U.S. DEPARTMENT OF ENERGY

Electricity Delivery & Energy Reliability

American Recovery and Reinvestment Act of 2009

Application of Automated Controls for Voltage and Reactive Power Management – Initial Results

Smart Grid Investment Grant Program

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RECOVERY ACT SMART GRID PROGRAMS

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Executive Summary

The U.S. Department of Energy (DOE), Office of Electricity Delivery and Energy Reliability (OE), is implementing the Smart Grid Investment Grant (SGIG) program under the American Recovery and Reinvestment Act of 2009. The SGIG program involves 99 projects that are deploying smart grid technologies, tools, and techniques for electric transmission, distribution, advanced metering, and customer systems.[1]

Of the 99 SGIG projects, 26 are implementing advanced voltage and volt-ampere reactive (VAR) optimization (VVO) technologies to improve electric distribution system operations. Advanced VVO is made possible through recent improvements in sensors, communications, control algorithms, and information processing technologies that for monitor voltage levels throughout the distribution system. This information is sent to devices that can adjust voltage regulating equipment and capacitor banks on distribution feeders in near-real time enabling quick adjustments in response to constantly changing load and voltage conditions. Adjustments to individual devices and systems can also be coordinated so that voltage levels can be optimized along feeder lines.

The 26 SGIG VVO projects are pursuing these strategies to achieve one or more of the following objectives: (1) lowering voltage levels during peak periods to achieve peak demand reductions, (2) lowering voltage levels for longer periods to achieve electricity conservation, and (3) reducing energy losses over feeders. Generally speaking, utilities applying VVO technologies expect to see 1% reductions in electricity consumption for every 1% reduction in voltage levels.

Achieving these VVO objectives results in the following benefits:

- Deferred capital expenditures and improved capital asset utilization
- Reduced electricity generation and environmental impacts
- More efficient utility operations, greater flexibility to address resiliency, and more opportunities to keep rates affordable

Analysis of Initial Results

Most of the SGIG VVO projects are in the early stages of implementation and have not finished deploying, testing, and integrating the smart grid devices and systems. However, 8 of the 26 SGIG projects implementing VVO have reported hourly load data for 31 feeders during the

[1] For further information, see the *Smart Grid Investment Grant Program Progress Report*, July 2012, found at www.smartgrid.gov.

periods April 2011 to September 2011 (summer) and October 2011 to March 2012 (winter). Analysis focused on the automated switching of capacitor banks and the impacts of that switching on reactive power compensation and subsequent reductions in line losses. In addition, two VVO projects seeking to conserve energy during peak periods (conservation voltage reduction for peak) reported initial results.

Observations from the analysis of these initial results and the efforts being undertaken by these projects include:

- For the 31 feeders for which projects have reported hourly load data, one-half are witnessing line loss reductions in the range of 0% to 5%, and 5 feeders experienced loss reductions greater than 5%. These results are in the range of other industry estimates which indicate that line loss reductions of 5%-10% are possible.
- In general, feeders with the worst baseline power factors (i.e., those with the highest amount of inductive loads) showed the greatest reductions in line losses. Many of the utilities are targeting their worst performing feeders. However, overcompensation for reactive power was observed in the remaining feeders, which resulted in line loss increases. In these cases, capacitor banks were often operated for voltage support rather than reactive power compensation.
- The initial results for conservation voltage reductions indicate a potential for peak demand reductions of approximately 1% to 2.5%. This is consistent with the expectations of the projects and results from other studies in the literature. There are no results yet from the SGIG VVO projects on conservation voltage reductions for longer periods to achieve electricity conservation. In comparison to energy savings attributable to line loss reductions, conservation voltage reduction practices have a greater impact on reducing energy requirements.

Next Steps

So far, most of the initial results reported by the SGIG VVO projects are focused on automated capacitor switching and its potential impacts on line loss reductions. Two projects have also reported initial results for conserving energy during peak periods. Future SGIG VVO analysis reports will continue to present the various approaches used to optimize voltage and reactive power levels in distribution feeders, as well as the benefits they will provide to utilities and customers.

1. Introduction

The U.S. Department of Energy (DOE), Office of Electricity Delivery and Energy Reliability (OE), is implementing the Smart Grid Investment Grant (SGIG) program under the American Recovery and Reinvestment Act of 2009. The SGIG program involves 99 projects that are deploying smart grid technologies, tools, and techniques for electric transmission, distribution, advanced metering, and customer systems. DOE-OE recently published the *Smart Grid Investment Grant Program Progress Report* (July 2012) to provide information about the deployment status of SGIG technologies and systems, examples of some of the key lessons learned, and initial accomplishments.[2]

DOE-OE is analyzing the impacts, costs, and benefits of the SGIG projects and is presenting the results through a series of impact analysis reports. These reports cover a variety of topics, including:

- Peak demand and electricity consumption reductions from advanced metering infrastructure, customer systems, and time-based rate programs
- Operational improvements from advanced metering infrastructure
- Reliability improvements from automating distribution systems
- Energy efficiency improvements from advanced volt/volt-ampere reactive (VAR) controls in distribution systems
- Efficiency and reliability improvements from applications of synchrophasor technologies in electric transmission systems

1.1 Purpose and Scope

This impact analysis report presents information on the 26 SGIG projects that are installing devices and systems for voltage and volt-ampere reactive (VAR) optimization (VVO), the types of devices and systems being deployed, and deployment progress to achieve one or more of the following objectives: (1) lowering distribution voltage levels during peak periods to achieve peak demand reductions, (2) reducing voltage levels for longer periods to achieve electricity conservation, and (3) reducing energy losses in the electric distribution system. Expected benefits include deferral of capital expenditures, energy savings, and greater operational flexibility and efficiency.

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[2] DOE-OE, *Smart Grid Investment Grant Program Progress Report*, July 2012, www.smartgrid.gov.

The SGIG VVO projects are in the early stages of implementation and have not finished deploying, testing, and integrating the smart grid devices and systems. However, 8 of the 26 SGIG VVO projects have reported hourly feeder load data covering the periods of April 2011 to September 2011 (summer) and October 2011 to March 2012 (winter). Initial results from these 8 projects are presented, in addition to initial results from 2 projects applying techniques for conservation voltage reduction. The report also discusses how smart grid technologies can help optimize voltage profiles on distribution feeders.

1.2 Background about VVO

Maintaining proper voltage levels throughout the electric distribution system is one of the most important challenges utilities face. [3] Customer demands for electricity change throughout the day, which means the power and voltage levels flowing through distribution systems increase and decrease throughout the day to meet changing loads. For decades, utilities have used voltage regulating equipment and capacitor banks to keep customer voltages within a desired range to meet demand. While this equipment works properly, utilities have known that performance could be improved if the equipment could also track loads and voltages more closely, and be operated to respond when those levels change.

Recent advances in sensors, communications, and information processing and control technologies have made it possible to monitor voltages throughout the distribution system and report that information to devices that can adjust voltage regulating equipment and capacitor banks. This information is available in near-real time, enabling these technologies to make adjustments quickly in response to constantly changing load and voltage conditions. In addition, adjustments to individual devices and systems can be coordinated by distribution management systems and other techniques so that they can be optimized in a comprehensive manner. This is the goal of VVO to make quick adjustments to voltage and reactive power levels within distribution circuits to address system needs.

1.3 Organization of this Report

Section 2 of this report provides information on the types of devices and systems being deployed by the SGIG VVO projects and their expected benefits. Section 3 describes the status of deployment, including details about the specific VVO objectives the projects are trying to achieve. Section 4 provides a summary of the DOE-OE analysis of the 10 VVO projects that reported initial results. Section 5 discusses next steps for DOE-OE analysis of the SGIG electric distribution reliability projects.

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[3] ANSI standard C84.1 specifies that the voltage provided to customers should be between 114 volts and 126 volts.

Two appendices provide supplementary information. Appendix A provides technical background information on the relationship between reactive power compensation and line loss reductions. Appendix B provides a table of the SGIG VVO projects and includes the types of technologies they are deploying and their respective objectives for improving energy efficiency and system flexibility.

2. Devices, Systems, and Expected Benefits

There are approximately 160,000 distribution feeders that deliver electricity to customers in the United States.[4] These distribution feeders vary with respect to the number of customers they serve, how they are configured (radial, looped, or networked), and what strategies are employed to maintain and control voltage and power levels.

Capacitors, voltage regulators and transformer load tap changers have traditionally been used for many years for voltage support and reactive power compensation on distribution feeders. However, new technologies, tools, and techniques are now available for accomplishing intelligent control of the existing equipment. Devices and systems such as sensors, communications systems, distribution management systems, and automated control packages enable intelligent control. When successfully implemented, these new capabilities provide benefits to utilities and customers.

2.1 Voltage Support and Reactive Power Compensation

Voltage levels drop along the length of the feeder lines due to electrical impedance, as shown in Figure 1. The amount that voltages drop depends on several factors, including the level of the load on the feeder and the distance of the load from the power source.

Table 1 summarizes the three types of equipment commonly used by utilities to keep voltage levels in the proper range along feeders. **Load tap changers** (LTCs) can increase or decrease voltage levels on transformers at substations. As feeder loads increase, LTCs can increase voltage levels to account for the larger voltage drop along the feeder caused by the higher load. **Voltage regulators** can also increase or decrease voltage levels and can be installed at substations or along distribution feeders. Like LTCs, voltage regulators adjust voltages as load changes. **Capacitor banks** installed along distribution feeders can increase voltage levels and compensate for reactive power to serve nearby inductive loads.

Load Tap Changers and Voltage Regulators

The electric grid is principally an alternating current (AC) system. A key advantage of AC is the ability to increase or decrease voltage levels with transformers. LTCs and voltage regulators are types of transformers. LTCs are devices on substation transformers used to raise or lower voltage outputs. Voltage regulators are devices that adjust voltage levels in response to

[4] Navigant Consulting Inc., "Assessment of the Total Number of Distribution Circuits in the United States," Analysis Memorandum to the U.S. Department of Energy, June, 2012.

Equipment		Grid Locations	Grid Functions
Load tap changers		Substation transformers	Adjusts feeder voltages at the substation
Voltage regulators		Distribution feeders or substations	Adjusts voltages at the substation or along the feeder
Capacitor banks		Distribution feeders or substations	Compensates for reactive power and provides voltage support

Table 1. Equipment for Voltage Support and Reactive Power Control

changes in load. Voltage regulators are typically installed along distribution feeders to regulate voltage farther from the substation.

On distribution feeders, as load increases, the amount voltages drop also increases. LTCs and voltage regulators make small adjustments to voltage as load changes. A voltage regulator on the feeder would detect that the voltage had decreased below its target level and step up to increase the voltage to return it to the desired range. LTCs and voltage regulators have multiple “raise” and “lower” positions and can adjust voltages automatically according to how they are configured.

Figure 1 and Figure 2 illustrate the effects of LTCs and voltage regulators on a hypothetical distribution feeder voltage profile. In Figure 1, the LTC can adjust the voltage at the head of the feeder to keep the profile within the acceptable voltage range.

