Regulatory Assistance Project
Issuesletter

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IS IT SMART IF IT'S NOT CLEAN?

Questions Regulators Can Ask About Smart Grid and Energy Efficiency
Part one: Strategies for utility distribution systems

Energy efficiency is among the federal government's objectives in the Recovery Act of 2009 (HR 1, 111th Congress) for modernizing the US electric grid. But unless utilities and others plan for energy efficiency benefits from the start, the smart grid will not live up to its promise.

An earlier Issuesletter *examined the potential values of smart grid for consumers and recommended policies for commissions to consider before committing ratepayer dollars for such investments.*[1] *This* Issuesletter *raises questions that public utility commissions and stakeholders can ask if they want smart grid investments to improve distribution system efficiency,*[2] *focusing on conservation voltage reduction and optimizing voltage and var control. It's the first of a two-part series on smart grid's potential benefits for energy efficiency and distributed generation.*

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Conservation Voltage Reduction and Volt-Var Control

The distribution lines that deliver energy to homes and businesses typically lose 3 percent to 7 percent of the electricity they carry.[3] Utilities can reduce line losses by operating the distribution system in the lower portion of the acceptable voltage range.[4] Reducing electric service voltage also reduces the energy consumption of some consumer equipment without affecting service.[5] In fact, according to research by the Northwest Energy Efficiency Alliance and the Electric Power Research Institute (EPRI), most of the energy savings potential may be on the customer side.

Utilities control distribution line voltage by changing settings on equipment at the substation serving the line or on equipment connected to the line. Voltage falls gradually as current flows further from the substation. Utilities must keep substation voltage at a level sufficient to ensure that voltage at the end of the line is within industry standards. While system operators may be used to a considerable margin above minimum voltage standards, real-time data communication and remote control allow for margins to be smaller without affecting service to customers or damaging their equipment. By reducing voltage to the lowest level within industry standards, utilities can reduce line losses, peak loads, and reactive power needs (a requirement of many kinds of equipment, including motors and transformers) and save (or defer) energy use by some types of consumer loads.

"Conservation voltage reduction" (CVR) is a general term for the changes to distribution equipment and operations needed to deliver those benefits. When remote monitoring and control equipment is used for CVR, it also can allow the utility to control capacitors to optimize reactive power (vars) on substation feeders and transformers and to balance feeder voltage and current – if circuits are properly configured and equipped. CVR and var optimization operated together can provide enhanced benefits.

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Distribution System Terms

Advanced Metering Infrastructure is a metering system that records customer consumption of electricity (and possibly other variables) hourly or more frequently and provides at least daily transmittal of measurements over a two-way communication network to a central collection point.

Capacitors control power factor and voltage by injecting reactive power into the system.

Conservation voltage reduction (CVR) is the intentional and routine reduction of system voltage, typically on distribution circuits, to reduce line losses and energy use by some types of end-use equipment while maintaining customer service voltage within applicable national standards (e.g., ±5 percent of nominal). CVR is different than voltage reduction required during periods of inadequate generation supply.

Distribution systems transmit electricity to retail customers. They typically consist of: 1) substations with equipment to control power flows and transform power from transmission voltages to lower voltages, 2) one or more distribution circuits (also called lines or feeders) that deliver power to step-down transformers that serve retail customers, and 3) sensors and control equipment along the circuits.

Load-tap changer is a manually or remotely controlled switch that alters the setting of a transformer or voltage regulator to adjust its output voltage – potentially while power is flowing through the device.

Power factor is the ratio of real power flow to a piece of equipment to the apparent power flow. The difference is determined by the reactive power required by certain types of loads, such as motors and transformers. The power factor is less than one if there is a reactive power requirement.

Reactive power establishes and sustains the electric and magnetic fields of alternating-current equipment and directly influences electric system voltage. Reactive power must be supplied to most types of magnetic (non-resistive) equipment and to compensate for the reactive losses in distribution and transmission systems. Reactive power is provided by generators, synchronous condensers, and electrostatic equipment such as capacitors. It typically is expressed in kilovars (kvar) or megavars (Mvar).

