Business & Technology Surveillance

Volt-VAR: Managing the Needs of Today and Into the Future

BY: Jim Weikert, Vice President of Utility Automation & Communications,
Power System Engineering

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America's Electric Cooperatives

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SUBJECT MATTER EXPERT ON THIS TOPIC:

David Pinney
Principal Analytical Tools & Software Products
Business and Technology Strategies
David.Pinney@nreca.coop

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ARTICLE SNAPSHOT

WHAT HAS CHANGED?

Volt-VAR Optimization (VVO) has been around for 50 years, but improvements in VVO technology enhances the tools available to us and provides us with more effective ways to adapt to changes such as increased distributed generation and more dynamic systems.

WHAT IS THE IMPACT ON ELECTRIC COOPERATIVES?

All engineering and operations teams perform VVO today, frequently with the same tools and methods they have used for years. Industry changes are introducing new challenges, but also new tools. Co-ops can benefit significantly from familiarizing themselves with these new tools and the data they provide to ready their organizations to adapt to these challenges with greater confidence.

WHAT DO CO-OPS NEED TO KNOW OR DO ABOUT IT?

It is beneficial for co-ops to carefully investigate the economic and power quality impact of Volt-VAR on their system today and as the industry changes. Along with this, regularly investigating new technologies can give insights into those that can be added to the trusted tools already in use.

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Executive Summary

Much of the technology that makes our distribution system so reliable has been in place for more than 50 years. The foundational building blocks of line regulators, capacitors, and conductors are trusted, reliable tools that continue to allow us to manage our systems in this high-tech age.

While we rely on these trusted tools, we continue to enhance our ability to control them and to address needs of our changing industry. We also cautiously introduce new tools which can be added to our existing options.

Managing voltage and power flow has been at the heart of engineering and operations—and our members' power quality expectations—for as long as we have had electricity. However, changes in the source of generation and type of load are introducing dynamics into voltage and power flow on our systems.

By blending proven approaches with innovation, we can maintain the reliability and quality of power delivery we have always provided, while adapting to a changing industry.

Volt-VAR Optimization (VVO) programs impact so many aspects of a co-op, having power quality and economic impacts, and they enable the increasing introduction of renewables. A high-level overview of the types of VVO programs, their impacts, and the nature of their benefits is summarized in Table 1.

Table 1: Overview of VVO Programs

Program	Impact	Description
Volt-VAR Optimization	Line Losses	Reduce power lost due to excess VARs
	Power Factor Penalties	Avoid charges from your power supplier for power factor excessively above or below 1.0
	Voltage Drop	Avoid excess voltage drop due to VARs
Conservation Voltage Reduction	Demand Reduction	Reduce voltage at peak times to reduce peak demand (charges)
	Energy Efficiency	Reduce voltage continuously to improve overall energy efficiency
Renewables Support	Voltage Impact	Optimize voltage to address potential voltage rise from DER

New technology is most successfully leveraged using a phased approach that includes testing incremental advances and adopting those with the greatest benefit. Advances to consider in managing Volt-VAR programs through technology include:

- Leveraging automation such as *Supervisory Control and Data Acquisition (*SCADA), Advanced Metering Infrastructure (AMI), and Advanced Distribution Management system (ADMS) for automating managing a Volt-VAR on your system.

- Data analytics for evaluating effectiveness and making data-driven decisions.
- Leveraging increasing adoption of standards for intelligent inverters.

While changes in distribution connected generation creates challenges, it also introduces more active tools that co-ops can use to manage their distribution system. A balanced approach allows you to build confidence in new technologies as they are tested – and using the increasing amount of data available from these technologies can help you uncover opportunities for performance enhancements.

Volt-VAR Framework

Maintaining reliable voltage is one of cooperatives' primary objectives. The diagram in Figure 1 highlights one portion of the American National Standards Institute (ANSI) C84.1 standard for distribution voltage, showing acceptable voltage ranges for electric service.

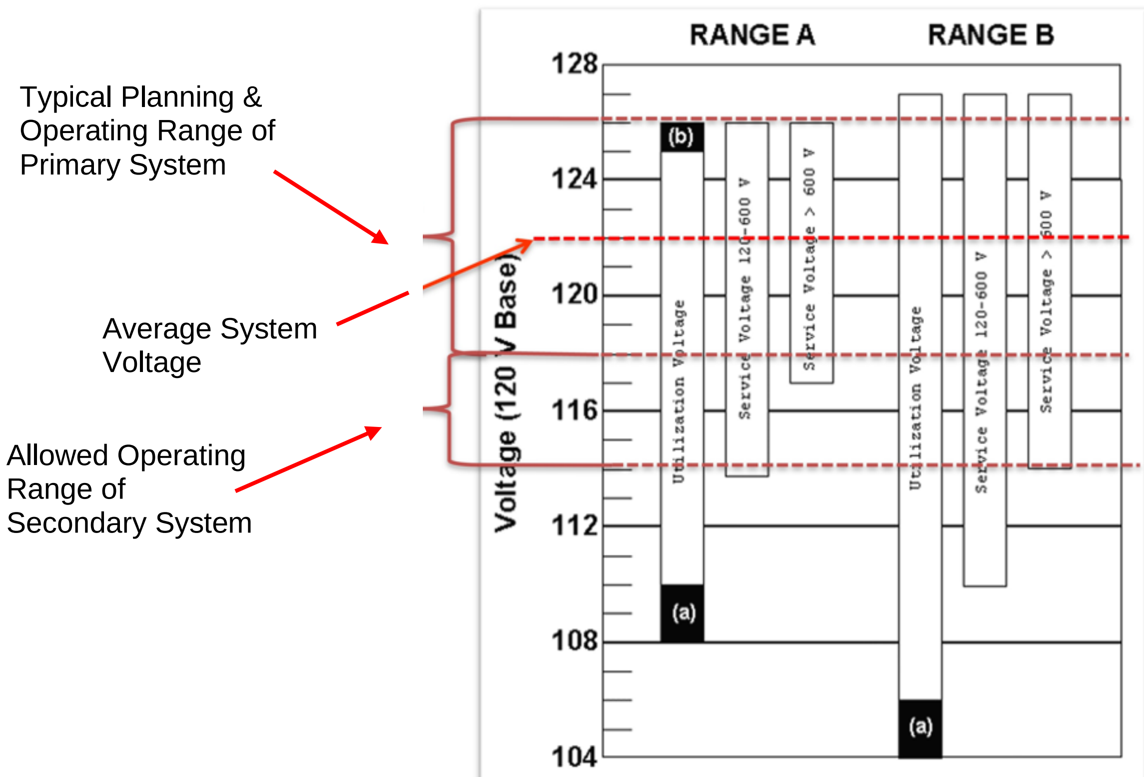


Figure 1: ANSI C84.1 Voltage Ranges

Source: ANSI C84.1-2020,
Electric Power Systems And Equipment - Voltage Ratings (60 Hz)