Figure 2 shows how a voltage regulator placed mid-way along a feeder adds a control point to raise or lower the downstream voltage levels. The figure also shows that a voltage profile within a feeder can be effectively lowered, or flattened (see the dashed lines), by conservation voltage reduction (CVR) practices such that the range of voltage variation along the feeder is reduced.

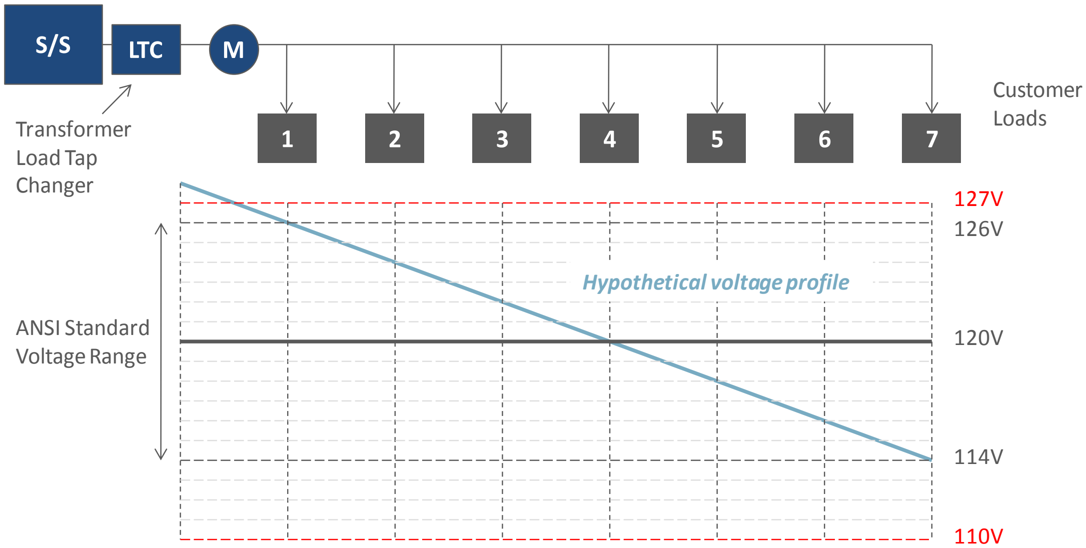

Figure 1. Hypothetical Feeder Voltage Profile with an LTC

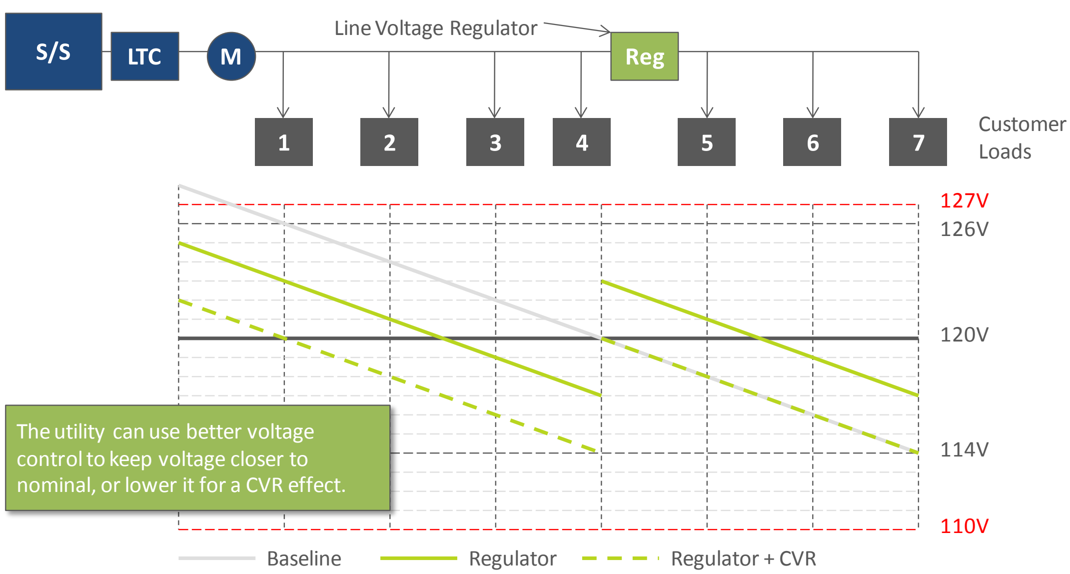

Figure 2. Hypothetical Feeder Voltage Profile with an LTC and Voltage Regulator

Capacitors

Utilities use capacitors to compensate for reactive power caused by inductive loads. Inductive loads involve equipment such as motors whose operation depends on magnetic fields. Using capacitors to compensate for reactive power reduces the total amount of power that needs to be provided by power plants. The end result is a flatter voltage profile along the feeder, and less energy wasted from electrical losses in the feeder. Appendix A provides a detailed discussion of the relationship between reactive power compensation and line losses.

A distribution capacitor bank consists of a group of capacitors connected together. The capacity of the bank depends on the number of capacitors, and typically ranges from 300 kVAR to 1800 kVAR.[5] Capacitor banks are mounted on substation structures, on distribution poles, or in enclosures ("pad-mounted").

Capacitor banks are either fixed or switched. Fixed banks are sized to compensate for relatively constant amounts of reactive load. Switched banks can be turned on or off as load and voltage conditions change. Switching frequencies depend on how often conditions change. Because the capacitors in the bank are normally switched as a group, reactive power and voltage levels change together in a single step. Typically, utility engineers specify the size of the bank so that switching the bank will not cause voltage to rise too high or fall too low. The voltage step-change that results from switching capacitor banks can be large compared to the smaller changes created by LTCs or voltage regulators. As a result, capacitor banks are not applied as much for voltage control as they are for voltage support.

Figure 3 shows how a capacitor bank placed along a feeder supports voltage. The combined effect of the three types of equipment is to help utilities keep overall profiles closer to desired levels under a variety of load conditions.

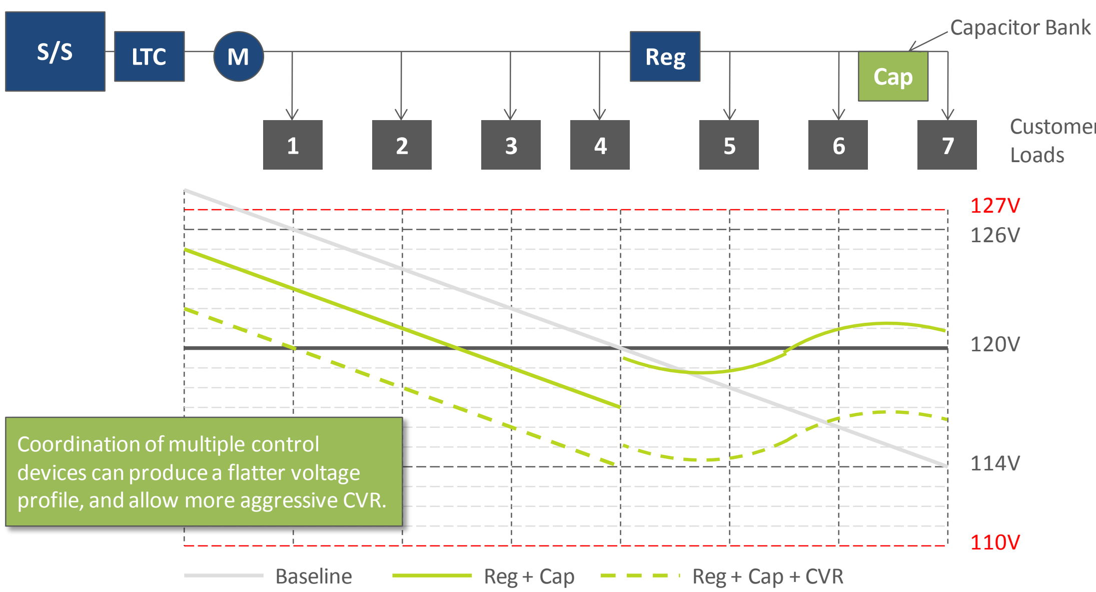

Figure 3. Feeder Voltage Profile with LTC, Voltage Regulator and Capacitor Bank

[5] The unit of measurement for reactive power is kilovolt-ampere reactive (kVAR).

2.2 Automated Controls

For many years, engineers designed the electric distribution system to serve customers over a wide range of expected load conditions. The size and placement of LTCs, voltage regulators, and capacitors were typically based on off-line modeling of peak- and light-load conditions, and operating experience. Historically, most utilities have not actively monitored loads and voltages along distribution feeders beyond the substation. For the last several decades, supervisory control and data acquisition (SCADA) systems have been used by many utilities for distribution system monitoring, but these reach only substations and do not monitor feeder conditions from substations to customers. The lack of operating visibility on distribution feeders has required utilities to design and operate their systems in a relatively conservative manner, often manually, to accommodate worst case scenarios. There has been little opportunity to optimize voltage and reactive power levels for constantly changing load conditions.

Centralized and Decentralized Controls

Utilities are applying both centralized and decentralized control schemes to enable VVO. Figure 4 provides a schematic that summarizes some of the differences between these two approaches.

In general, centralized control involves a centrally located computer and SCADA or other communication networks to coordinate automated equipment operations among multiple feeders. In contrast, decentralized controls use local control packages to operate equipment on a single feeder, or on a relatively small numbers of feeders according to pre-established logic schemes. Many projects use a combination of centralized and decentralized approaches, depending on feeder characteristics and VVO objectives.

The two types of approaches can vary on the amount of time it takes to accomplish VVO actions. For example, centralized systems can account for more factors when determining control strategies but may take longer to execute the strategies than do decentralized systems. However, centralized systems can deal with a broader spectrum of system conditions and thus can be more flexible than decentralized systems. This includes better integration with transmission providers.

Communications Systems

Communications systems connect sensors to information processors (e.g., a distribution management system [DMS]), and connect information processors to the control devices that regulate voltage and power factor. Most power companies use a two-layer system to support communications between the DMS and control devices. The first layer, which connects the

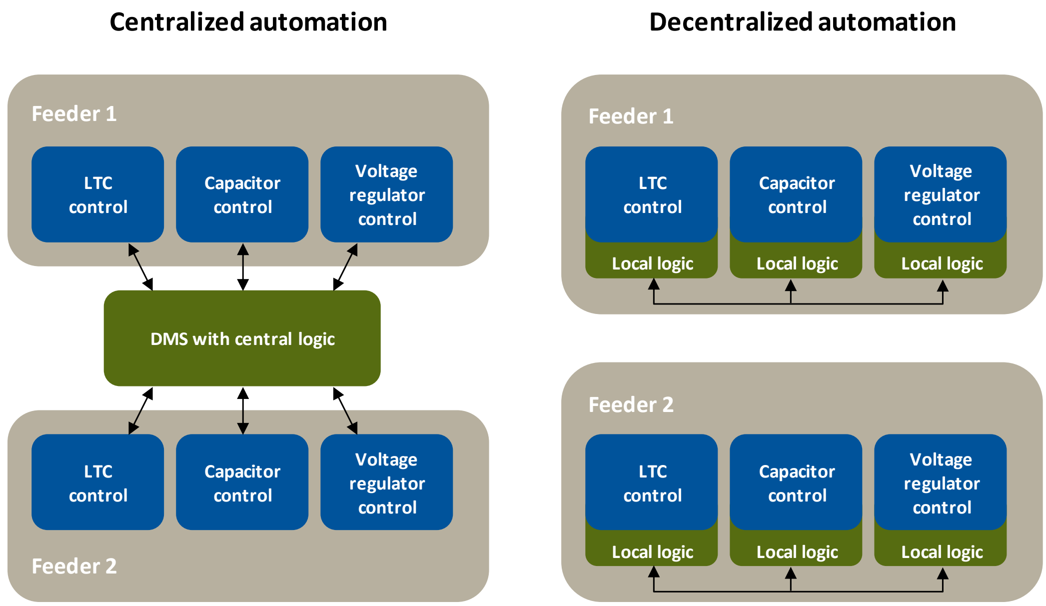

Figure 4. Centralized and Decentralized Controls

DMS to utility substations, consists of high-speed fiber optic or microwave communications systems. Some utilities utilize existing SCADA communications networks for this layer. Wireless technology is commonly used for the second layer connecting substations to VVO devices.