SCADA – Supervisory Control and Data Acquisition – is a system of remote control and telemetry used to monitor and control the distribution and transmission system.

Shunt capacitors connect a feeder to ground at some point along the feeder's length and are used to compensate for a low power factor caused by motors and other inductive loads on heavily loaded or long rural feeders, improving the feeder's power factor, raising voltage on the line, and lowering line losses.

Substations reduce the voltage level of alternating current electricity from transmission or subtransmission facilities and deliver it to feeders for distribution.

Switches at strategic locations open or close circuits – redirecting power flows for load balancing, allowing for equipment maintenance, or limiting the number of customers interrupted during outages.

Transformers are electromagnetic devices that change the voltage level of alternating current electricity.

Volt-Ampere Reactive (var) is a unit of reactive power.

Voltage for an electrical system is the difference in electrical potential between any two conductors, a conductor and ground, or any two points on the system. It is a measure of the electric energy that electrons can acquire or give up as they move between the two conductors.

Voltage regulators are devices, typically installed in a substation at the beginning of a feeder, that maintain distribution voltage within industry standards by increasing or decreasing voltage as needed.

Voltage transducers are voltmeters that produce a signal that can be transmitted to a readout.

Techniques for Reducing Voltage

A long-used approach to controlling voltage along a feeder is "line drop compensation," where the utility controls the voltage at substation transformers and regulators at the head of the feeder so that, based on engineering calculations, estimated voltage remains within acceptable limits all the way to the end of the feeder. See Figure 1. Line drop compensation can be used to provide some amount of energy savings and, therefore, may be operated as a form of CVR. Another approach is "end of line" control in which voltage is monitored at the far end of a feeder and equipment is adjusted to maintain acceptable voltage at the end of the line. See Figure 2. End of line control is more expensive but allows for tighter control of voltage and increased energy savings.[6] Regardless of approach, greater voltage reductions can be achieved cost effectively when coupled with distribution system improvements such as upgrading distribution line size or voltage and reconfiguring or adding feeders.[7]

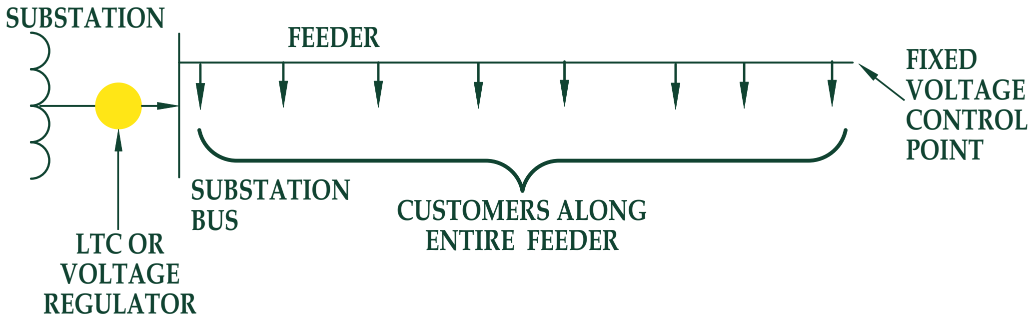

Figure 1. Line drop compensation control used in the Northwest Distribution Efficiency Initiative. Control settings were adjusted to fix the voltage at the end of the feeder. LTC = load tap changer. Figures 1 and 2 are from RW Beck, *Distribution Efficiency Initiative Project: Final Report*, prepared for the Northwest Energy Efficiency Alliance, December 2007, at http://www.rwbeck.com/neea/. *Used with permission*.