While maintaining service voltage within these ranges is essential, co-ops must consider many other factors in supplying good quality power efficiently to their members, including:

- Voltage range
- Reducing losses
- Optimizing capacity
- Power quality
- Harmonics and transients
- G&T power factor requirements
- Managing impacts from renewable generation

This article provides insights into tools utilities can use to optimize power to benefit themselves and their members.

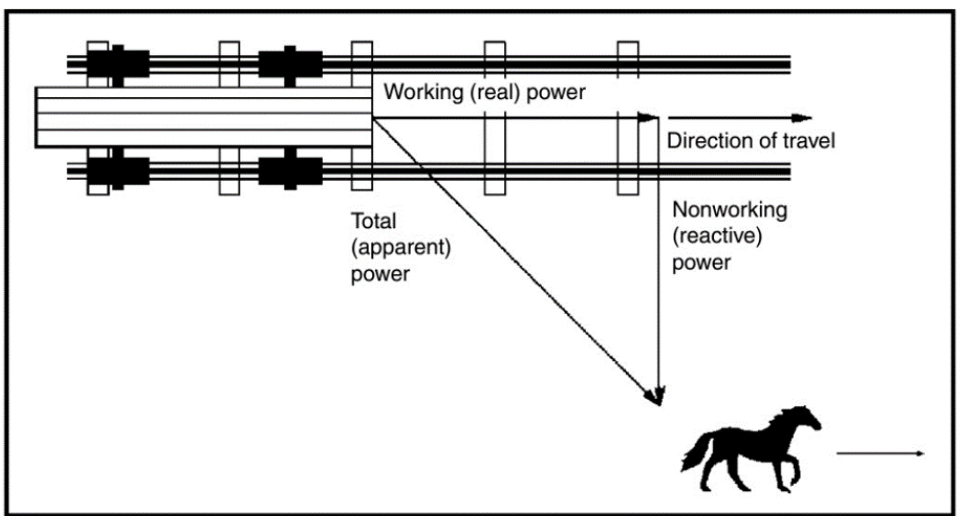
VAR & Power Factor

A key to optimizing power is to reduce the impact of reactive power, often referred to as VARs (Volt-Amps Reactive). In alternating current circuits, voltage and current changes do not always propagate at the same rate, and VARs quantify the mismatch between these components which leads to lower real power (Watts) delivery.

In Figure 2, which illustrates the impact of reactive power, a horse is pulling a carriage along some tracks. The horse's pulling power would be most productive if the horse were pulling from a position directly in front of the carriage, in line with the direction of travel. The pulling power is less productive the farther the horse is positioned from the direction of travel.

Pulling from an angle reduces the effectiveness of the effort (or power) it is exerting on the carriage. The more aligned the horse is with the carriage, the more that its power is effective in moving the carriage. The more the horse is off to the side, the more that its power is ineffective in pulling the carriage in the desired direction.

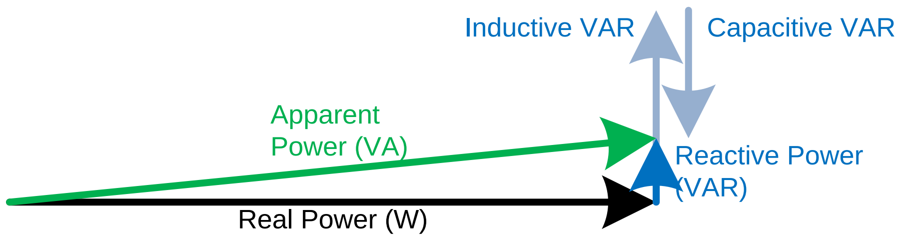
Figure 2: Impact of Reactive Power (Horse and Carriage)



Source: Reducing Power Factor Cost, Motor Challenge Fact Sheet, U.S. Department of Energy

This analogy illustrates a similar concept with electricity. Real power, expressed in Watts (W), represents real work performed (shown as the black arrow in the Figure 3). Reactive power, expressed in Volts-Amps Reactive (VAR), represents non-productive power. This is shown by the blue arrows.

Figure 3: Impact of Reactive Power (Electricity)



The reactive components (VARs) are often the result of loads on your system such as motors and capacitors. Motors, pumps, air-conditioners, and other similar devices contain large coils of wire and magnets which form inductors. These inductors skew the power flow so that it is no longer just real power. They add a reactive current. Capacitors impact reactive power flow as well, having an opposite effect.

The term used to refer to the ratio of apparent power (VA) to real power (W) is power factor (PF). A PF of 0.9 means that 90% of the apparent power is real. See Equation 1.

Equation 1: Power Factor

$$\text{Power Factor} = \frac{\text{Real Power (W)}}{\text{Apparent Power (VA)}}$$

The purpose of a utility's VAR program is to reduce the reactive current, reducing unbillable and unproductive power and excess current, thereby increasing capacity and reducing losses and voltage drop on a utility's feeders.

Volt-VAR Program Goals

Managing voltage and VARs can help you achieve multiple goals simultaneously. Table 2 offers three categories of improvements that can be targeted.