The expansion of communications networks to connect VVO devices to SCADA and DMS, and to each other, increases the ability of power companies to manage voltages and other aspects of distribution system operations. Communications architectures are being designed to accommodate future growth and the broader use of sensing and control capabilities, including those used for feeder switching and smart meter operations.

Distribution Management Systems

Some utilities are deploying a central computer and software to analyze distribution power flow data and make decisions about switching capacitor banks and adjusting load tap changer and voltage regulator set points.[6] Such a DMS typically uses an electrical model of the distribution system, SCADA information, and data from other control packages to predict how distribution systems will respond to certain control actions.

After calculating the best control actions, the DMS implements its decision by sending commands to the control packages to adjust the capacitors, load tap changers, and voltage

[6] Distribution management systems are also used for automated feeder switching, fault identification, and equipment health monitoring.

regulators. The result is that the DMS can operate a group of VVO devices in a coordinated fashion to achieve specific performance objectives in the set of distribution circuits it controls, for example, reducing demand during a system peak by lowering distribution voltage levels.

Automated Control Packages

Automated control packages integrate the control of field devices with user interfaces and communications systems. New voltage regulators and capacitor banks equipped with these controls are available, and retrofitting new control packages on existing equipment is also common. Interoperability of automated controls with existing equipment is an important concern for utilities considering deployment.

Automated control packages use data from sensors to determine voltage and current on the distribution line.[7] Controllers can be programmed to switch capacitors in or out of service automatically, depending on the voltage level and power factor, or in response to a command from an operator or other control system. Controllers may also use more complex software algorithms to coordinate its operation with other devices or systems to perform different operations. The control software may be built into the controller itself, or may reside in a central computer.

Voltage Sensors

Voltage sensors provide engineers and grid operators with voltage information from virtually any part of the distribution system, including customer premises. This makes it possible to see voltage profiles on distribution feeders and the changes made by VVO equipment. In the past, utility engineers might only obtain actual voltage and load information along feeders infrequently by making manual measurements in the field. Knowledge of low voltage points, often at the end of the feeder, will allow utilities to operate distribution feeders less conservatively and regulate voltage closer to design specifications.

Two types of voltage sensors are commonly used: (1) dedicated voltage sensors located on the primary distribution system (e.g., pole-mounted), and (2) voltage sensors built into smart meters. A communications network is required to collect data from stand-alone sensors. This data is sent to another device or system for processing. Voltage sensors may also be connected directly to automated control packages.

[7] Some controls use voltage information only. Controls that use power factor information must also have a current sensor, which increases the cost.

2.3 Expected Benefits

The VVO operations provide utilities with enhanced capabilities compared to traditional approaches. Expected benefits include optimization of voltage profiles to address changing system conditions, energy conservation, and reduced costs for operations and maintenance. Table 2 provides a summary of expected VVO impacts and benefits.

Improvement Area	Impacts	Primary Benefits
Better voltage control	Lower real power (MW) peak demand from CVR	Reduce capacity payments and/or defer capacity additions/upgrades
	Lower real power (MWh) consumption from CVR	Reduce fuel consumption with lower greenhouse gas and polluting emissions
Better VAR control	Lower reactive power (MVAR) peak demand	Reduce capacity payments and/or defer capacity additions/upgrades
	Lower line losses (MW)	Reduce fuel consumption and environmental emissions
Better operations and maintenance	Fewer service trips	Reduce O&M cost and vehicle emissions
Better integration of distributed energy resources	Acceptable voltage profiles over a wider range of generation and load conditions	Less expensive distribution system upgrades

Table 2. Summary of Impacts and Benefits

Improved Voltage Control

Coordinated VVO devices and systems enable utilities to more precisely control voltage and reactive power levels when and where they want. Operators can execute control decisions with more confidence, knowing that they will be alerted if customer voltages exceed limits. Since customer loads change constantly, VVO operations can respond and quickly adjust voltages to keep them closer to optimum levels, including flattening voltage profiles along feeders, when it is advantageous to do so.

Conservation voltage reduction (CVR) is an operational strategy designed to reduce the energy used by customer appliances and equipment by reducing distribution feeder voltages. While utilities have known about CVR for a long time, the inability to observe voltage levels along the length of distribution feeders has limited its use. The improved visibility and control provided by VVO is prompting more utilities to consider using CVR as a way to achieve peak demand reduction and energy conservation.

Reducing feeder voltage reduces energy consumption proportionately. The proportionality constant, shown in Equation 1, is called the “CVR factor.” A CVRf of 1 indicates that a 1% reduction in voltage corresponds to a 1% reduction in energy consumption.

$$CVRf = \frac{\Delta E(\%)}{\Delta V(\%)}$$

Equation 1. CVR factor

The CVR factor depends on the type of load connected to the feeder. Studies conducted by utilities in different parts of the country have shown that CVR factors between about 0.7 and 1.0 are common.[8]

Peak demand reduction

Utilities can apply CVR for short periods of time to reduce peak demand. This can be valuable for deferring capacity additions and distribution upgrades. One utility attempting to reduce peak demand with a distribution energy efficiency project estimated a potential demand reduction of 200 MW if implemented on its over 560 distribution feeders.[9] Another example is a utility implementing capacitor controls and an integrated VVO model aimed at reducing both line losses and peak demand. Deployment of advanced VVO on 400 circuits is anticipated to reduce peak demand by about 75 MW. Pilot testing on four circuits has produced peak demand reductions between 0.8% and 2.4%.[10] Reductions on this scale are significant; a 200 MW reduction is similar in size to a large peaking power plant.

CVR can also help reduce capacity payments for those distribution companies that are billed on the basis of their maximum monthly peak demand. This could be especially valuable to smaller electric cooperatives and public power utilities that purchase wholesale power with a capacity

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[8] "Voltage Optimization More than Pays for Itself," *Transmission & Distribution World*, August 1, 2010.

[9] "Can a Grid be Smart without Communications? A look at an Integrated Volt VAR Control (IVVC) Implementation," Barry Stephens, Georgia Power, Bob McFetridge, Beckwith Electric, April 25, 2012.

[10] "Ventyx Launches Network Manager DMS v5.3 With Model-Based Volt/VAR Optimization," Ventyx, December 5, 2011.

charge. These utilities could reduce their annual capacity-rated costs even if CVR were applied for only a few hours per year.

Electricity conservation

Utilities can use CVR for longer periods of time to conserve electric energy. This reduces the amount of fuel required to produce electricity, along with the associated cost and environmental impacts of power plants. In a recent utility study, VVO capabilities were deployed on eleven feeders at five substations for a 60-day evaluation. Ten of the eleven feeders showed lower energy consumption, with an average reduction of 2.9%. Over thirty operating days, CVR saved 251 MWh of electricity in total over the eleven feeders. Three feeders contributed 83% of the savings, with a reduction in energy consumption of 7% on one feeder.[11]

Since CVR reduces the energy consumed by connected appliances and equipment, customers use less electricity and have lower bills. This results in losses of revenues for utilities. One of the reasons that CVR is not commonly used is because many utilities cannot earn rates of return on lost revenues. In addition, gaining regulatory approvals for CVR investments also needs to be examined.

Improved VAR Control

As discussed, compensating for reactive power from inductive loads using switched capacitors improves power factor and reduces line losses. This saves energy and the fuel required to produce electricity to serve customers. Overall, line losses in distribution feeder lines range from 5%-13%[12] of the electricity produced to serve customers. A fraction of the line losses may be saved by improving power factor. For example, an overall savings of 0.04% to 0.2% of total electricity generation can be achieved with line loss reductions of 1% to 5% where utilities can correct for power factor. VVO can help improve power factor, while optimizing voltage profiles for better power quality and reliability.

Improved Operations and Maintenance

Adding automation to capacitor banks, LTCs and voltage regulators can reduce operations and maintenance (O&M) costs. Without automation a service worker must travel to a capacitor bank to physically operate the switch or check on the health of a voltage regulator. This can take hours and require many miles of driving if the equipment is far away from a service center,

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[11] K.P. Schneider and T.F. Weaver "Volt-VAR Optimization on American Electric Power Feeders in Northeast Columbus."

[12] Wagner, T.P., Chikhani, A.Y., Hackam, R. Feeder Reconfiguration for Loss Reduction: An Application of Distribution Automation. IEEE Transactions on Power Delivery, Vol. 6, No. 4, October 1991.

increasing both time and fuel costs. Automation can also provide operators and engineers with important status and condition information for maintenance. For example, one SGIG project recently reported failure rates of 20% on some of their capacitor banks.[13] Failures went undetected until a technician was sent to adjust the switch on the bank. Automation can notify operators of blown fuses or other maintenance requirements, saving time, money and vehicle miles.

Improved Integration of Distributed Energy Resources

Integrating renewable and distributed energy sources and electric vehicles into the grid presents new challenges for grid planners and operators. VVO enables control of voltage profiles along distribution feeder lines and helps with the grid integration of renewable energy systems, distributed generation and storage, and electric vehicles.

[13] Avista Corp., "Spokane Smart Circuit" Smart Grid Investment Grant Proposal, August 11, 2009.

3. SGIG VVO Projects and Deployment Progress

Table 3 provides a list of the 26 SGIG projects that are deploying various VVO technologies, tools, and techniques. The projects include a range of types and sizes of utilities from across the country and provide a representative sample for analysis of the impacts of VVO operations.