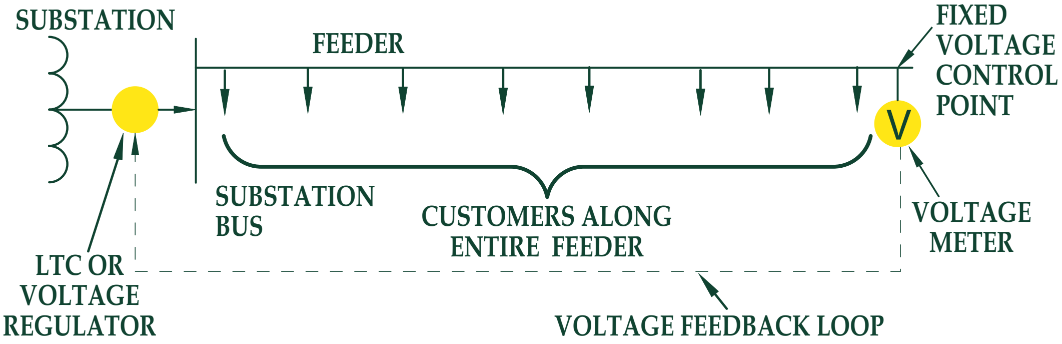

Figure 2. End of line voltage feedback control, a closed-loop system that measures and communicates end of line voltages in real time to the voltage regulating device at the substation.

Heavily loaded lines, long lines, and lines with large motor or air conditioning loads[8] may require the utility to install voltage regulators or shunt capacitors that can be switched on or off to maintain voltage at proper levels as loads change. The control equipment, at the substation or along the line, may be set manually or remotely. Smart grid's measurement, communication, and control capabilities may provide an opportunity for advanced forms of voltage and var optimization – continually optimizing tradeoffs in service voltage and energy use by precisely controlling voltage within acceptable limits. For example, if distribution SCADA systems are extended along the length of the feeder, shunt capacitors can be remotely controlled to compensate for the variation in voltage throughout the day based on local voltage measurements, allowing for greater CVR. See Figure 3.

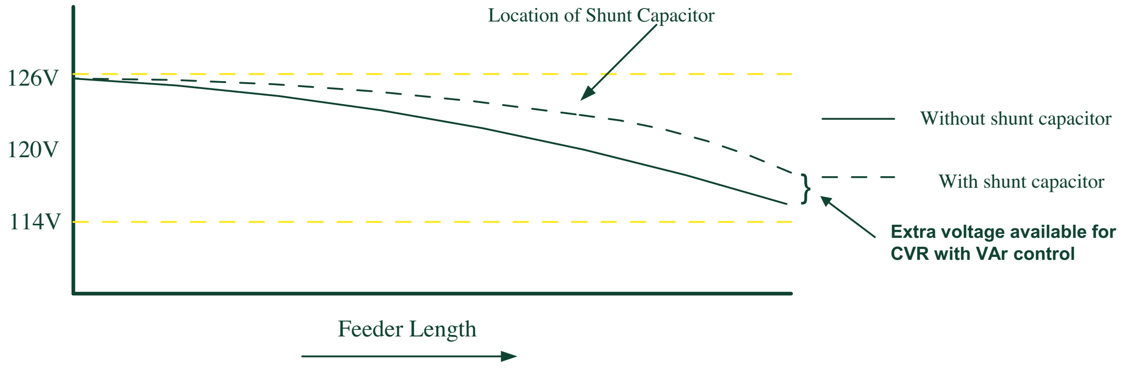

Figure 3. Var control makes extra voltage available for CVR. *Source*: Pratt, *et al*. See footnote 5. *Used with permission*.

Voltage and Var Control Today

Utilities have used voltage reduction during periods of capacity shortages for many years. For example, ISO New England's operating procedures include it among the actions system operators may take to avoid involuntary load curtailments. The ISO estimates that a 5 percent voltage reduction saves 421 megawatts in a 28,000 megawatt system.[9]

Conservation voltage reduction or "voltage optimization" – a term sometimes used to refer to advanced forms of CVR that include var control – is designed to reduce capacity needs overall, to reduce energy use, or both. The Northwest Energy Efficiency Alliance sponsored an extensive load research and field study of CVR with 11 utilities in the Pacific Northwest involving 31 feeders and 10 substations from 2004 to 2007.[10] According to the final project report, "operating a utility distribution system in the lower half of the acceptable voltage range (120-114 volts) saves energy, reduces demand, and reduces reactive power requirements without negatively impacting the customer."[11] The study estimated CVR could save 1 percent to 3 percent of total energy, 2 percent to 4 percent of kW demand, and 4 percent to 10 percent of kvar demand. As the report pointed out, major distribution efficiency improvements beyond CVR were required to reach the highest levels of savings. (Such improvements are discussed further below.)

