite of innovative smart grid technologies on 70 circuits serving 132,000 customers in Central Ohio. The project was awarded $75 million in American Recovery and Reinvestment Act funds, for a total project value of $150 million, with cost recovery support from the Public Utilities Commission of Ohio and in-kind vendor contributions.

Battelle led 11 regional utilities, six technology partners and two universities under one smart grid project called the Pacific Northwest Smart Grid Demonstration Project. The project was awarded $89 million in American Recovery and Reinvestment Act funds, for a total project value of $178 million, and impacts 60,000 customers.

NRECA's Enhanced Demand and Distribution Management regional demonstration project involved 23 co-ops in 12 states. Its reach is broad, with 34 million customers and a territory covering 70 percent of the landmass of the United States and managing 50 percent of distribution lines. The project was awarded $34 million in American Recovery and Reinvestment Act funds, for a total project value of $68 million.

KCP&L's $50 million project was funded with nearly $24 million in American Recovery and Reinvestment Act funds to demonstrate, test, and assess the feasibility of integrating new and existing technologies in an end-to-end smart grid serving 13,427 customers. KCP&L deployed smart grid technologies across a 5-square-mile area of Kansas

[3] AEP Ohio, Smart Grid, https://www.aep.com/about/IssuesAndPositions/Distribution/SmartGrid/, accessed 2/17/15

[4] Jim Weikert for NRECA, The Why of Voltage Optimization, https://www.nreca.coop/wp-content/uploads/2013/08/TS_Volt_VAR_January2013.pdf, accessed 4/14/15

City, Missouri in its Green Impact Zone SmartGrid Demonstration.

Controlling Power Quality

Utilities control voltage magnitude and the angle between the apparent and real power. Volt-VAR control (VVC) is a fundamental operating requirement of all electric distribution systems. The prime purpose of VVC is to maintain acceptable voltage at all points along the distribution feeder under all loading conditions.

VVC is achieved by employing voltage regulators (Vregs) or transformers with load tap changers (LTCs) that automatically raise or lower the voltage in response to changes in load and capacitor banks to supply some of the reactive power that would otherwise be drawn from the supply substations. A more detailed description of the distribution system and its control via voltage and reactive power management describes utility approaches to and experiences from the DOE Smart Grid Investment Grant projects[5].

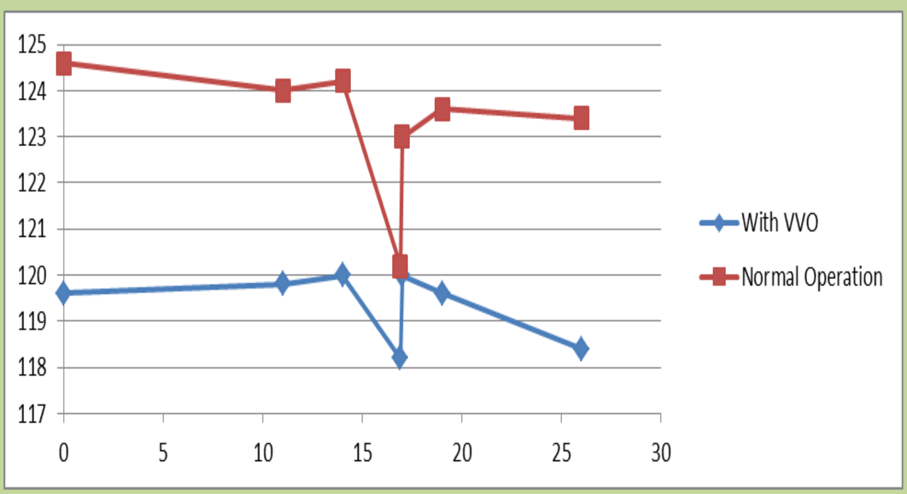
Conserving Energy with Conservation Voltage Reduction

To save energy, CVR lowers voltages on distribution circuits while keeping every end customer supplied with adequate power. This requires specialized smart grid equipment to implement CVR system-wide. "You better make sure you have at least the voltage sensors or smart metering in place so you know what's happening across the whole circuit, not just at the substation," Douglas Dorr of EPRI stated in a report[6] on big data and the grid. With sufficient control of voltage, power quality can be maintained to customer loads, for instance, with a voltage regulator as Figure 1 indicates (apparently at position 17 along the x-axis).