Electric Cooperatives	Investor-Owned Utilities	Investor-Owned Utilities (cont.)
• Northern Virginia Electric Cooperative, Virginia • Rappahannock Electric Cooperative, Virginia • Talquin Electric Cooperative, Inc., Florida **Public Power Utilities** • City of Auburn, Indiana • City of Wadsworth, Ohio • EPB, Tennessee • Knoxville Utilities Board • Modesto Irrigation District, California • Public Utility District No. 1 of Snohomish County, Washington • Sacramento Municipal Utility District, California	• Avista Utilities, Washington • Consolidated Edison Company of New York, Inc., New York • Duke Energy Carolinas, LLC, North Carolina, South Carolina • FirstEnergy Service Company, New Jersey, Ohio, Pennsylvania • Florida Power & Light Company, Florida • Indianapolis Power and Light Company, Indiana • NSTAR Electric Company, Massachusetts • Oklahoma Gas and Electric, Oklahoma • PECO, Pennsylvania	• Potomac Electric Power Company – Atlantic City Electric Company, New Jersey • PPL Electric Utilities Corporation, Pennsylvania • Progress Energy Service Company, Florida, North Carolina • Southern Company Services, Inc., Alabama, Georgia, Louisiana, Mississippi • Sioux Valley Southwestern Electric Cooperative Inc., Minnesota, South Dakota • Vermont Transco, LLC, Vermont • Wisconsin Power and Light Company, Wisconsin

Table 3. SGIG VVO Projects

Table 4 describes the different VVO devices and systems being deployed by the 26 SGIG VVO projects. As shown, most are installing capacitor banks with automation controls, or are retrofitting existing capacitor banks with control packages. Many projects are also automating voltage regulators or transformer load tap changers to work in conjunction with the automated capacitors. Some projects plan to coordinate the operation of this equipment using DMS or other forms of control algorithms.

SGIG Project	Objectives			VVO Devices			Voltage Sensors		
	CVR for Peak	CVR for Energy	Reduce Losses	Capacitors	LTCs or Regulators	Coordination Operations[14]	VVO Controller	Line Sensor	Smart Meter
Avista Utilities		◆	◆	◆	◆	◆	◆		
City of Auburn, Indiana				◆			◆		
City of Wadsworth, Ohio	◆	◆	◆	◆	◆	◆	◆	◆	◆
Consolidated Edison Company of New York, Inc.	◆		◆	◆	◆	◆	◆		
Duke Energy Carolinas, LLC		◆	◆	◆	◆	◆	◆		
EPB	◆		◆		◆	◆	◆	◆	◆
FirstEnergy Service Corporation			◆	◆	◆	◆	◆	◆	
Florida Power & Light Company				◆	◆	◆	◆		
Indianapolis Power & Light Company	◆			◆	◆	◆	◆	◆	◆
Knoxville Utilities Board	◆			◆	◆		◆	◆	◆
Modesto Irrigation District	◆		◆	◆	◆	◆	◆		◆
Northern Virginia Electric Cooperative	◆		◆	◆	◆		◆		
NSTAR Electric Company			◆	◆		◆	◆	◆	
Oklahoma Gas & Electric	◆		◆	◆	◆	◆	◆	◆	
PECO	◆	◆	◆	◆	◆	◆	◆	◆	◆
Potomac Electric Power Company – Atlantic City Electric Company			◆	◆		◆	◆		
PPL Electric Utilities Corporation		◆	◆	◆		◆	◆	◆	
Progress Energy Service Company	◆		◆	◆		◆		◆	
Public Utility District No. 1 of Snohomish County					◆	◆			
Rappahannock Electric Cooperative					◆		◆		◆
Southern Company Services, Inc.	◆			◆	◆	◆	◆		◆
Sacramento Municipal Utility District	◆	◆	◆	◆	◆	◆	◆		
Sioux Valley Southwestern Electric Cooperative Inc.		◆			◆		◆		◆
Talquin Electric Cooperative			◆	◆	◆	◆		◆	
Wisconsin Power and Light				◆		◆	◆		
Vermont Transco, LLC					◆	◆	◆		◆
Totals	11	7	16	20	19	21	22	10	9

Note: Regulation devices include transformer load tap changers and voltage regulators at the substation or along the distribution feeder. A dedicated smart meter may be used as a line voltage sensor.

Table 4. Summary of SGIG VVO Projects

[14] Coordinated operation may be accomplished with centralized automation using a DMS or similar system with central logic, or with decentralized automation using local logic.

Figure 5 provides an update on deployment progress and shows the number of automated capacitors and voltage regulators that have been installed and were operational as of June 30, 2012. This represents approximately 50% and 51%, respectively, of the total numbers of these devices expected at completion of the SGIG program.

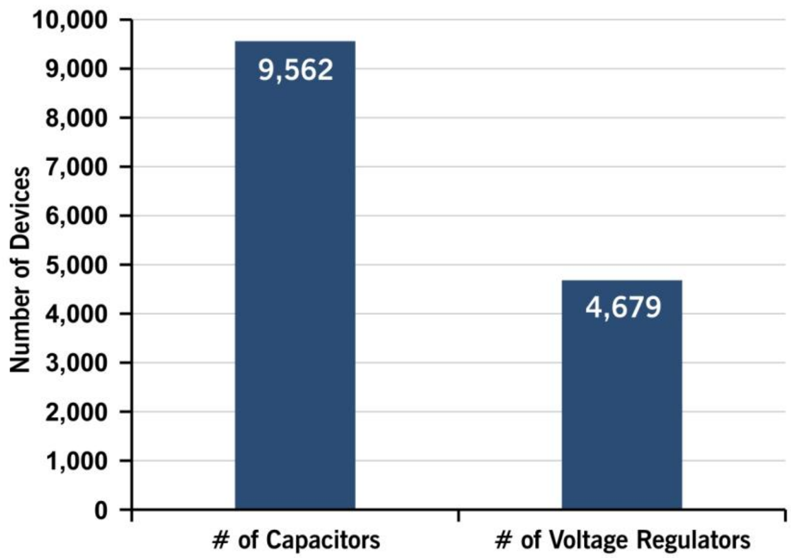


Figure 5. Numbers of Automated Capacitors and Voltage Regulators Deployed as of June 30, 2012

3.1 SGIG VVO Project Objectives

All of the SGIG VVO projects are interested in improving power factors and flattening voltage profiles on their distribution feeders. Better management of voltage on the distribution system presents opportunities to improve operations and electric service quality for customers. The primary objectives for the SGIG VVO projects generally fall into three main categories:

- Reduce peak demand (CVR for Peak)
- Reduce electricity consumption (CVR for Energy)
- Reduce distribution line losses

Some recipients are focused on only one objective, while others aim for multiple objectives. Figure 6 shows the number of projects that are pursuing each of the three primary VVO objectives.

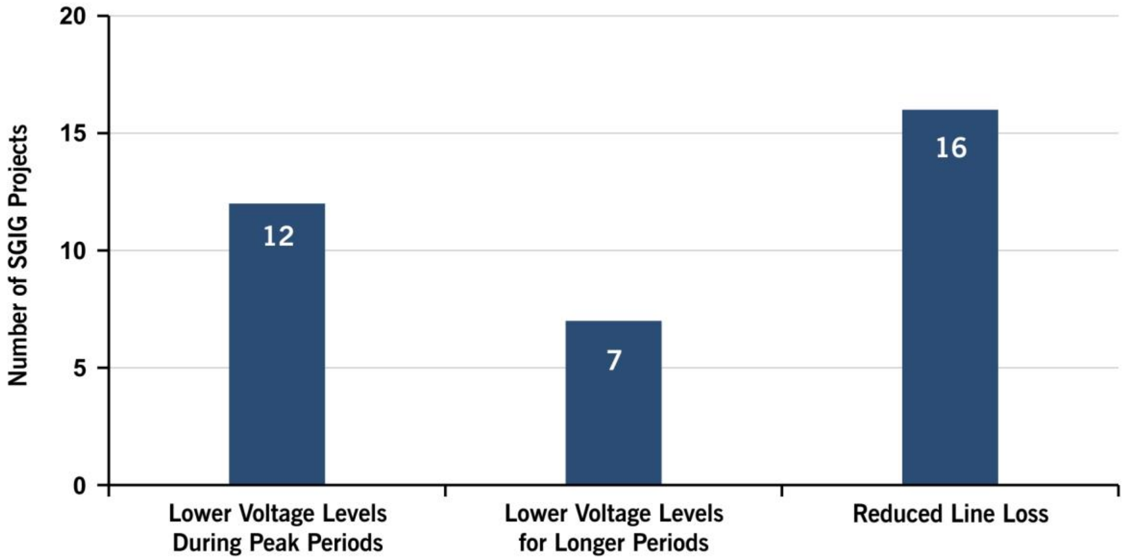


Figure 6. SGIG VVO Projects by Type of Objective

3.2 Deployment of VVO Devices and Systems

The SGIG VVO projects are deploying three types of VVO devices and systems for controlling voltage levels and power factors:

- Automated voltage regulators (including load tap changers)
- Automated capacitor banks
- Distribution management systems or other types of coordination algorithms

Figure 7 shows the number of projects deploying the various types of VVO devices and systems. Voltage monitors and sensors deployed along distribution feeders communicate voltage information to control equipment, and are an enabling capability for VVO operations. In many cases, the control packages installed on capacitor banks and voltage regulation equipment include voltage sensors that monitor voltage levels at that device. In some cases, line voltage sensors are being installed independently on feeders. Several of the projects are also using voltage information provided by smart meters.

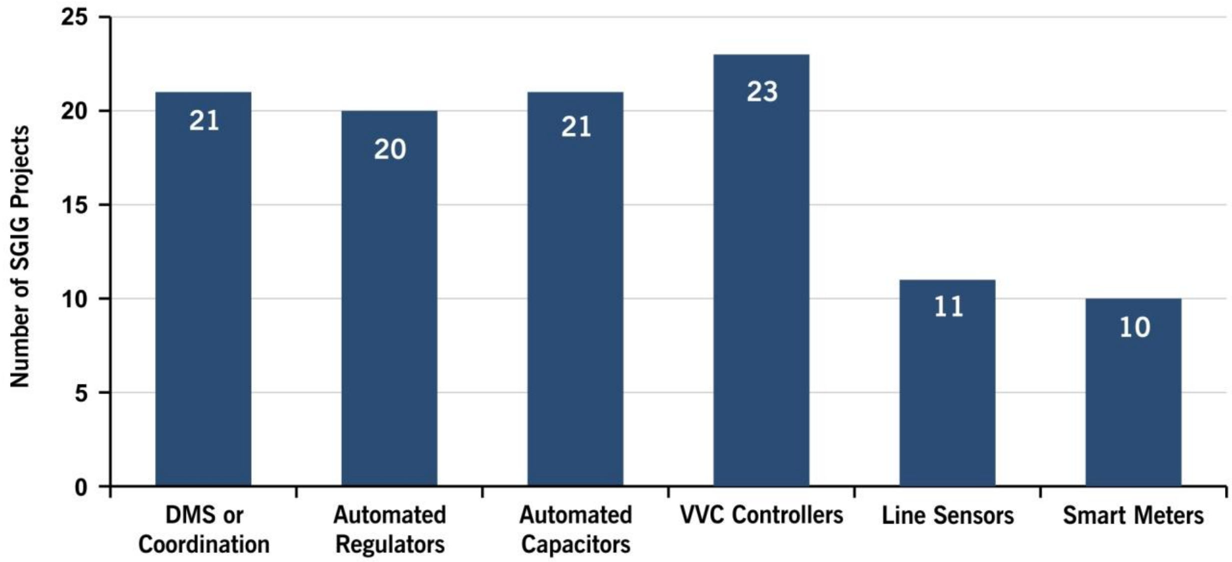


Figure 7. SGIG VVO Projects by Type of Devices and Systems

3.3 Project Examples

The SGIG VVO projects are pursuing objectives using a variety of devices and systems. To provide a better understanding of what the projects are doing and why, this subsection presents three examples.