Voltage reductions ranged from 1 percent to 3.5 percent. The study found that a 1 percent reduction in distribution line voltage provided a 0.25 percent to 1.3 percent reduction in energy consumption, with most substations seeing results between 0.4 percent and 0.8 percent.[12] The results further indicate that when voltage reduction is coupled with major system improvements, 10 percent to 40 percent of the energy savings are from reduced losses on the utility distribution system. That means the majority of savings are from reduced consumption in homes and businesses due to equipment operating at lower voltage.

Extrapolating the results to the four Northwest states, the Northwest Power and Conservation Council estimates the regional savings potential of CVR combined with distribution system upgrades at more than 400 average megawatts by 2029.[13] The Council also estimates that the cost of acquiring those savings is low, with two-thirds of the potential savings at a levelized cost of less than $30 per megawatt-hour.[14]

Little is known about how CVR might interact with smart grid technologies. As part of its Smart Grid City project in Boulder, Colo., Xcel Energy is testing dynamic voltage/var optimization based on monitored real-time conditions. A recent review of the field by Pacific Northwest National Laboratory concluded that, while additional research is needed, combining var control with smart grid technologies could potentially reduce total electricity consumption by 2 percent. That's the *incremental* savings beyond CVR as practiced today.[15]

EPRI launched a Green Circuits project[16] in 2008 to build on the Northwest Distribution Efficiency Initiative by expanding field deployments of technologies and strategies and testing smart grid measurement, communication, and control. (See table below.) The project is intended to improve modeling and loss analysis methods, analyze economics of various strategies to improve distribution efficiency, and develop general guidelines for improving efficiency as a function of circuit and customer load characteristics.

EPRI Distribution Green Circuits Research Project

Distribution Efficiency Improvement	Technologies to Improve Efficiency
1. Reduce distribution line losses	Re-conductoring Phase balancing Capacitor placement, var control
2. Reduce equipment losses	Distribution transformers (high efficiency and amorphous metal transformers)
3. Improve distribution operations	Voltage optimization Smart distribution control

The project involves 24 utilities and related organizations in 33 states and four countries. Roughly 90 circuits in rural and urban areas are included. Initial studies have been completed for 50 circuits. Distribution efficiency options were modeled as modifications to the base case, including:

- **Voltage optimization/CVR** – keeping feeder voltage in the lower band of the allowed range[17]
- **Phase balancing** – rearranging loads on each phase of the circuit to lower the current on the most heavily loaded phase(s)
- **Reactive power optimization** – adding capacitor banks or modifying switching schemes
- **Reconductoring** – replacing selected conductor sections with larger, lower-resistance conductors
- **High-efficiency transformers** – replacing lower-efficiency line transformers with higher-efficiency units

Initial results were compared with control circuits without such treatment. Among the preliminary findings:

- A 1 percent to 3 percent reduction in energy consumption is achievable.
- The majority of energy savings – perhaps 80 percent – is from customer loads such as motors running more efficiently.
- Peak demand can be reduced by 1 percent to 4 percent.
- Reactive power requirements can be reduced by 5 percent to 10 percent.
- The average CVR savings factor – the percentage change in load resulting from a 1 percent reduction in voltage – is 0.79, with a range of 0.66 to 0.92. That's higher than determined in the Northwest Energy Efficiency Alliance study described above, likely due at least in part to the high levels of (resistive) electric heating loads where the Alliance study was conducted.

The next phase of the EPRI project will validate these preliminary findings, assess costs and benefits, test reaction of specific customer end-use devices to voltage optimization using advanced metering infrastructure (AMI) data, and evaluate additional efficiency measures such as coordination with distributed resources for loss reduction and load management through distribution automation.[18]

Smart Grid Opportunities to Improve Distribution Efficiency

While not a prerequisite for improving distribution efficiency, smart grid technologies may increase energy savings. Regulators can ask utilities the following questions about opportunities to improve distribution efficiency when reviewing smart grid plans or investments. Preliminary answers are provided based on the general status of smart grid technologies at this time.