Table 2: Volt-VAR Program Goals

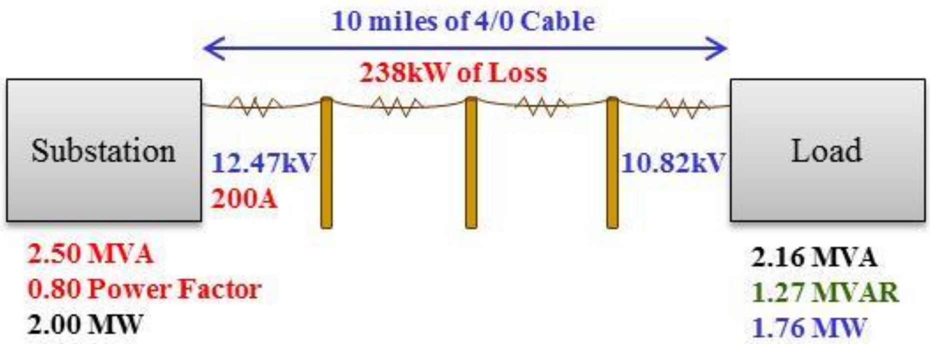
Program	Impact	Description
Volt-VAR Optimization	Line Losses	Reduce power lost due to excess VARs
	Power Factor Penalties	Avoid charges from your power supplier for power factor excessively above or below 1.0
	Voltage Drop	Avoid excess voltage drop due to VARs
Conservation Voltage Reduction	Demand Reduction	Reduce voltage at peak times to reduce peak demand (charges)
	Energy Efficiency	Reduce voltage continuously to improve overall energy efficiency
Renewables Support	Voltage Impact	Optimize voltage to address potential voltage rise from DER

Co-ops have historically considered Volt-VAR programs that fell into the first category (Volt-VAR optimization). Excess losses, power factor penalties, and excess voltage drop are issues that tend to become prominent and merit intervention. The second category, conservation voltage reduction, is more often considered by co-ops that are subject to significant peak demand charges. Finally, renewables support, and the resulting of impact on voltage, is a more recent consideration as the number of large renewable installations increases.

Volt-VAR and Loss Reduction

Reactive power on a line contributes to losses along that line. The diagram in Figure 4 illustrates the impact of VARs on voltage drop, losses, and excess power. It shows a 10-mile-long feeder constructed of 4/0 wire. The substation feeder voltage is 12.47 kV and the current 200 A, the limit of the conductor. For simplicity, the load is shown at the end of the feeder. In reality, of course, it would be distributed along the feeder.

Figure 3: Impact of VARs on Voltage Drop, Losses, and Excess Power



In the illustration, the load is in part reactive, from devices such as motors at a large factory, and causes a power factor of 0.8. The factory receives 1.76 MW of real power, but the substation needs to provide 2.00 MW of real power, so 2.50 MVA must be generated in order to account for the 238 kW of loss caused by the reactive load along the feeder.

Table 3 summarizes changes and improvements that can result from adding a capacitor. By placing a capacitor bank close to the inductive factory load, the voltage drop is improved by 3%, current reduced by 15%, and losses reduced by 30%.

Table 3: Changes and Improvements from Adding a Capacitor

	Initial	Added Capacitor
Voltage Drop	13.2%	10.4%
Current	200A	175A
Losses	238kW	181kW
Power Demand	2.00 MW 2.50 MVA	2.06 MW 2.18 MVA

Each of these improvements yields economic benefits. Most significant is the reduction of feeder losses by 65 kW, which represents an estimated savings of $3,250 (based on assumed implementation for 2,000 hours per year during times of high A/C use and a rate of $0.025/kWHr). Table 4 summarizes a couple of these benefits.

Table 4: Benefits of Adding a Capacitor

	0.8 PF to 0.95 PF Difference with IVVC
Recovered Losses	65kW * 2,000Hr/Yr * $0.025/kWH = $3,250/Yr
Capacity	200A to 175A = 25A Increase

Volt-VAR for Demand Reduction

Depending on the type of load, voltage can impact the power (demand) on the system. Two illustrations of this effect are shown in Figure 5 and Figure 6.

Figure 5: Voltage Impacts on Power (demand)

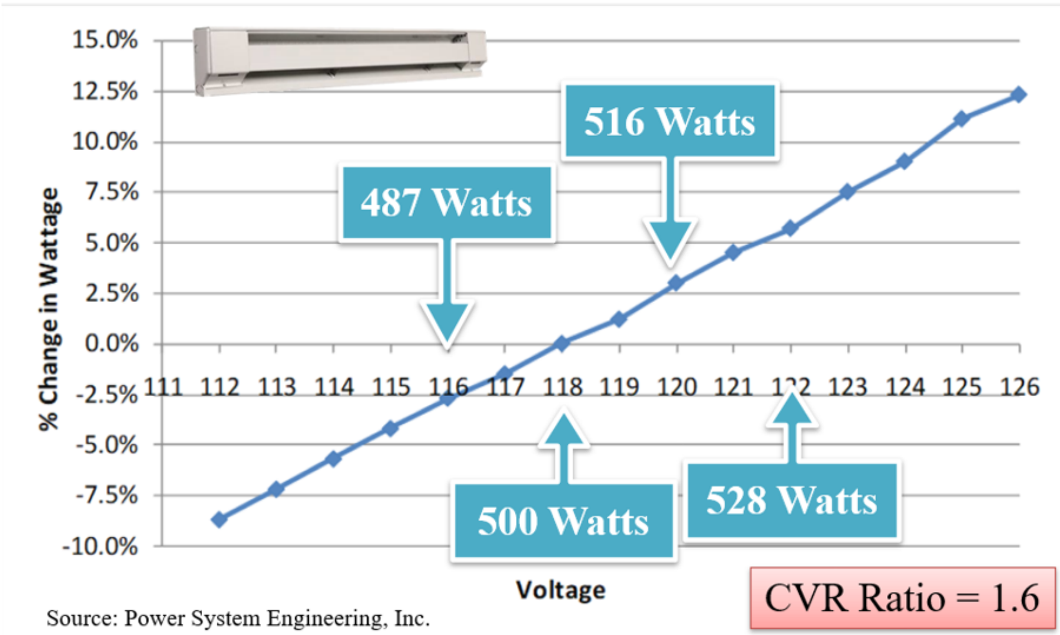
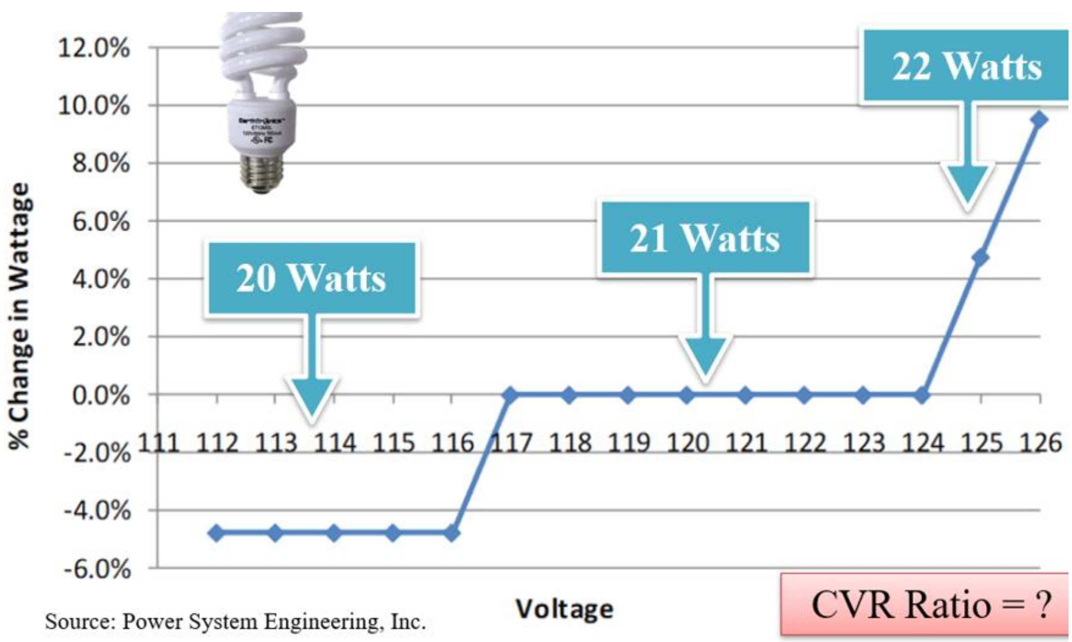