Avista

Avista's VVC project coordinates substation voltage regulators and line capacitor banks using a DMS. The objective is to flatten voltage profiles on distribution feeders in order to safely lower the voltage levels and achieve energy savings with CVR. Avista also expects to reduce line losses by improving feeder power factor. Figure 8 shows Avista's equipment configuration.

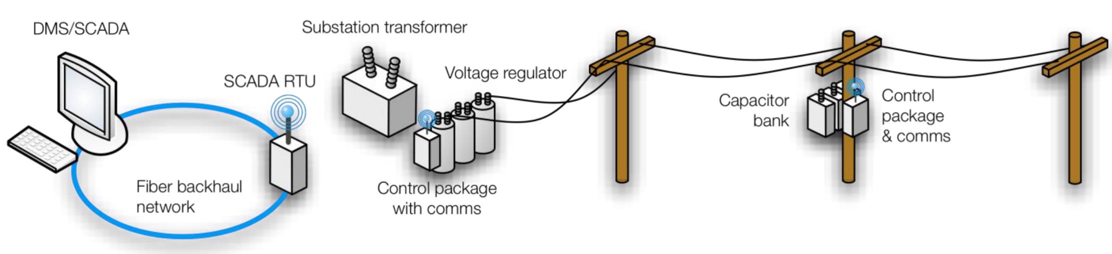


Figure 8. Avista's VVO Configuration

The DMS collects voltage information by polling voltage regulators and capacitor banks through SCADA RTUs at each substation. The DMS is connected to the SCADA RTUs by a new or existing fiber optic backhaul network. When appropriate, the DMS can send control signals to the voltage regulator to lower baseline voltage at the substation and switch in capacitor banks on the feeder as load increases. If switching a capacitor causes voltage levels to rise too much, the substation voltage regulator lowers the voltage to compensate.

The Avista DMS includes an Integrated Voltage and VAR Control (IVVC) algorithm that automatically monitors and controls individual capacitor banks to minimize feeder losses while maintaining voltages and power factor within specified limits. The DMS estimates the feeder loads to calculate voltage, branch flows, and power factor. The capacitor banks are sorted according to the reactive load they detect, and the capacitor seeing the highest reactive load becomes the switching candidate. The DMS checks the capacitor banks on each feeder and prioritizes the “OFF” capacitors according to the reactive loads they detect. If switching can be done without violating a voltage limit, the capacitor is switched “ON”. If the capacitor cannot be switched the DMS selects the next capacitor down the list. The DMS uses a dead-band to prevent excessive switching. Failures of the capacitor bank switches are reported through alarms.

Northern Virginia Electric Cooperative (NOVEC)

NOVEC is pursuing two VVC objectives. One focuses on improving feeder power factor with switched capacitor banks, and the other focuses on lowering feeder voltage at the substation. Switched capacitors can improve distribution feeder power factor and reduce line losses while flattening the feeder voltage profile. NOVEC expects to achieve significant cost savings from operating the switched capacitors to achieve peak demand reductions and lower line losses. One of the expected results involves releasing over 20 MVA of peak capacity. Figure 9 is a view of NOVEC’s configuration.

Lowering substation voltage regulator set points reduces peak demand by lowering distribution feeder voltage. NOVEC is installing electronic voltage regulator controls on the single-phase voltage regulators at the substation. These control packages include communications and are accessible through the SCADA system, enabling NOVEC to adjust the feeder voltage set point according to system conditions.

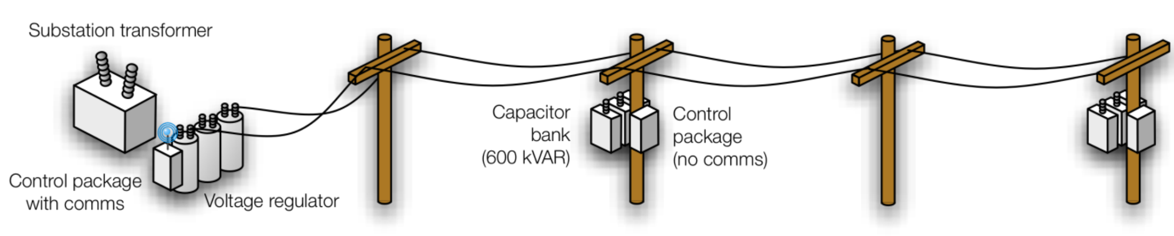


Figure 9. NOVEC's VVO Configuration

NOVEC has installed 600 kVAR switched capacitor banks and equipped them with automated controllers. The controllers do not include communications, but operate autonomously according to a proprietary control algorithm. NOVEC does not plan to coordinate their operation at this time due to the cost of adding the communications, and the fact that the technology is working so well to maintain voltage using the local control algorithm. The system could be upgraded in the future if it can be shown that the benefits are worth the added expense.

Pennsylvania Power and Light (PPL)

Development of a DMS and an integrated communications network is at the heart of the PPL project. As shown in Figure 10, the DMS monitors and controls all of the smart devices being installed in the PPL distribution system including automated switches, sectionalizers, and capacitors. PPL is building new multiprotocol-label-switching (MPLS) fiber communications between substations and the service center located in Harrisburg, PA, and WiMAX point-to-multipoint communications between substations and field devices. The company is building a new fiber network to connect the MPLS network to the DMS and other back office systems. An important outcome of the project is that it extends PPL's existing substation SCADA system to the new distribution automation system. The project has two primary goals: reduce restoration time following outages, and reduce overall energy consumption through improved VVO and voltage stabilization. PPL expects to reduce line losses and reduce customer energy consumption by optimizing voltage.

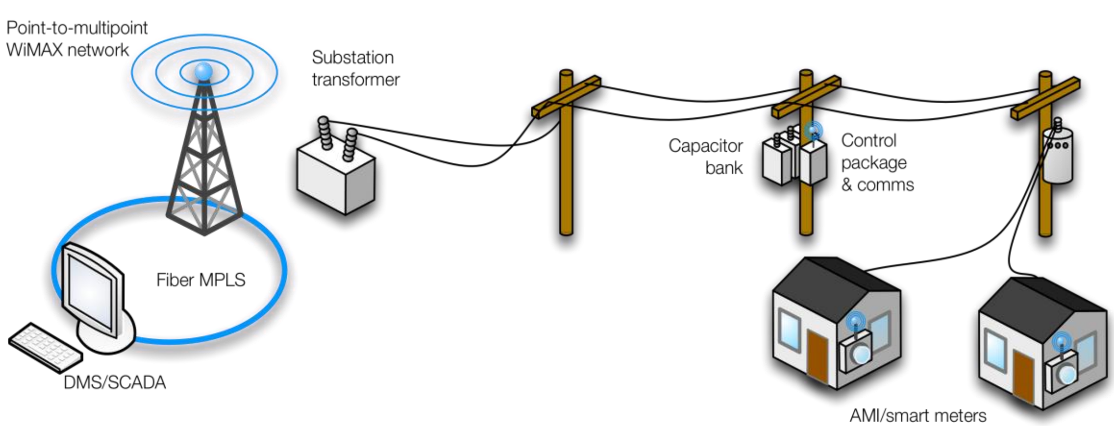


Figure 10. PPL's VVO Configuration

Southern Company

The primary objective of the Southern Company project is peak demand reduction from CVR. To this end, Southern Company is automating capacitor banks and voltage regulators on several thousand distribution feeders. This allows Southern Company to lower feeder voltages at the substation and reduce customer demand during peak periods. Southern Company is doing CVR projects in its Georgia Power and Alabama Power service territories. The goal for each service territory is to reduce peak demand by 200 MW, for a total peak demand reduction of 400 MW. Figure 11 depicts Southern Company's equipment configuration.

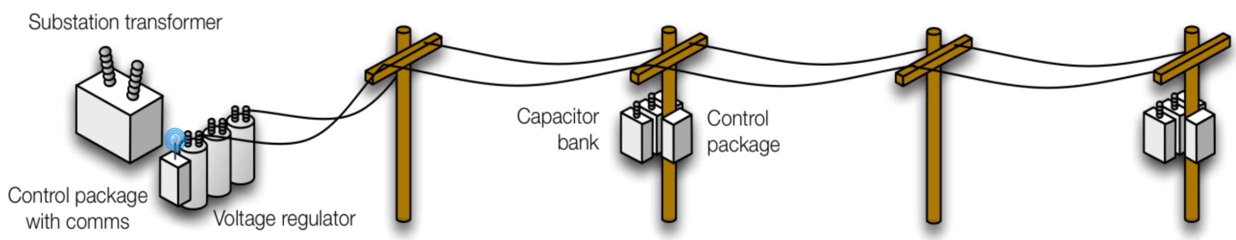


Figure 11. Southern Company's VVO Configuration

Southern Company is using capacitor controls to switch on capacitor banks in the event that voltage reductions at the substation reduce the end-of-line voltage below the desired range. Operators can adjust the voltage set points of the voltage regulator controls through SCADA. However, the capacitor controls operate independently in response to the voltage at each capacitor bank. So far Southern Company has seen good results from this approach and has been able to operate its distribution feeders close to unity power factor most of the time. In the future, the company plans to incorporate AMI smart meter data to monitor end-of-line voltages. Southern Company will also use a VVO control algorithm in its DMS, which is currently under development.

4. Analysis of Initial Results

This section examines the results obtained from the operation of automatically or remotely controlled switched capacitor banks, as well as efforts by two projects to apply CVR practices. Demonstrating the successful operation of automatically switched capacitor banks and other equipment is an important step in the progression toward fully capable VVO in response to changing load and system conditions.

As of March 31, 2012, 8 of the 25 SGIG VVO projects have reported initial results on 59 switched capacitor banks involving 31 feeders. Some of the capacitor banks involve new equipment, and some involve retrofits to existing equipment. Four of the eight projects use coordinated capacitor switching with voltage regulators at the substation or on distribution feeders. Six of the eight projects expect to use distribution management systems to control capacitor switching.

Figure 12 provides a summary of the types and sizes of the capacitor banks for the 8 projects, as estimated from analysis of hourly load data recorded from each feeder. All of the 31 feeders had at least one switched capacitor bank, more than half had two, and nearly a third had three. Six feeders also used a fixed capacitor bank. The sizes of the banks range from 0.1 MVAR to 2.0 MVAR.