➡ *Can advanced metering systems measure voltage at customer premises and transmit the data to the utility?*

Today, even advanced meters for homes can measure voltage. While voltage measurement may not be automatically enabled, no change in hardware is required and this function may be remotely activated. Even if meters are not used to measure voltage for CVR, visibility of voltage at customer premises – measuring it remotely in real time – may become increasingly important to maintain electric service within industry standards given projected levels of distributed generation and plug-in electric vehicles. Regulators can ask utilities whether voltage measurement capability will be unlocked and available and, if not, why not. Communications for advanced metering systems generally are designed to transmit any type of meter data. However, regulators can ask whether the proposed communication system has "headroom" to transmit additional data that may become available over the system's life, such as voltage measurements from an adequate sampling of meters across the utility grid in a timely manner.

Can advanced meters measure vars?

Large customers already have meters that measure vars, and utilities charge these customers extra for a poor power factor. Today's advanced meters for homes are not capable of measuring vars. Such capability may become important in the near future, as variable-speed motors make their way into home equipment. These motors are more energy-efficient, but some have a poor power factor. Var measurement would expose the issue, encourage power factor specification for energy efficiency programs, and promote improved motor design. Regulators can ask utilities whether planned advanced metering systems can be upgraded to measure vars.

Power Factor & Energy Efficiency

Suppose the power factor on a circuit is 70 percent, a very poor value but one that might be seen on a circuit with large motor loads. If the real power load on the circuit is 100 kW, the utility would need to produce about 100 kvar of reactive power to serve the load. If the power factor were improved to 95 percent, a typical target value for utility planners, the utility would need to produce only about 33 kvar of reactive power to serve that load. Delivering kvar from the utility's generators is not as costly as delivering real power, but improving the power factor on a circuit by installing capacitors is generally even less expensive.[19]

Is AMI necessary to implement CVR?

No. In fact, we are aware of only one US utility that uses AMI for this purpose.[20] While voltage must be measured at one or more points on the feeder and communicated back to the utility to go beyond the line drop compensation approach, SCADA and strategic placement of a small number of voltage transducers on each circuit are sufficient to get the currently identified benefit from CVR.

Can utilities use AMI to increase energy savings from CVR?

AMI provides time-stamped data in real time or after-the-fact that provide more detailed information on end-use patterns and diversity factors on the system, compared to traditional voltage transducers, and may allow better quantification of distribution losses. The additional data provided by AMI also might allow tighter control of voltage – and increased energy savings – and help overcome utility concerns about the feasibility of lowering voltage.

Can utilities use other smart grid technologies to increase distribution efficiency savings?

Smart grid's real-time data communication and remote control capabilities enable voltage and var optimization. More research is needed, however, on how smart grid technologies interact with CVR, how they can be used to optimize energy savings, and whether it would be cost-effective to do so. For the highest savings levels, the utility would need to deploy near real-time sensing, monitoring, and control capability for a coordinated capacitor control scheme that operates on multiple feeders and interacts with demand response and distributed energy resources.[21] Similar real-time capabilities also would be needed to get the most out of controlling other devices, such as load-tap changers, and balancing phases and circuits in real time.

➡ *How can utilities address operational issues with CVR during peak demand periods?*

When loads on a feeder are high, additional equipment such as voltage regulators or shunt capacitors may be needed to maintain voltage at the end of the line without raising the voltage at the substation too much. SCADA can be extended down feeders to measure loads and voltages and to remotely control shunt capacitors to enable voltage reduction on-peak. The extra savings from such end of line approaches may well exceed the additional costs, compared to line drop control.

➡ *How are potential savings affected if the utility operates CVR only during off-peak periods?*

The decision whether to reduce voltage during peak periods, off-peak periods, or both depends on the utility's motivation for implementing CVR. Operation during peak periods will help the utility meet demand reduction goals; operation during off-peak hours will reduce energy requirements and prevent high voltage conditions and associated power quality issues. Some utilities avoid using CVR during peak demand periods to avoid the risk of voltage falling below minimum thresholds during those times. However, operating CVR only during off-peak periods affects cost-effectiveness, because demand reductions are an important incentive for utilities that rely on high-cost peaking units or face high wholesale costs for peak capacity. Commissions can review the specific operating regime a utility will apply to CVR and whether it will maximize energy savings and net benefits for ratepayers.