Figure 6: Voltage Impacts on Power (demand)



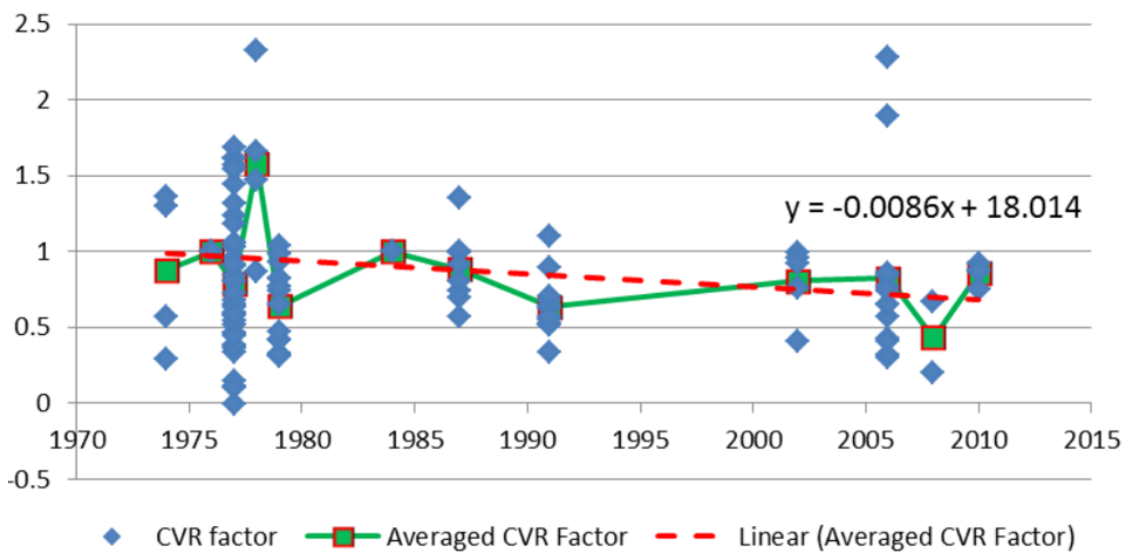
The illustration in Figure 5 shows power draw for electric strip heat changing by +/- 8% as voltage changes +/-6V from a nominal of 118 V. An 8% change in power from a 5% change in voltage reflects a ratio of 1.6 (%Watts / %Volt). This shows a significant impact of demand reduction for voltage reduction.
The illustration in Figure 6 shows that power draw from a compact fluorescent light is much more dependent on the exact voltage and much more difficult to calculate.

Reducing voltage during times of peak demand, often referred to as conservation voltage reduction (CVR), can have a significant economic benefit by reducing peak demand charges. A utility with a $15/kW peak demand charge can see a monthly charge of $150,000 for a system load of 10 MW at peak. Reducing this by 1% could result in $18,000 of savings in a year.

Savings depend on the ratio of demand reduction to voltage reduction, or CVR ratio. All co-ops' feeders are a composite of varying types of loads, each of which has its own responsiveness to changes in voltage. CVR ratios can vary from as low as 0.3 (0.3% power reduction for each 1% voltage reduction) to 1.0 and sometimes greater.

Figure 7 from a DSTAR report "Conservation Voltage Reduction (CVR) Evaluation: Testing, Methods, and Results"[1] shows published CVR ratios from 109 tests. The large variance in these results highlights the need for screening feeders on your system to determine their characteristics.

Figure 4: CVR Ratios from Published Tests



Source: DSTAR Report "Conservation Voltage Reduction (CVR) Evaluation: Testing, Methods, and Results"

In order to determine the value of CVR for your co-op, the most significant step is to evaluate each feeder's (or substation's) CVR ratio and determine which portions of the system have ratios high enough

[1] https://www.cooperative.com/InterestAreas/CRN/ProductsServices/Reports/Documents/CVREvaluation.pdf