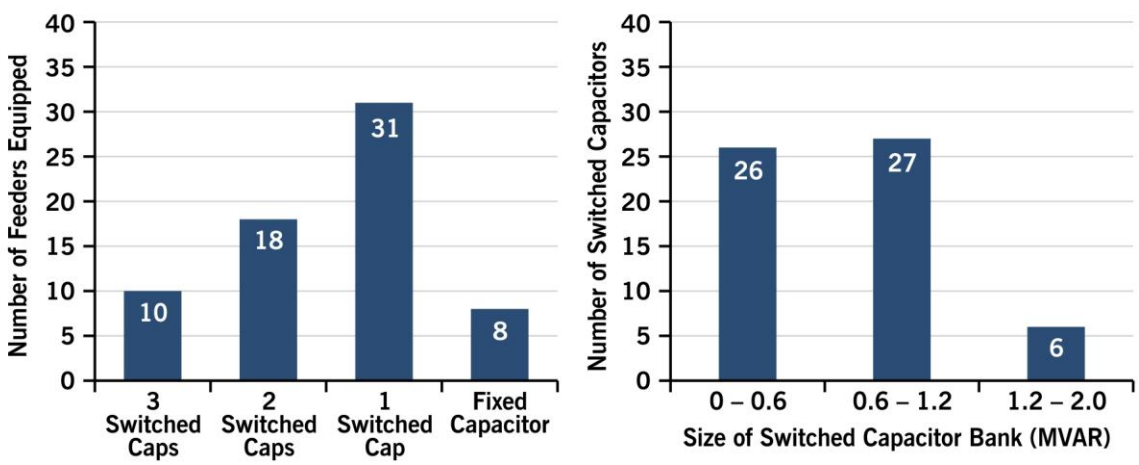


Figure 12. Number and Size of the Capacitor Banks

Section 4.1 provides information on the extent of capacitor bank switching. Section 4.2 provides information on the impacts of capacitor bank switching on line losses. Section 4.3 provides an example of CVR for achieving peak load reductions. Section 4.4 provides several observations about the initial results in these three areas.

4.1 Capacitor Bank Switching

Hourly data from the 31 feeders were analyzed to estimate switching statistics for each of the switched capacitor banks. Figure 13 shows the number of switching events on the capacitor banks. The period of analysis is 1–6 months, depending on the feeder, with an average duration of about four months.

The data shows that the projects operated the switched capacitor banks relatively frequently. There is some uncertainty associated with estimating switching events from hourly load data, but, compared to the traditional approach of seasonal switching by line crews (where manual switching may occur twice a year), the number of switching events initiated by the automatically-switched capacitor banks is orders of magnitude greater. Having the capability for automated capacitor bank switching is an important step toward fully-functional VVO.

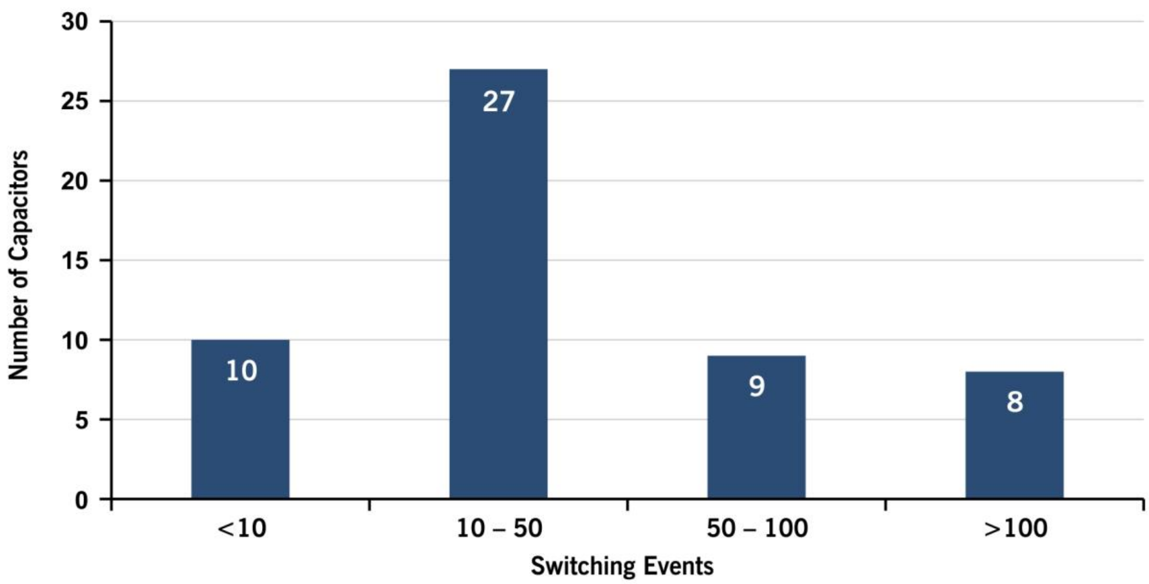


Figure 13. Capacitor Bank Switching Statistics

4.2 Line Loss Reductions

Figure 14 provides an example of capacitor bank control for a nine day period in July, 2011. The capacitor bank in this example switched on and off four times, as shown by the shaded areas in the chart. Switching intervals of several hours were common for the equipment deployed on this feeder. The chart shows that one of the results was an improvement in the power factor of the feeder of about 0.05 due to reactive power compensation by the capacitor banks. Improvement in the power factor reduces the amount of current flowing on the feeder and results in line loss reductions of about 4%.

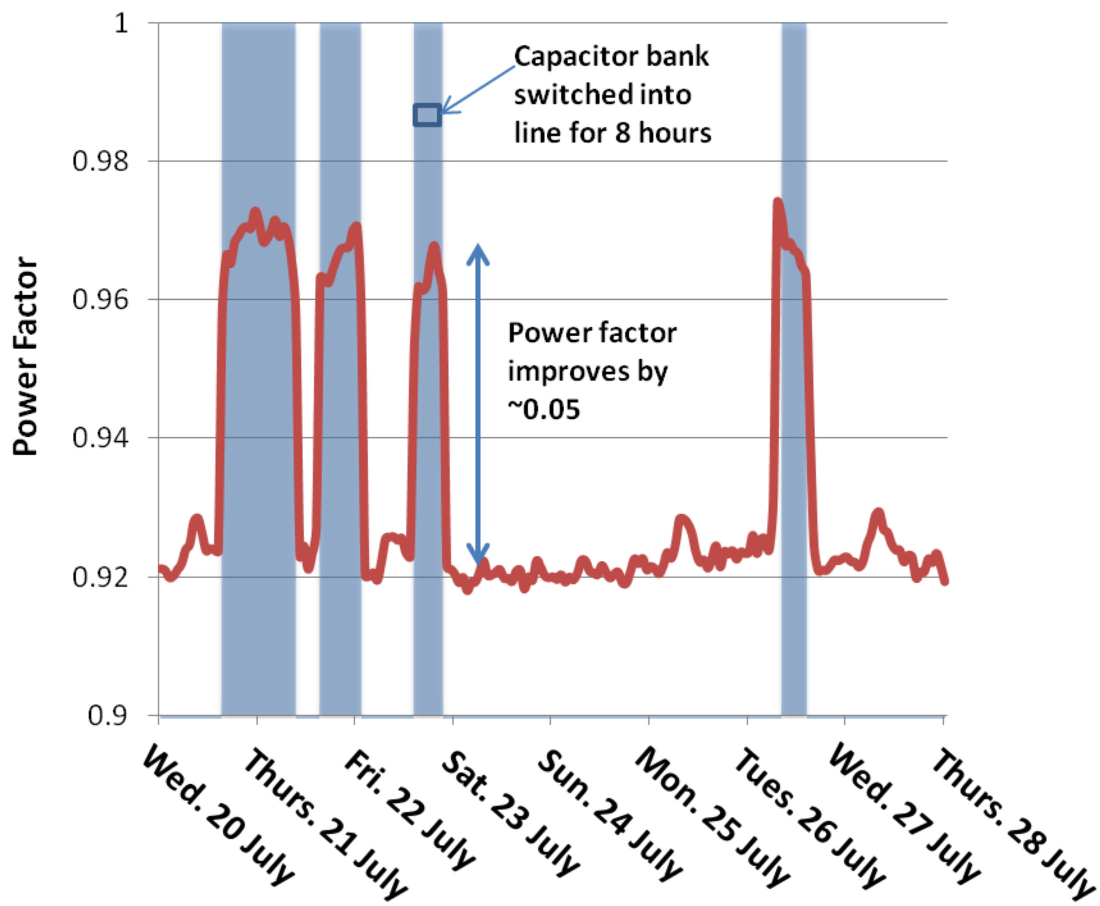


Figure 14. Example of Automated Capacitor Bank Control

Figure 15 presents the results of analysis to estimate line loss reductions for the 31 feeders from automated capacitor switching. Positive values indicate line loss reductions while negative values indicate line loss increases. The figure shows that 21 of the 31 feeders experienced line loss reductions.

Because of higher amounts of inductive loads on the feeders during the summer (primarily due to air conditioning), line loss reductions from automated feeder switching tended to be higher then. About one-half of the feeders experienced line loss reductions in the 0% to 5% range, which is in line with expectations and examples from the literature.[15]

[15] For example, Hydro One estimated line loss improvements of 3.1% with reactive power compensation. Source: Hydro One, "Distribution Line Losses," available at http://www.hydroone.com/RegulatoryAffairs/Documents/EB-2007-0681/Exhibit%20A/Tab_15_Schedule_3_Distribution_Line_Losses_Study.pdf, accessed June 16, 2012.

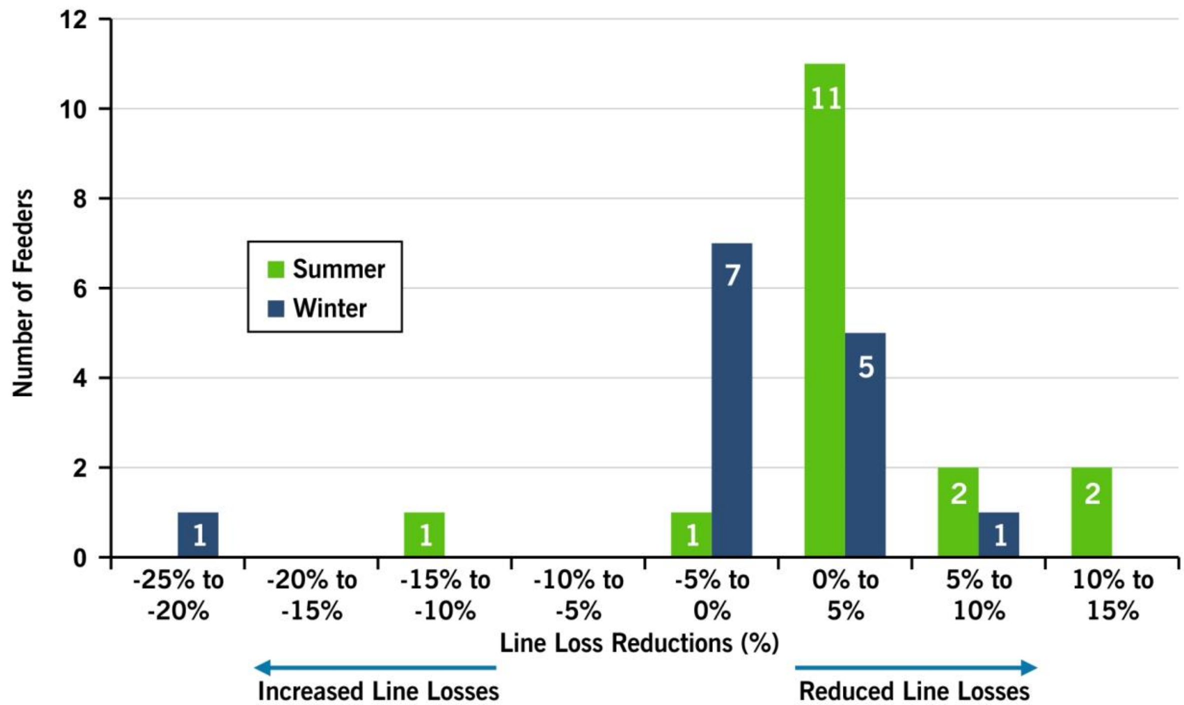


Figure 15. Histogram of Line Loss Reductions

4.3 Conservation Voltage Reduction

There are 11 SGIG VVO projects with the objective of accomplishing conservation voltage reductions during peak periods to reduce peak demand. Two of the projects – Oklahoma Gas and Electric (OG&E) and Sacramento Municipal Utility District (SMUD) – reported initial results from test operations for the summer of 2011. Figure 16 is a schematic of the devices and systems being implemented by OG&E for its CVR and other VVO activities.