➡ *What are the key considerations when analyzing CVR cost-effectiveness?*

Regulators can consider factors such as the characteristics of the affected loads, load forecasts, line losses, remaining distribution equipment life, and CVR operational cycles. The extent of distribution system upgrades and smart grid investments also affects CVR savings and cost-effectiveness.

➡ *What are the barriers to utilities adopting CVR and volt-var control?*

Utility participants in the Northwest Distribution Efficiency Initiative identified many barriers including:[22]

- Most of the energy savings are inside customer premises, reducing utility sales and profits[23]
- Skepticism that lowering voltage does not necessarily lower load
- Current design standards focus on reliability and power quality, not efficiency
- Lack of priority for distribution efficiency improvements compared to growth-oriented activities
- Resistance to changing operational practices, including perceived value of a margin for error above the minimum voltage needed to meet standards, despite the opportunity for more precise system operation to allow for margins to be smaller
- Reluctance to implement non-traditional energy efficiency measures, especially those not focused on customers
- Lack of coordination between the engineering/operations department and the energy efficiency department
- Limited awareness of efficiency opportunities, methods, and tools for distribution systems
- Difficulties in quantifying benefits
- Limited information and tools to guide planning decisions for distribution systems
- Lack of distribution system automation, such as SCADA
- Fear of adverse impacts on customer service quality and customer complaints
- Concerns about switching loads to other feeders during efficiency upgrades and maintenance

➡ *How can these barriers be overcome?*

Among the solutions to these bariers:[24]

- Decouple utility profits from sales to minimize the effect that reduced throughput has on utility financial metrics
- Demonstrate the cost-effectiveness of distribution efficiency practices and technologies to attract upper management support
- Improve understanding of existing system configurations and modifications required for implementing CVR
- Assess distribution efficiency projects along with other demand- and supply-side options in integrated resource plans
- Focus the utility's mission and management on finding and delivering on opportunities for efficiency so that it is a priority on a par with reliability, service quality, and earnings
- Ensure that voltage regulation will not adversely affect customer service or end-use equipment
- Improve measurement and verification methods and protocols for energy and demand savings
- Adopt standard engineering practices that define methods for CVR design, modeling, metering, and maintenance and likely results
- Make distribution system efficiency eligible for energy efficiency resource standards
- Assess whether near-term investments in AMI, SCADA, sensors, and other distribution equipment are at least capable of supporting CVR in the future

➡ *Has the utility considered other distribution efficiency measures?*

Among the measures to consider are load balancing, optimizing reactive power, upgrading conductors, coordinating with distributed resources to reduce line losses, and smart purchasing practices for distribution equipment (see text box). CVR may be deployed alone or in concert with these other strategies, with or without smart grid technologies.

Smart Equipment Purchasing

Transmission and distribution equipment can be ordered in a range of loss ratings. For example, power transformers include many layers of wire wrapped around metal cores. The thicker the wires, the lower the losses from the transformer, but the greater its initial cost. The optimal tradeoff depends on how quickly power cost savings from reduced losses overcome the higher initial cost. When a utility seeks price quotes for new transformers, it also asks the manufacturer to quote a loss figure so it can determine what efficiency level to buy. Or the utility can provide the formula to the manufacturer who then provides a cost and losses proposal. Smart purchasing practices include paying close attention to the formula used, ensuring the values are up to date and complete, and applying these tradeoffs to all relevant types of equipment and to decisions about whether to replace an existing transformer in use or in inventory with a new one.

1 David Moskovitz and Lisa Schwartz, "Smart Grid or Smart Policies: Which Comes First?" Regulatory Assistance Project *Issuesletter*, July 2009, at http://www.raponline.org/showpdf.asp?PDF_URL=Pubs/Issuesletter_July09.pdf.

2 Some strategies for improving distribution system efficiency are applicable to transmission systems. *See* Electric Power Research Institute, *Transmission Efficiency Initiative: Key Findings, Plan for Demonstration Projects, and Next Steps to Increase Transmission Efficiency*, publication no. 1017894, 2009, at www.epri.com.