According to Mr. Dorr, typical energy savings are 2-3 percent of the typical energy that circuit uses. Possible benefits include taking inefficient generating plants offline during non-emergency conditions. According to Mr. Dorr, it takes "a lot of analytics to cost-justify [conservation voltage reduction] for the entire system."

Energy savings are also dependent on the profile of devices on the system. CVR can lower losses in lines, transformers, and consumer end-use devices. A byproduct of the VVO/CVR is better power factors leading

Figure1. Line voltage profile for Gahanna 13 kV line in the AEP Ohio territory, showing profiles with (blue) and without (red) VVO, including the conservation voltage reduction feature. The vertical axis is in units of Volts, whereas the horizontal axis marks distance in arbitrary units. *Image courtesy of AEP Ohio.*

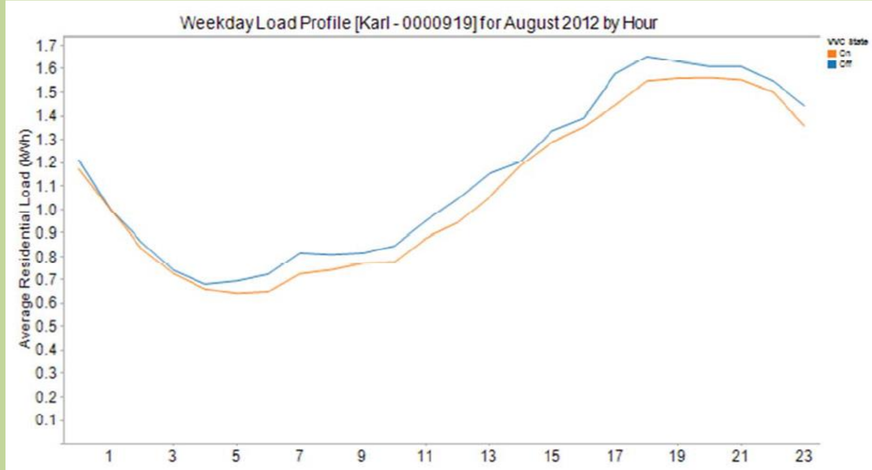


[5] Voltage and Reactive Power Management, https://www.smartgrid.gov/files/VVO_Report_-_Final.pdf, accessed 6/2/15

[6] Douglas Dorr of EPRI, quoted in Big Data on the Smart Grid: 2013 in Review and 2014 Outlook, http://www.greentechmedia.com/articles/read/Big-Datas-5-Big-Steps-to-Smart-Grid-Growth-in-2014, written by Jeff St. John of GreenTechMedia

to more real power throughput[7]. Once this power quality is achieved, characteristics of the individual devices determine energy and power savings.

Figure 2. As this graph from AEP's Technical Performance Report shows, turning volt VAR control on (represented by the orange line) produced lower average loads than when volt VAR control was turned off (represented by the blue line). *Image courtesy of AEP Ohio.*



Resistive devices such as incandescent light bulbs use less power at a lower voltage, therefore using less energy over time. Other resistive devices such as toasters, water heaters, electric baseboard and space heaters are thermostatically controlled. If the voltage is reduced, they must run longer to produce the same amount of thermal energy as the higher voltage case. That is, for example, a water heater would take longer to heat the water to a desired temperature. Although total energy use remains the same, by extending the time period over which energy is delivered, peak power is reduced, which can lead to system benefits.

CVR Results

Three of these four projects reported quantitative results from CVR testing. AEP Ohio, testing on 11 circuits, demonstrated that 2-4% in both energy (kWh consumed) and demand reduction (power, in kW) is achievable (for example, see Figure 2), and the results of testing showed "VVO provided an average of approximately 3 percent reduction in residential load for consumers with AMI meters."