OG&E is pursuing CVR on nearly 100 feeders with the objective of reducing peak demand by about 16 MW. They have plans to expand this effort to 300 more feeders by 2017 to increase peak demand reduction capabilities to approximately 74 MW, subject to business needs and regulatory approvals. The project uses two-stage control in near real-time. The first stage corrects power factor through capacitor switching, minimizing losses and levelizing voltage along the feeders. The second stage regulates load tap changer voltage to reduce demand while maintaining minimum voltage thresholds for each connected feeder. In addition, meter reads are sampled off line to gather customer-level voltage information. This helps ensure that voltages are maintained within acceptable ranges and guide adjustments of the minimum voltage thresholds that are used by the control scheme.

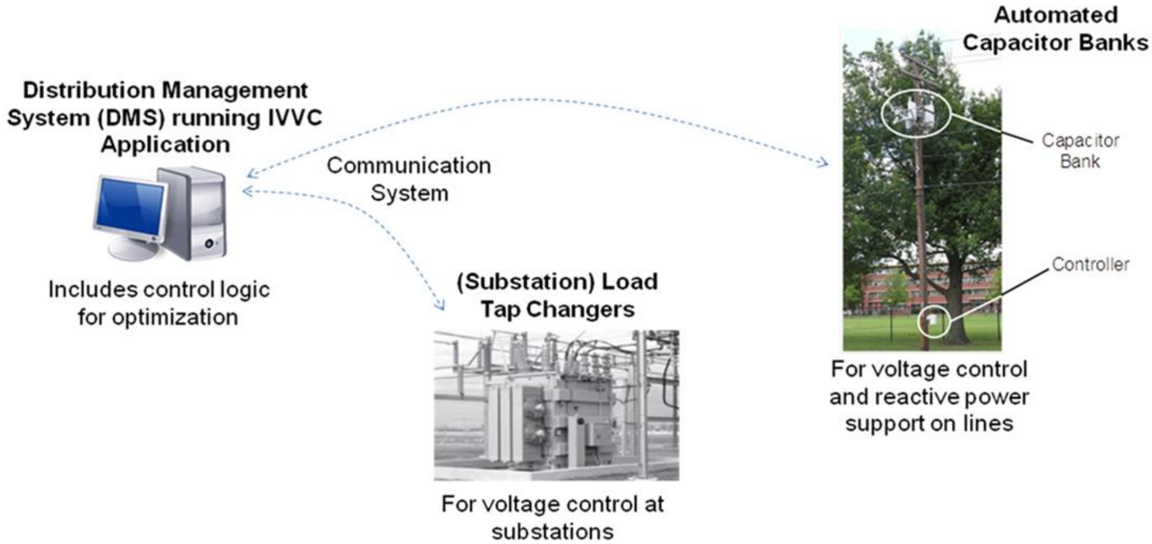


Figure 16. OG&E Devices and Systems for VVO Operations

OG&E test results from the summer of 2011 on the first 42 feeders showed an average peak demand reduction of 2.06%, which exceeded slightly the 2.0% target. This resulted in the capability for 8 MW of peak demand reduction for the 42 feeders. There will be about 474 capacitor banks equipped for CVR operations once the efforts on the nearly 100 feeders are completed in 2013. Once fully implemented, the utility plans to set controls to activate CVR for peak demand reductions during high demand periods.

SMUD is pursuing CVR and VVO for both peak demand reductions and electricity conservation. The project includes 109 feeders and uses 180 automated capacitor banks which cover about 18% of their system. The CVR objective for peak demand reduction is 10.4 MW; the CVR objective for electricity conservation is 36,520 megawatt-hours per year of energy savings. The latter objective is achieved by implementing CVR over several additional hours during the days when the peak demand reduction capabilities have been activated. The VVO objectives include peak demand reduction of 6.1 MW and energy savings of 11,150 megawatt-hours per year by improving the efficiency of the distribution feeders.

SMUD's method of implementing CVR is utilizing the voltage reduction feature of the LTC control at the distribution substation. A command is issued to the LTC control by a Distribution System Operator via SMUD's energy management system (EMS) which implements one of three levels of voltage reduction available in the control. The percent reduction at each level is a configurable value which SMUD has initially set at 1%, 2%, and 3%, for evaluation purposes.

Additionally, SMUD is implementing VVO which centrally controls substation capacitor banks and line capacitor banks in order to achieve a target power factor at the high voltage side of the distribution substation transformer. The line capacitors are strategically located to reduce line losses and provide voltage support on the distribution feeder. The substation and line capacitor banks are automatically switched in a predetermined order based on SMUD-developed control logic that operates within their EMS system.

In the summer of 2011, SMUD conducted a pilot test on two 69/12kV distribution substation transformers, each serving 3 - 12kV feeders, to demonstrate the CVR and VVO capabilities. For these two substations, the test showed an average peak demand reduction of 1% and 2.5%, respectively, for a 2% voltage reduction during the test implementation. SMUD plans to perform additional testing during 2013 and 2014 on forty-one 69/12kV distribution substation transformers and associated feeders.

4.4 Observations

While the SGIG VVO projects have not yet fully implemented all of their expected voltage management activities, eight of the projects have been operating switched capacitor banks and other devices and systems and initial results have been reported. In addition, two of the projects have tested conservation voltage reductions to lower peak demand. Observations from the initial results include:

- For the 31 feeders for which projects have reported hourly load data, one-half are witnessing line loss reductions in the range of 0% to 5% and 5 feeders experienced loss reductions greater than 5%. In general, feeders with the worst baseline power factors (i.e., those with the highest amount of inductive loads) showed the greatest reductions in line losses. Many of the utilities are targeting their worst performing feeders. However, overcompensation for reactive power was observed in the remaining feeders, which resulted in line loss increases. In these cases, capacitor banks were often operated for voltage support rather than reactive power compensation.
- The initial results for conservation voltage reductions indicate the potential for peak demand reductions of approximately 1% to 2.5%, which is consistent with expectations and the results of other studies in the literature. There are no results yet from the SGIG VVO projects on conservation voltage reductions for longer periods to achieve electricity conservation. In comparison to energy savings attributable to line loss reductions, practices to affect conservation voltage reduction will have the greatest impact on reducing energy requirements.
- Projects are applying different approaches depending on their objectives to better manage volt/VAR levels within their distribution systems. While all projects are

deploying automated controls to new and existing equipment, the extent to which field devices are integrated and the application of distributed versus centralized control schemes differs across them. In addition, some are actively attempting to apply conservation voltage reduction practices to conserve energy during peak periods and for longer durations, while many others are more focused on improving volt/VAR management (including reducing related operations and maintenance costs) and hope to achieve line loss reduction through power factor correction in addition to voltage stabilization.

5. Next Steps

So far, most of the initial results reported by the SGIG VVO projects have focused on automated capacitor switching and its potential impacts on line loss reductions. Only two projects have reported initial results on the application of conservation voltage reduction practices. Future SGIG VVO analysis reports will continue to focus on impacts from activites related to conservation voltage reduction and power factor correction, as well as convey best practices and lessons learned.

Collaboration between DOE-OE and the SGIG VVO projects is essential to ensure that appropriate data are gathered and reported, and for understanding the factors that lie behind the quantitative results. DOE-OE routinely discusses the progress being made and data being reported with the projects to validate the results of the analysis and encourage the active exchange of information among the projects. DOE-OE continues to monitor the installation of VVO devices and systems and to explore the technology configurations and operating techniques upon which impacts are based. DOE-OE will publish follow-up analysis on the SGIG VVO projects in the future. In the meantime, updates on deployment progress and case studies highlighting project examples are posted regularly on www.smartgrid.gov.

Appendix A. Reactive Power Compensation and Line Losses

The purpose of this appendix is to provide basic information on the significance of reactive power and the role of capacitors in reactive power compensation and line losses.[16]

Direct and Alternating Current Circuits

Electricity permits energy to be transferred to devices within electric circuits so they can do useful work in the form of heat, light, and motion. Power is defined as the rate of energy expended per unit time and is expressed in watts (energy/time). Power (P) is equal to the product of current (I) and voltage (V) in electrical circuits (P=IV).

In a direct current (DC) circuit, current and voltage move in one direction along a conductor (wire) and energy is transferred to devices according to P=IV. In an alternating current (AC) circuit, current and voltage periodically reverse direction (60 cycles per second in North America) and there is an exchange of energy between magnetic and electric fields. In doing so, a portion of the energy is taken up in this exchange and the remainder is available to perform useful work.

The fundamental circuit elements are resistors, inductors, and capacitors. Electrical resistance is the property of a material or an electric device to resist the flow of current through it. Examples of such devices (i.e., resistors) include incandescent light bulbs and toasters. Reactance is the property of devices (i.e., inductors and capacitors) to influence the relative timing of alternating voltage and current on AC circuits. Examples include motors in devices such as refrigerators and air conditioners.

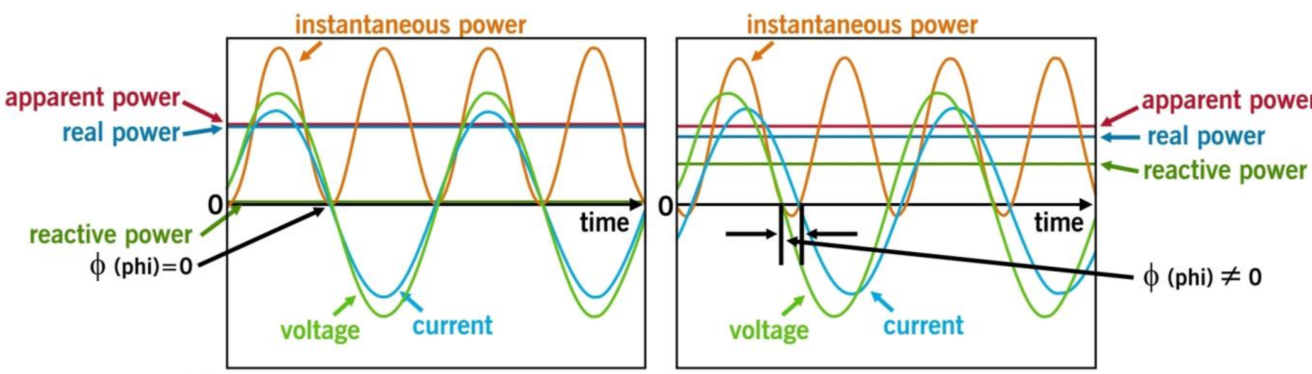
Real Power, Reactive Power, and Power Factor

In AC circuits with only resistive loads, voltage and current are in phase, and oscillate simultaneously, as shown in Figure A-1 (a). Instantaneous power is equal to the product of current and voltage at any given point in time. Electrical energy is transmitted or consumed over more than a single point in time and is determined by average power. Average power (or real power) is measured as the product of the root-mean-square (RMS) values of I and V, and represents the actual power transmitted or consumed by devices on the circuit. The RMS value of voltage in a standard outlet is 120 V even though the maximum amplitude of the instantaneous voltage is 170 V.