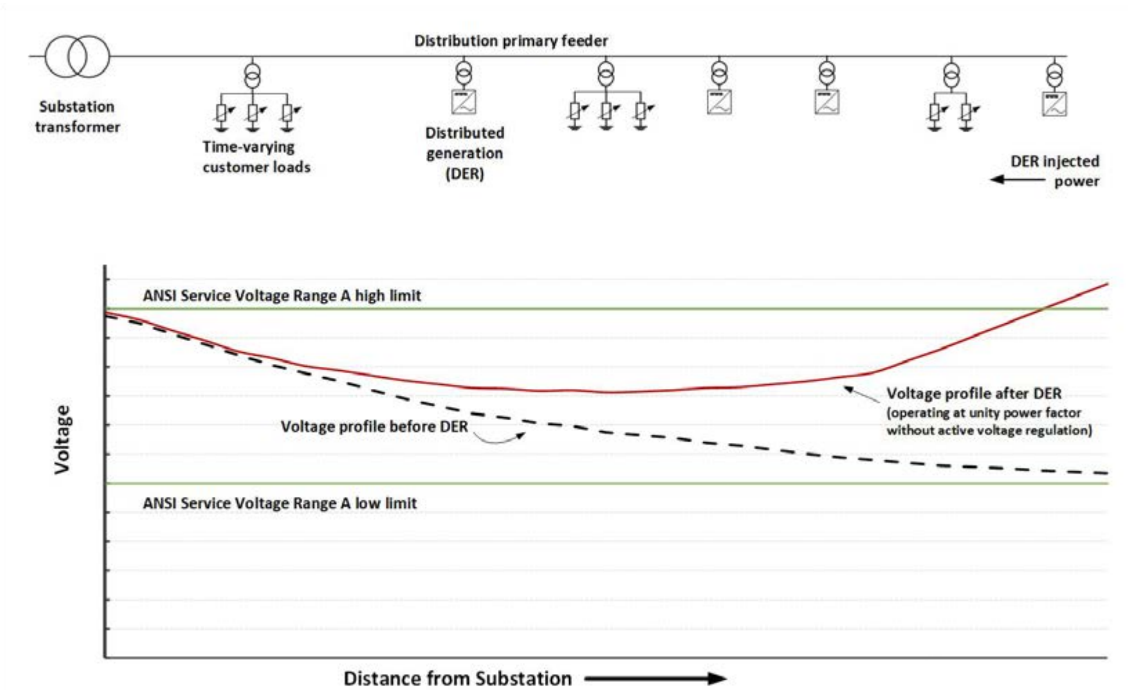
to result in good demand reduction. This process involves making step voltage adjustments during peak load at the substation and measuring the change in power. This needs to be done with care to make sure the corresponding voltage stays within acceptable limits at all points along the feeder.

Volt-VAR with Renewable Generation

Utility-scale solar and storage generation is increasingly interconnected to distribution feeders. Typically, co-ops determine the anticipated system impact by sizing the solar site to avoid reverse power flow onto the G&T's transmission system at minimum load.

An equally important consideration at minimum load is the resulting voltage and power factor at all points on the feeder. Figure 8[2] highlights the voltage rise that can occur when generation is distant from the substation. If poorly designed, the voltage at the point of interconnect (POI) can exceed the ANSI limits at minimum load.

Figure 5: Voltage Rise from DER Interconnection



Source: National Renewable Energy Laboratory, Technical Report, NREL/TP-5D00-77156, September 2021. Adapted from McGranaghan et al. (2008)

The following section considers how DER inverters can assist in mitigating the voltage rise that comes from distribution-connected generation.

[2] Narang, David, Rasel Mahmud, Michael Ingram, and Andy Hoke. 2021. An Overview of Issues Related to IEEE Std 1547-2018 Requirements Regarding Voltage and Reactive Power Control. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D0077156. https://www.nrel.gov/docs/fy21osti/77156.pdf.

Implementing Volt-VAR

Whether your goal is to reduce losses, reduce demand, or support renewables, Volt-VAR programs are clearly beneficial. Voltage regulators and capacitors are foundational building blocks for any Volt-VAR program. The location, number, and size of each will depend on your system and its particular needs. A new building block — the inverter — is becoming available to help address the challenges DER can introduce.

Intelligence Location & Open/Closed Loop Monitoring Considerations

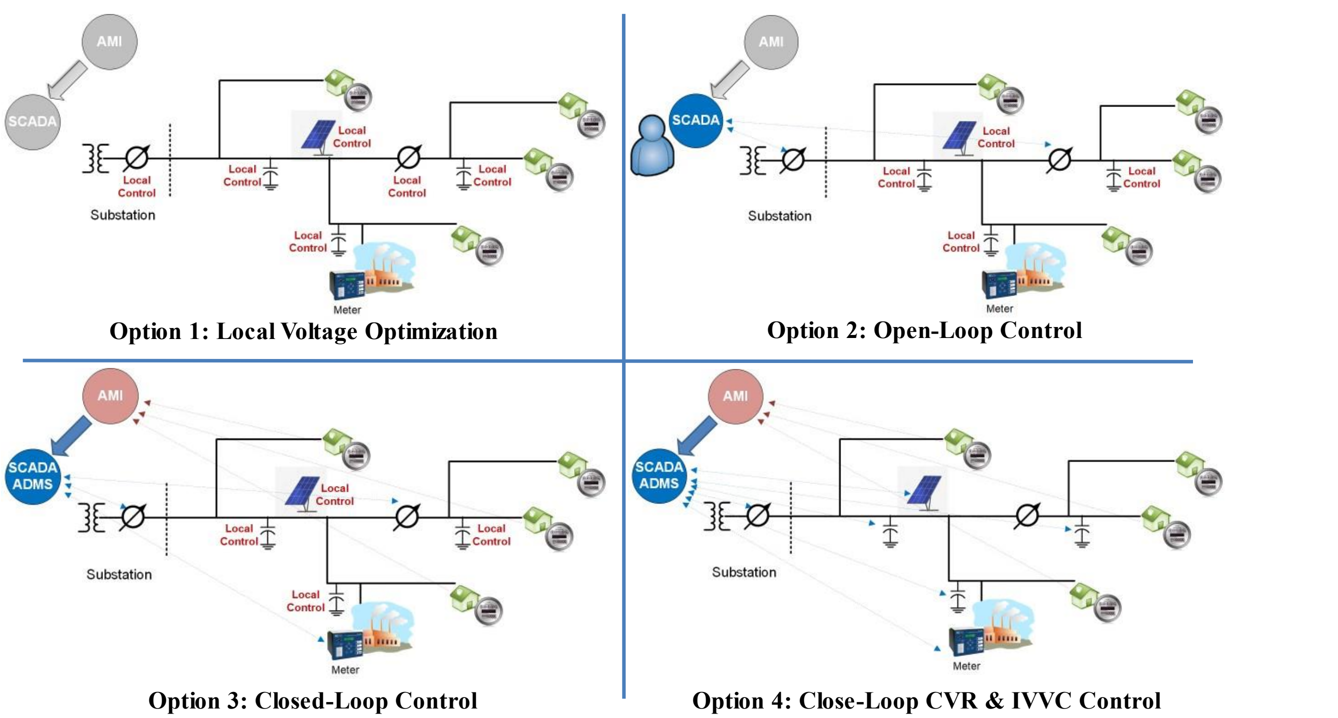
Regulators and capacitor controls are intelligent pieces of equipment that can make localized decisions on how they perform and can be controlled through centralized software, such as SCADA, ADMS, and Distributed Energy Resource Management (DERM) systems.

