The BLeading Edge...
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Changing the Shape of Load with Voltage and VAR Optimization

Introduction
Maintaining proper voltage levels throughout the electric distribution system is a critical challenge for electric utilities. Electrical load from customers is constantly changing, which means that voltage levels are constantly changing. As a result, utilities have used voltage regulating equipment and capacitor banks to keep customer voltages in the desired range. While the equipment has worked adequately in most cases, there is a significant opportunity to improve.

Smart grid technologies including sensors, communications, information processing and advanced control algorithms are making it possible to manage the operation of voltage and reactive power devices. This can be done in near-real time, enabling a coordinated response called voltage and VAR optimization (VVO).

VVO has the potential to reshape a utility’s load profile in two important ways:

- By enabling CVR; and
- By helping to integrate distributed renewable energy.

Conservation Voltage Reduction (CVR)
Simply put, CVR lowers the voltage on distribution feeders in an attempt to save energy. CVR is not new. Utilities in California have known about CVR since the 1970s when research on reducing voltage was conducted as part of a push for energy efficiency. Since the 1980s, utilities in the northwestern US have been researching and testing CVR and CVR applications. Utilities and grid operators have temporarily lowered system voltage as a way to reduce load during peak demand periods. These actions are sometimes done as part of regional load reductions called for by system operators.

So if utilities have known about CVR for a long time, why is CVR getting so much attention now? It comes down to two things:

1. There is a strong interest in energy efficiency and greenhouse gas reduction; and
2. Technology is available today (smart grid) that allows utilities to better manage voltage and reactive power and to make sure that customer voltages stay in the appropriate range when they do that.

What is CVR?
Figure 1 shows a distribution feeder, including the substation and the distribution line that emanates from the substation connecting to the customer loads. The top of the figure shows a plot of the voltage along the distribution feeder. Notice that the voltage is highest at the point closest to the substation, and lowest at the load at the end of the line. The graph assumes that no voltage regulating equipment is present along the feeder.

Figure 1: CVR voltage profile

The black line on the voltage plot is the feeder voltage with no CVR (CVR-OFF). The blue line is the feeder voltage after the source voltage has been reduced at the substation (CVR-ON). Such a change at the substation is commonly done by adjusting the secondary tap on the transformer, or by changing the set point of device called a load tap changer or a substation voltage regulator.

How Does CVR Work?
Many appliances, equipment and devices that we plug in, use less energy when the applied voltage is...
lower. The percentage change in energy divided by the percentage change in voltage is called the “CVR factor”.

The CVR factor of various equipment differs, but most of the connected load on our power systems decreases by some amount when voltage is reduced. Typical CVR factors range from 0.7 to 1.0. This means that a 1% reduction in voltage yields about a 1% reduction in energy consumed.

Some equipment, like motors, operates less efficiently when the applied voltage is too high. Lowering the voltage allows these machines to operate more efficiently, reducing the energy they require.

**Potential Impact of CVR**

There have been a number of utility pilot programs over the last few years that have tried to quantify the energy savings of CVR. The bottom line is that CVR works - studies show that lowering the voltage on distribution feeders reduces the energy consumed by the connected loads. Utilities like CVR because they can get energy savings or peak demand reductions from the distribution system without worrying about consumer behavior or program adoption or stickiness.

Lots of utilities across the country are implementing CVR and other voltage and reactive power control measures at some level. Their objectives fall into two categories:

1. Reducing peak demand; and,
2. Reducing energy consumption (energy efficiency).

Peak demand reductions may be limited to 100 hot summer hours per year or less. These are focused on alleviating capacity constraints and the problems related to them. Energy savings may be achieved throughout the year, and could contribute significantly to energy efficiency and reduction of greenhouse gas emissions.

These four examples indicate that savings of about 2-3% have been demonstrated, and CVR factors range from about 0.7 to about 1.0. The Pacific Northwest National Laboratory released a study report in 2010 where they estimated the potential energy savings from CVR if it was implemented nationwide. They found that the potential savings was between 2 and 3 percent depending on how many feeders were treated. The “high value” feeders they mention refer to the percentage of feeders responsible for 80% of the benefit (Figure 4.1 in their report) - these feeders would be the ones for which CVR would offer the greatest energy reduction.

So, why didn’t utilities do CVR in the past? There are three important reasons:

1. Lack of visibility of voltage on the distribution system, and concern over ensuring that customer voltages didn’t go too low. “It’s better to operate a little high and know that no customer voltages would be too low at the end of the feeder.”

2. Limited ability to reliably operate voltage and VAR control equipment in a cost effective manner.

3. No meaningful incentive to use CVR to save energy - this is also true for losses.

As shown in Table 1, there have been a number of utility pilot programs over the last few years that have tried to quantify the energy savings of CVR. The bottom line is that CVR works - studies show that lowering the voltage on distribution feeders reduces the energy consumed by the connected loads. Utilities like it because they can get energy savings or peak demand reductions from the distribution system without worrying about consumer behavior or program

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**Table 1: Summary of Some CVR Experiments**

<table>
<thead>
<tr>
<th>Utility Study</th>
<th>Demonstrated Result</th>
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<tbody>
<tr>
<td>Alabama Power and Duke Energy</td>
<td>Energy reductions between 1.6% and 2.7%</td>
</tr>
<tr>
<td>American Electric Power, North Columbus</td>
<td>Energy reduction of 3%</td>
</tr>
<tr>
<td>PECO Energy</td>
<td>CVR-energy factor of 1.08</td>
</tr>
<tr>
<td>Distribution Efficiency Initiative, Northwest Energy Efficiency Alliance</td>
<td>CVR-energy factor of 0.69</td>
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adoption or stickiness.