[16] For further information see Alexandra von Meier "Electric Power Systems a Conceptual Introduction", IEEE Press, 2006 and MIT "Future of the Electric Grid, Appendix B" December, 2011.

Inductors produce magnetic fields that interact with the flow of current in a conductor. This is because the current in an inductor cannot be changed instantaneously. As currents oscillate, so do the magnetic fields. This exerts inhibitory effects on the changes in current flows. This inhibitory effect results in a delay of the alternating current relative to the alternating voltage, as shown in Figure A-1 (b). As a result of inductance, the average power (and the power available to do real work) is reduced since the relative timing of voltage and current has been shifted and, in fact, one quantity is sometimes negative when the other is positive.

The difference in the relative timing of the alternating current and voltage is also referred to as the phase angle, denoted by ϕ (phi), which is often specified in terms of radians or degrees (since oscillating current and voltage are mathematically represented as sinusoidal waves). In this case, the average power is related to the amount of phase shift according to $P_{ave} = I_{rms}V_{rms}\cos(\phi)$ or $P_{ave} = \frac{1}{2}I_{max}V_{max}\cos(\phi)$. Reactive power results when the voltage and current are out of phase and is measured in volt-amperes reactive (VAR). Reactive power is exchanged between the electric and magnetic fields in the power system and does no real work.



(a) Current and Voltage In-Phase ($\phi = 0$) (b) Current Lags Voltage ($\phi \neq 0$)

Figure A-1. Current, Voltage, and Power in an AC System

The mathematical relationship between real power and reactive power is represented by the power triangle shown in Figure A-2. The phase angle represents the shift of the current and voltage waveforms. Apparent power is the product of the magnitudes of currents and voltages. The magnitude of apparent power is denoted by the absolute value of S, where $S = I_{rms}V_{rms}$. Apparent power is measured in terms of volt-amperes and is always greater than or equal to real and reactive power.

System load is the power drawn by appliances and equipment. The apparent power of the load determines the total current supplied by the source, including the portion supporting reactive power. Therefore, loads with higher reactive power components draw higher currents. This is important because the capacity rating of some equipment is determined by current.

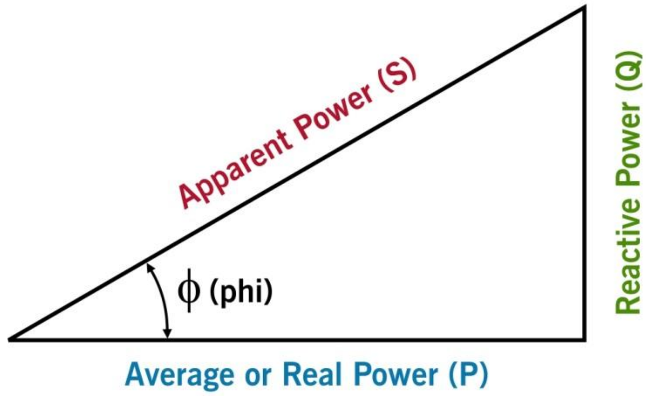


Figure A-2. Power Triangle

Power factor (pf) is a term used to express the relationship between real power and reactive power. As shown in Figure A-2, power factor can be expressed as the cosine ofϕ, or as average power/apparent power. A larger phase angle (ϕ) corresponds to a larger amount of reactive power and a lower power factor. Power factor is always between zero and one, and a power factor of one is often referred to as "unity."

Capacitors and Power Factor Correction

Utilities can use capacitors to improve power factors. Like inductors, capacitors cause a phase shift between current and voltage, but in the opposite direction. A capacitor and inductor can exchange energy with each other in an alternating manner without consuming or dissipating real power. Capacitors are often connected near large inductive loads where they can compensate the load most directly.

Without capacitors, additional current supplied by generators results in increased line losses (lost energy) due to the greater amount of current being carried through conductors according to $P=I^2R$, where P is the dissipated power (that is converted to heat) and R is the resistance of the conductor measured in ohms. Higher currents also mean that conductors, transformers, and other equipment must be sized to carry the total current, not just the current that does useful work.

Appendix B. SGIG VVO Projects

SGIG Project	Objectives			VVO Devices			V Sensors			Scale and Scope of Project	Project Objectives
	CVR Peak	CVR Energy	Reduce Losses	Capacitors	Regulation [1]	Coordination [2]	VVO Control [3]	Line Sensors	Smart Meters		
Avista Utilities		◆	◆	◆	◆	◆	◆			Expands existing program, adds DMS and integrated control.	Reduce energy consumption and CO2 emissions
City of Auburn, Indiana				◆			◆			10 new automated capacitor banks.	Minimize changes in reactive power demand using power factor corrections
City of Wadsworth, Ohio	◆	◆	◆	◆	◆	◆	◆	◆	◆	20 capacitor controls, automated regulators and new DMS software.	Improve power factors and reduce line losses
Consolidated Edison Company of New York, Inc.	◆		◆	◆	◆	◆	◆			Deployment on a portion of the service territory.	Use capacitors to decrease losses and release effective capacity. Use coordinated load tap changers to improve control on 4kV grids.
Duke Energy Carolinas, LLC		◆	◆	◆	◆	◆	◆			Large-scale project with 2600 regulation devices and 3700 capacitor controls.	Integrate devices with SCADA systems targeting line losses and voltage controls
EPB	◆		◆		◆	◆	◆	◆	◆	Pilot program on five circuits. “Virtual Power Plant” with a DMS to control capacitors and line voltage regulators.	Testing if feeder voltage profiles can be flattened, with a goal of reducing peak demand by 30 MW
FirstEnergy			◆	◆	◆	◆	◆	◆		Pilot project on 21 feeders in OH and 22 feeders in PA (MetEd)	Targeting 3% voltage/energy reduction, 5% peak demand reduction[3]
Florida Power & Light Company				◆	◆	◆	◆			Replacing existing capacitor controls with automated capacitor controls	Better operation of VVO equipment
Indianapolis Power & Light	◆			◆	◆	◆	◆	◆	◆	Large-scale project on 400 feeders across the service territory.	Reduce peak demand by 40 MW to lower capacity costs
Knoxville Utilities Board	◆			◆	◆		◆	◆	◆	Testing peak demand CVR on one circuit and VAR control two circuits.	Looking to measure reduction in peak energy usage (peak demand).
Modesto Irrigation District	◆		◆	◆	◆	◆	◆		◆	Automation and communications for 40 existing capacitor banks for 8 substations.	Targeting reduction in system losses and peak demand. Focused on improving power factor and voltage stabilization.

[1] Regulation includes load tap changers and voltage regulators.
[2] Coordinated operation may be accomplished with centralized automation using a DMS or similar system with central logic, or with decentralized automation using local logic.
[3] Voltage sensor is installed as part of VVO control packages.

SGIG Project	Objectives			VVO Devices			V Sensors		Scale and Scope of Project	Project Objectives
	CVR Peak	CVR Energy	Reduce Losses	Capacitors	Regulation [1]	Coordination [2]	VVO Control [3]	Line Sensors	Smart Meters		
Northern Virginia Electric Cooperative	◆		◆	◆	◆		◆			Adds automation and control to new and existing equipment.	Energy savings by reducing line losses and reduce peak capacity by 25 MVA.
NSTAR Electric Company			◆	◆		◆	◆	◆		Adds automation to existing capacitor banks to allow better switching of the cap banks.	Targeting reduction in system losses and improvement of power factor. Avoid truck rolls.
Oklahoma Gas & Electric	◆		◆	◆	◆	◆	◆	◆		Expanding existing VVO by 100 feeders enables voltage optimization.	Defer capacity additions by reducing peak demand by 74 MW
PECO	◆	◆	◆	◆	◆	◆	◆	◆	◆	Expands existing program and enables advanced CVR.	Simple CVR - 0.5% energy and demand reduction, Advanced CVR - Test and learn
Pepco – Atlantic City Electric Company			◆	◆		◆	◆			Add controls and communications to new and existing capacitors.	Reduce line losses with power factor correction, flatten distribution voltage profiles.
PPL Electric Utilities Corporation		◆	◆	◆		◆	◆	◆		205 automated capacitors in the Harrisburg region of the service territory.	Optimize voltages and reduce line losses
Progress Energy Service Company	◆		◆	◆		◆		◆		SGIG accelerates large-scale deployment (97% of service territory) in the Carolinas.	Reduce peak demand with CVR
Public Utility District No. 1 of Snohomish County					◆	◆				Small-scale project on up to 10 circuits.	Reduce line losses
Rappahannock Electric Coop					◆		◆		◆	Adds controls to voltage regulators.	Reduce voltages when called upon by PJM
Southern Company	◆			◆	◆	◆	◆		◆	Large-scale (100s of feeders).	Primary goal is reducing peak demand (200 MW at Georgia Power, 200 MW at Alabama Power)
Sacramento Municipal Utility District	◆	◆	◆	◆	◆	◆	◆			Large-scale deployment of automation equipment.	Improve power factor and reduce peak demand
Sioux Valley Southwestern Electric Coop		◆			◆		◆		◆	Automation of voltage regulators to improve voltage optimization and reduce peak demand.	Reduce peak demand by 1.5 MW in summer and 2.5 MW in winter

[1] Regulation includes load tap changers and voltage regulators.
[2] Coordinated operation may be accomplished with centralized automation using a DMS or similar system with central logic, or with decentralized automation using local logic.
[3] Voltage sensor is installed as part of VVO control packages.

SGIG Project	Objectives			VVO Devices			V Sensors			Scale and Scope of Project	Project Objectives
	CVR Peak	CVR Energy	Reduce Losses	Capacitors	Regulation [1]	Coordination [2]	VVO Control [3]	Line Sensors	Smart Meters		
Talquin Electric Cooperative			◆	◆	◆	◆		◆		DMS will coordinate the operation of 55 new automated capacitor banks and existing regulators.	Improve power quality and reduce line loss
Wisconsin Power and Light				◆		◆	◆			Upgrade 750 capacitor banks with communications and controls.	Manage power factors closer to unity
Vermont Transco, LLC					◆	◆	◆		◆	Automating 47 feeders, targeting reliability improvements and O&M savings.	Reduce line losses

[1] Regulation includes load tap changers and voltage regulators.
[2] Coordinated operation may be accomplished with centralized automation using a DMS or similar system with central logic, or with decentralized automation using local logic.
[3] Voltage sensor is installed as part of VVO control packages.