Figure 9 illustrates four approaches to control these intelligent devices:

1. Option 1: Open-Loop with Local Voltage Optimization
2. Option 2: Open-Loop with SCADA Controlled Voltage
3. Option 3: Closed-Loop with SCADA Controlled Voltage
4. Option 4: Closed-Loop with Full SCADA Control

While this is not an exhaustive list, it is representative of a range of options co-ops can consider – and each option contains varying complexity and benefits.

Figure 6: Intelligent Device Control Options



Option 1: Local Voltage Optimization

Option 2: Open-Loop Control

Option 3: Closed-Loop Control

Option 4: Close-Loop CVR & IVVC Control

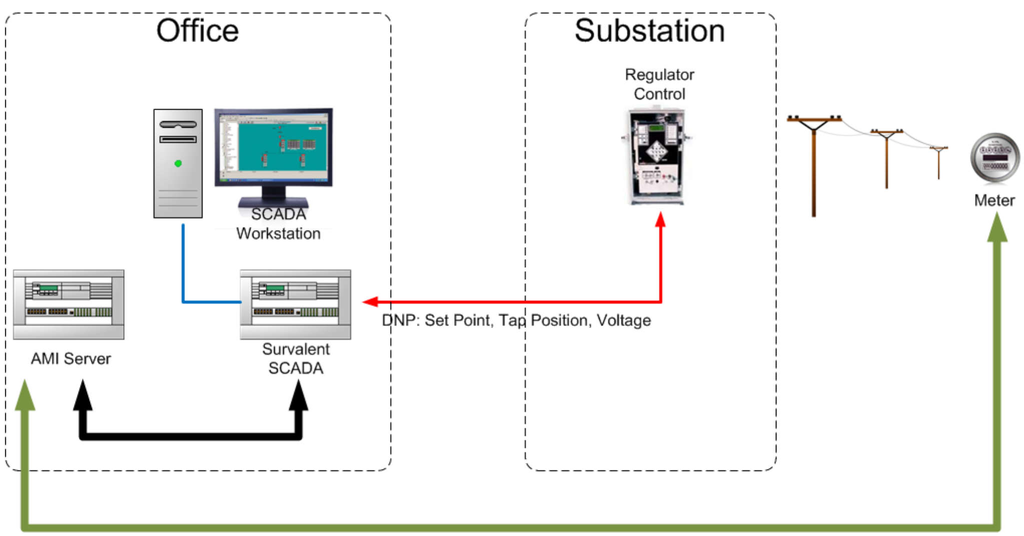
Option 1, open-loop with local voltage optimization, is representative of what most co-ops incorporate initially. It is the first step beyond manually opening and closing capacitors seasonally. Intelligent controls are programmed to switch cap banks based on voltage or VAR settings and regulator controls are programmed to regulate based on a load-drop compensation setting to estimate end of line voltage. While simplistic, localized intelligence is a significant improvement over manual control.

Option 2, open-loop with SCADA controlled voltage, incorporates remote control by an operator through SCADA. This is most beneficial for implementing periodic changes, such as changing regulator settings during peak demand for CVR. This simple open-loop control requires minimal investment and enables co-ops to evaluate how much demand reduction your system exhibits.

Option 3, closed-loop with SCADA controlled voltage, builds on Option 2 by integrating real-time AMI voltage measurements. This allows the SCADA/ADMS software to optimize the amount of reduction based on actual end-of-line voltage measurements. The additional investment required for the AMI integration can be used to maximize the demand reduction if you determine, via implementation of Option 2, that the CVR factor is high enough. However, this option still does not incorporate communications to capacitor controls, simply allowing them to control themselves locally.

Finally, Option 4, closed-loop with full SCADA control as shown in Figure 10, adds communications to all utility field equipment and reflects a scenario in which the utility is looking to continuously optimize voltage and VARs in addition to CVR. With this option, the SCADA/ADMS functionality is expanded beyond CVR to Integrated Volt-VAR Control (IVVC).

Figure 7: Closed-Loop with Full SCADA Control



While these levels are somewhat arbitrary, they reflect an incremental evolution in investment as the co-op finds the benefit.

Inverters as a Volt-VAR Management Tool

While regulators and capacitors will likely remain the foundational tools for managing Volt-VAR, inverters are capable of much more than simply converting DC from solar panels and batteries to AC. The newest IEEE standard for inverters, IEEE 1547-2018,[3] defines an expanded set of capabilities required of various categories of inverters.

While this standard has been published for a while, state-led adoption of this standard takes time. Figure 11 from EPRI illustrates adoption as of early 2024.

As standardization of the technology increases, understanding the capabilities and impact the inverters may have on your system is important, regardless of whether you use them as a tool in your Volt-VAR program or simply define acceptable operating modes as a part of your interconnection standards.