3 EPRI, "Green Circuit Field Demonstrations," March 2008, at http://mydocs.epri.com/docs/public/000000000001016520.pdf.

4 Refer to the text box "Distribution System Terms" for definitions.

5 The net efficiency benefit depends on distribution system design, types of loads on the system, and generating resource mix. Motors and other constant power loads tend to draw more current to compensate for reduced service voltage levels. And some loads use the same amount of power over time in order to reach their set-point, even if they consume less when voltage is lowered. In such cases, the redistribution of power consumption over a longer period may still reduce peak demand and operation of less efficient generating units. *See* Rob Pratt, MCW Kintner-Meyer, PJ Balducci, TF Sanquist, C Gerkensmeyer, KP Schneider, S Katipamula, and TJ Secrest, Pacific Northwest National Laboratory, *The Smart Grid: An Estimation of the Energy and CO2 Benefits*, publication no. PNNL-19112, prepared for the US Department of Energy, January 2010, at http://energyenvironment.pnl.gov/news/pdf/PNNL-19112_Revision_1_Final.pdf.

6 RW Beck. Full reference under Figure 1 on page 3.

7 *Ibid*. For some substation infrastructures, system improvements can reduce voltage by an additional 0.5 percent to 1.5 percent compared to end of line controls alone.

8 The type of load these end-uses impose (lagging power factor) drags down voltage unless power factor is corrected.

9 *See* http://www.iso-ne.com/rules_proceds/operating/isone/op4/op4a_rto_final.pdf.

10 RW Beck. The Northwest Energy Efficiency Alliance is a nonprofit organization that accelerates the market adoption of energy-efficient products, technologies, and practices. *See* www.nwalliance.org.

11 *Ibid*., p. E-1.

12 *Ibid*.

13 One average megawatt equals the energy produced by one megawatt of capacity operating every hour of the year.

14 Northwest Power and Conservation Council, 6th Power Plan, February 2010, p. 4-13, at http://www.nwcouncil.org/energy/powerplan/6/default.htm.

15 Pratt, *et al*., based on research sponsored by the Northwest Energy Efficiency Alliance and engineering estimates for dynamic optimization of voltage and reactive power. Assumes 100 percent penetration of the required smart grid technologies in 2030.

16 Material in this section is based on information from Karen Forsten, EPRI, March 2010.

17 Voltage set point = 118.5 V; bandwidth = 2 V (+/- 1 V).

18 *Coordination with distributed resources for loss reduction* is the dispatching of distributed generation to supply power to a feeder and avoid line losses during peak loads. Load management through distribution automation means controlling customer loads by remote means to limit peak load.

19 *See* "Reducing Power Factor Cost," Motor Challenge Information Clearinghouse, US Department of Energy, at http://www1.eere.energy.gov/industry/bestpractices/pdfs/mc60405.pdf.

20 Dominion Virginia Power is running a CVR pilot using AMI. *See* Exhibit SN-5, Direct Testimony of Scott Norwood on behalf of the Office of the Attorney General's Division of Consumer Counsel, Virginia State Corporation Commission, Case No. PUE-2009-00081, Jan. 13, 2010. The utility withdrew its proposal for full-scale AMI and CVR, proposing further evaluation.

21 Pratt, *et al*.

22 Global Energy Partners, *Utility Distribution System Efficiency Initiative, Phase I: Final Market Progress and Evaluation Report*, prepared for Northwest Energy Efficiency Alliance, June 27, 2008, at http://www.nwalliance.org/research/reportdetail.aspx?ID=138.

23 In sample calculations for a wires-only utility, a 1 percent change in sales resulted in a reduction in profits on the order of 10 percent. A similar calculation for a vertically integrated utility resulted in a 7 percent change in earnings with each 1 percent change in sales. *See* Regulatory Assistance Project, *Revenue Decoupling Standards and Criteria: A Report to the Minnesota Public Utilities Commission*, June 2008, at http://www.raponline.org/Pubs/MN-RAP_Decoupling_Rpt_6-2008.pdf.

24 Global Energy Partners; other potential solutions added by the authors.

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