Table 2. Demand and Energy Reduction Results for Utilities in SGDP testing CVR. *based on sampling **modeled

Reduction	Utility	Voltage reduction	Energy reduction
Energy	AEP	*3-5%	2.90%
	Battelle	**3-4%	2.50%
	KCP&L	2.05%	1.63%
Reduction	Utility	Voltage reduction	Power reduction
Peak Demand	AEP	*3-4%	2-3%
	Battelle	**3%	**1.8%
	KCP&L	1.64%	1.13%

AEP Ohio also determined that the peak load was reduced 3 percent. All results were the same whether the load was measured at the voltage regulator or at the customer's smart meter and did not differ from early results from the test. Table 2 shows the circuit level results for the three demonstrations, compared with the projections. KCP&L did a detailed study with a conservative 2.05% drop in voltage, yielding 1.63% decreases in energy use. KCP&L also studied peak energy use reduction, achieving 1.13% energy use reduction from a reduction of voltage of an average of 1.64% over numerous peak days. The team found CVR to be less effective on high peak load days. This is consistent with the idea that all assets need to be maximally utilized during system emergencies. An implication of this is that CVR can be used to defer some future capacity investments but not emergency (highest priced) standby generation.

[7]EPRI, Conservation and Optimization Via Volt/Var Control, http://mydocs.epri.com/docs/PublicMeetingMaterials/1028/Session_2_Conservation_and_Optimization_via_Volt-Var_Control.pdf, accessed 4/2/15

For AEP, voltage reduction was inferred from sample plots on particular feeders, and is therefore indicated as "sampled" and for Battelle, the following assumptions were used to develop "modeled" results:

- For energy reduction, a reduction of 0.8% in energy use is caused by each percent reduction in voltage, (see KCP&L results, which are consistent with this assumption).
- For power reduction, a reduction of 0.6% in power is caused by each percent reduction in voltage (this is 0.1% more conservative than the KCP&L results)
- Voltage reduction in peak demand situations is about 80% of voltage reduction for energy reduction applications.

In particular, AEP Ohio's demonstration did not show any deferred capacity investments, nor was there any measurable effect on equipment reliability and maintenance. Power quality was high with or without VVO, at 0.978, but with VVO on, the power factor tended towards lagging. Lagging power factor means that the current peaks after the voltage in time. Inductors are said to be lagging devices and consume reactive power and capacitors are said to be leading devices and generate reactive power[8]. Capacitors on the line can restore power quality to near 1.0, correcting for lagging power.

Battelle's initial work with CVR showed consistent voltage reductions and energy savings. The results show slightly smaller energy savings than expectations of 2-3% based on previous pilot efforts. The best results were obtained when voltages were measured through AMI at customer sites, not just at the voltage regulators.

Next Steps

The utilities are already planning the next steps. The AEP Ohio gridSMART® program was successful and is already being replicated as a Phase 2 deployment:

> AEP's deployment of VVO began in AEP Ohio as part of the gridSMART® Demonstration Project and has since expanded to Indiana Michigan Power, Kentucky Power and Public Service Company of Oklahoma. The Indiana Utility Regulatory Commission and Michigan Public Service Commission have each ruled that VVO can be recognized as an energy efficiency program in their respective states. AEP's operating companies will be selectively reviewing options for deploying this technology where conditions are favorable.[9]

Under the American Recovery and Reinvestment Act of 2009, the U.S. Department of Energy and the electricity industry have jointly invested over $1.5 billion in 32 cost-shared Smart Grid Demonstration Program projects to modernize the electric grid, strengthen cybersecurity, demonstrate energy storage, improve interoperability, and collect an unprecedented level of data on smart transmission, distribution operations and customer behavior.

[8] Taggart, David F., Voltage Stability and Reactive Power in the PV Industry, http://www.slideshare.net/lightspeed65/voltage-stability-and-reactive-power-in-the-pv-industry, accessed 6/1/15

[9] AEP Ohio, Smart Grid, https://www.aep.com/about/IssuesAndPositions/Distribution/SmartGrid/, accessed 2/17/15

Further Reading

For more information on the utilities or the Smart Grid Demonstration Program in general, visit smartgrid.gov. The relevant project descriptions are in Table 3. Energy efficiency calculation methods[10] are presented in a DOE presentation, *Energy Efficiency in Distribution Systems, Impact Analysis Approach.*

Table 3. Performers and Project Titles

Performer	*Project Title*
AEP Ohio	gridSMART™ Demonstration Project
Battelle	Pacific Northwest Smart Grid Demonstration Project
KCP&L	Green Impact Zone SmartGrid Demonstration
NRECA	Enhanced Demand and Distribution Management Regional Demonstration

[10] Energy Efficiency in Distribution Systems, Impact Analysis Approach, Navigant, 11/30/2011, https://www.smartgrid.gov/sites/default/files/Distribution%20System%20Energy%20Efficiency%2017Nov11.pdf, accessed 4/2/15