Figure 11: U.S. States Adopting IEE Std 1547-2018

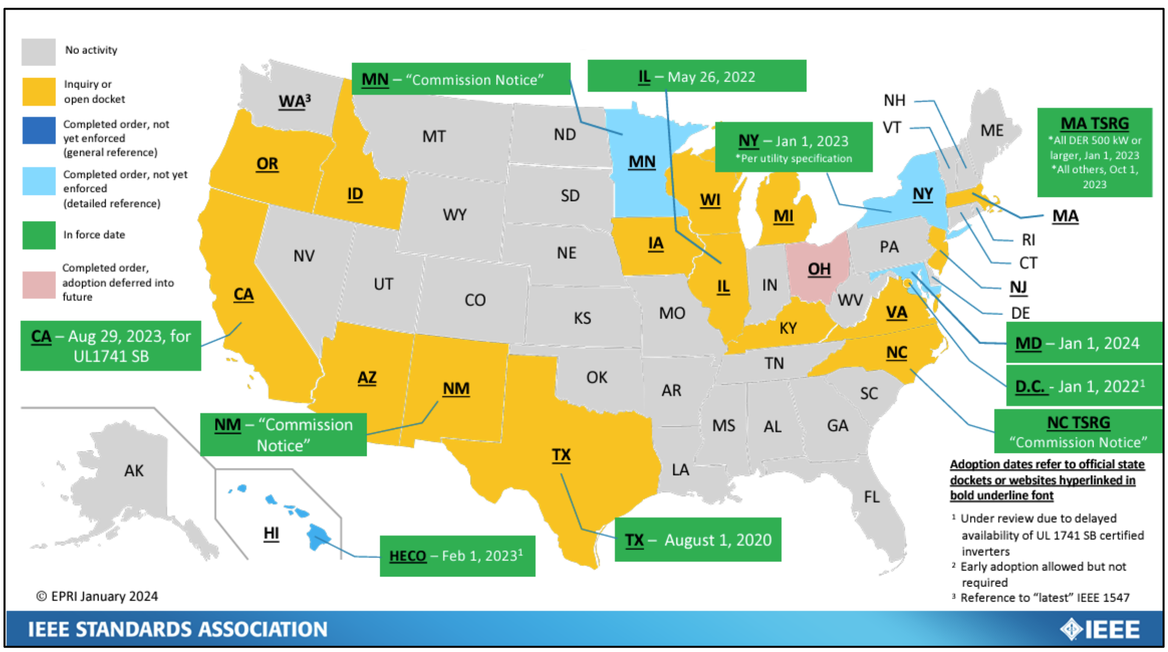


Table 4 summarizes the expanded set of performance modes in the standard that impact the Volt-VAR performance of the inverter.

[3] https://www.cooperative.com/topics/transmission-distribution/Pages/NRECA-Guide-to-IEEE-1547-2018-Standard-for-DER-Interconnections.aspx

Table 1: IEEE Std 1547 Performance Modes

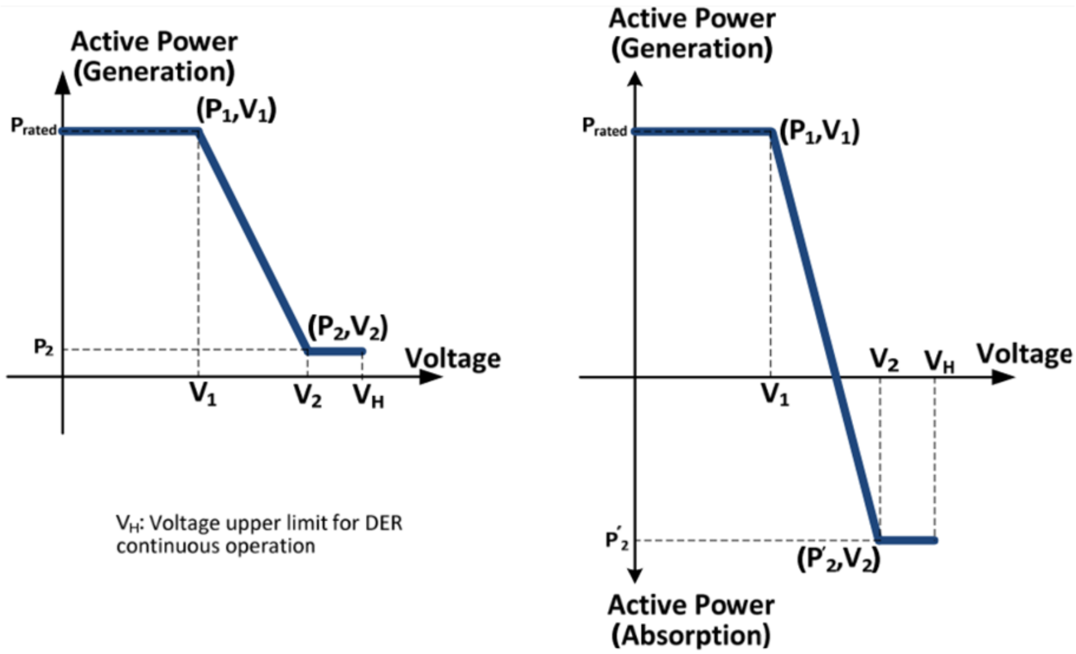
Modes		Description	Real Power	Reactive Power
A & B	Constant Power Factor	Adjusts VAR to maintain PF as Watt changes	As able	Adjust VAR for constant PF output
	Constant Reactive Power	Keep VAR constant as Watt changes	As able	Fixed VAR Out
	Volt-VAR (Voltage / Reactive Power Mode)	Adjust VAR to push voltage back to nominal	As able	Adjust VAR to keep voltage in a range
B	Watt-VAR (Active Power / Reactive Power Mode)	A curve defines how VAR is adjusted based on Watts (rare)	As able	Proportional to Real Power
	Volt-Watt (Voltage / Active Power Mode)	Watt at or below a limit to keep voltage below a limit (used in conjunction with another mode)	Limited by Voltage	Based on Additional Mode Set

As the table shows, these modes allow the inverter to adjust the power factor of its output, which consequently impacts the voltage on the system.

In Constant Power Factor mode, for example, the inverter adjusts the VAR output to maintain a power factor it has been programmed to maintain. The other modes adjust VAR output to meet other objectives. In these modes, it is important to understand that the inverter may need to reduce the amount of active power it produces in order to meet the reactive power objective. This is referred to as Reactive Power Priority.