**Integration of Renewable Energy**

Distributed renewable energy connected to utility distribution systems is on the rise. Solar photovoltaic (PV) systems are the most common form of this distributed resource. The challenges of interconnecting large amounts of PV on distribution systems have caused concern among electric utilities. Among the challenges to transmission and distribution system operations are:

- Voltage regulation;
- Reverse or changing power flow;
- Power fluctuation and frequency regulation; and,
- Harmonics.

Voltage regulation has been a concern due to changes in distribution feeder load while PV is producing electricity, particularly when production is variable due to cloud transients. Moreover, voltage can be depressed following a power outage that knocks PV systems offline. Recent studies have indicated that high PV penetration on distribution systems may not be as problematic as once thought (Source: National Renewable Energy Laboratory, Impact of SolarSmart Subdivisions on SMUD's Distribution System, July 2009). However, VVO can increase a utility’s ability to respond to changes in load and voltage.

The ability to coordinate and control voltage regulating equipment and sources of reactive power can enable utilities to reliably integrate more renewable energy. The coincidence of PV production with air conditioning load means that future summer peak load may look significantly different than it does today.

**System Integration Challenges and VVO**

Implementing VVO presents system integration challenges. Historically, utilities have been organized in departments that provided specific services and operate with IT systems designed to support those services. This has created operating “silos” or “islands of automation” where unique interfaces have been built between systems that interact between departments. A peer-to-peer (PTP) approach results in an “accidental architecture” that limits interoperability, is resistant to upgrading, and is somewhat unsustainable without major rework in many cases.

**Figure 2** shows the complexity of a non-architected PTP approach as compared with service oriented architecture (SOA) that is a standards based approach designed to share data on an enterprise service bus.

**Figure 2: Before & After SOA**

With SOA, rather than seeing your IT as a set of applications, databases, storage and other resources,
Aging infrastructure and homegrown applications past their prime require replacement and upgrades. Unfortunately, the tight coupling amongst these applications within an IT ecosystem precludes such upgrades and poses significant risk to smart grid programs such as VVO. Because of the P2P architecture and the impacts on other downstream applications, this is not a trivial exercise. SOA does provide the promise of developing a Loosely Coupled Architecture that has the capability to undo tight coupling amongst applications.

Second, SOA provides a capability to develop services that can be developed once and leveraged across various smart grid programs many times over. These are core SOA capabilities that can make smart grid and VVO a success. SOA is a good tool and must be used carefully. Improper use of a good tool can result in failure. Program managers should exercise caution and be prudent about leveraging SOA. Not using SOA, however, is a greater risk.

SOA is strategic, business driven and top-down approach, based upon the premise that the Business drives the architecture. Based upon that premise, an IT organization that delivers services is equipped to handle the needs of the Business as, and when, needed. VVO requires that kind of agility. In other words, as opposed to IT offering monolithic applications, IT builds a set of services that it threads together for the purposes of the Business. This gives agility to the organization, as these services can be threaded together as needed without engaging in unduly expensive projects. IT, then, becomes a true service organization that brings agility to the business of Smart Grid and advanced applications like VVO.

**Policy Challenges (and Potential Solutions) for CVR**

Smart grid technology is making it easier for utilities to reliably implement CVR and ensure high service quality for electricity consumers. However, barriers exist that can only be addressed in the policy arena. Here are three challenges and ideas for overcoming them.

**Lost Revenue from Lower Electricity Sales**

Lowering the voltage on connected load can reduce the amount of electricity used. This reduction translates to lower sales, and goes against the interest of companies that make money from electricity sales. A potential solution is revenue decoupling, which is a regulatory mechanism that breaks the link between a utility’s profits and electricity sales. Today 15 states have adopted electric decoupling and it is pending in 6 more.

**Lack of Incentives**

Most states lack sufficient incentives necessary to encourage energy grid efficiency investments by utilities, including CVR. Two notable exceptions are the states of Washington and Pennsylvania. In both cases policies exist that mandate cost effective energy efficiency investments by utilities. This has resulted utilities implementing CVR and seeing meaningful energy efficiency results. Creating meaningful incentives for grid efficiency would help encourage other utilities to do the same.

**Competition for T&D Capital**

In a capital constrained environment it may be difficult to justify a CVR project when comparing it to a reliability or system expansion project. Creating a performance based rate for CVR investments is an example of how to make it more attractive. It could be similar to the reliability-based rate programs implemented in the 1990s that encouraged some utilities to invest in reliability projects. 

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**Author Profile**

**Forrest Small** is a VP of Grid Optimization Strategy for BRIDGE Energy Group. He leads the company’s Grid Optimization practice focusing on outage and restoration management, voltage and VAR optimization, and transmission grid operations. He is a recognized expert in advanced power delivery technologies and smart grid applications. Forrest has twenty-two years of combined experience in management consulting and grid planning and operations at an electric utility.