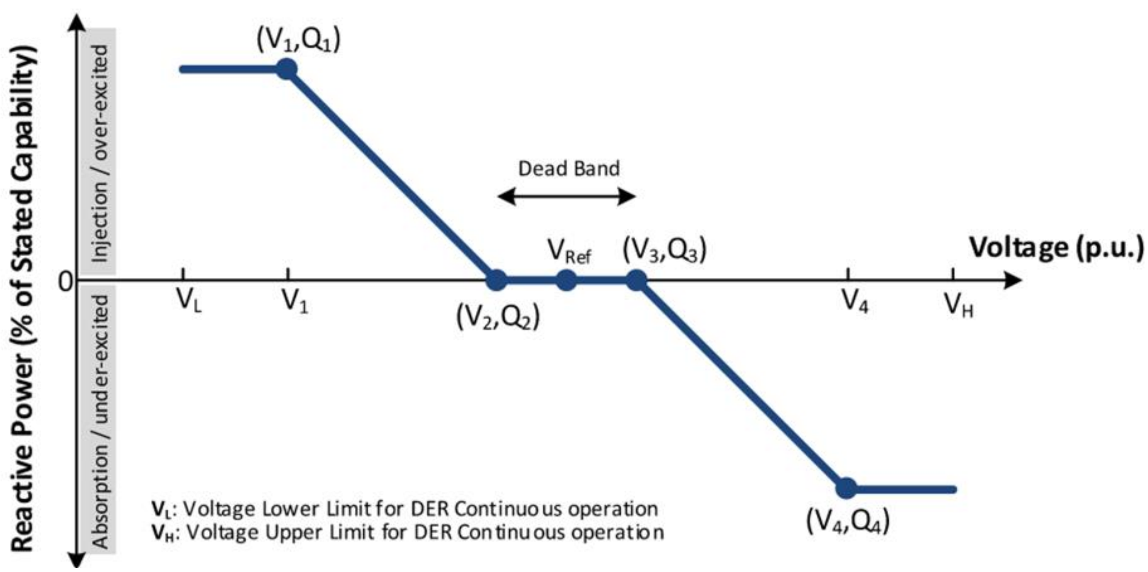
Depending on the generation capability of the resource, the impact of the additional VAR contribution may be significant or insignificant. To gain additional benefit, it is possible to use Volt-Watt mode in conjunction with Constant Power Factor.
Figures 12 and 13 illustrate performance curves of several of the modes. Volt-Watt mode can be particularly advantageous in supporting renewables in tough situations, because it automatically limits the output to keep the voltage from going above a certain level.

Figure 12: Volt-Watt Mode



Source: IEEE Standards Association

Figure 13: Volt-VAR Mode



If you are interested in more details about inverter settings in general, NRECA has a report on inverter field trials[4] with much more detail about the options and tradeoffs.

Evaluating Effectiveness

Will my co-op's investment in Volt-VAR be merited by the return? While intuition can provide some inclinations, analytics leveraging the data available from your AMI, SCADA and other systems can uncover insights you might otherwise have missed.

It is relatively easier to evaluate the effectiveness of Volt-VAR optimization against an absolute value than to measure its effectiveness against previous performance. VVO evaluation for power factor and voltage drop can be done by looking at real-time measurements with VVO enabled. Similarly, the effectiveness of supporting renewables is determined by looking at system AMI voltages during key moments, especially when generation is high, and loading is light.

Table 5 summarizes several methods for evaluating Volt-VAR effectiveness.

Table 2: Evaluation Approaches for Volt-VAR Effectiveness

Category	Objective	Evaluation Approach
Volt-VAR Optimization (VVO)	Line Losses	Comparison of substation load to member sales measured with AMI.
	Power Factor Penalties	Real-time measurement of PF at substation.
	Voltage Drop	Comparison of end-of-line voltage from AMI meters with and without VVO at time of peak demand.
Conservation Voltage Reduction (CVR)	Demand Reduction	Comparison of demand with and without CVR on 1) similar days or 2) similar feeders
	Energy Efficiency	Comparison of energy sales with and without CVR on 1) similar days or 2) similar feeders
Renewables Support	Voltage Impact	Ability of system to perform within voltage limits during combinations of generation and loading

In some cases, it is important to compare performance with and without Volt-VAR, in order to determine effectiveness. This can be challenging, however, because other factors change along with enabling and disabling Volt-VAR.

[4] https://www.cooperative.com/topics/transmission-distribution/Pages/Smart-Inverters-as-a-Grid-Asset.aspx

Two methods can be effective in isolating the impact of Volt-VAR independent of other factors:

1. Similar Day Evaluation
2. Similar Feeder Evaluation

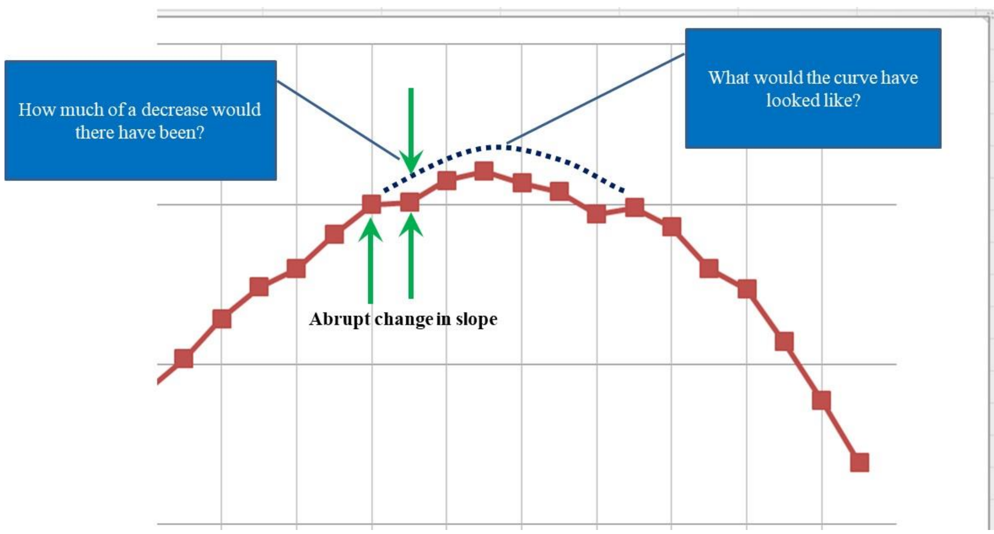
The following sections describe these methods with a focus on evaluating CVR for demand reduction.

Similar Day Evaluation

A similar day evaluation asks: what would have occurred on this feeder on this day if CVR had not been enabled?

The red line in the diagram in Figure 14 illustrates demand measurements for a feeder (or substation) at intervals during a time of peak demand. The left-most green arrow indicates the last measurement for which CVR was disabled. The second (set of) arrows indicate the first measurement for which CVR was enabled. The blue dashed line provides an estimation of what demand may have looked like during the period in which CVR was enabled.

Figure 14: Similar Day Evaluation



The data shown is representative of field measurements. It shows a change in slope of the increasing demand at the point at which CVR is enabled. This is fairly easy for most people to see and leads to an intuitive determination that CVR has an impact. The challenge, however, comes in quantifying that impact.

Figure 15 shows season-long demand measurements and daily temperature measurements for a system in which CVR was being evaluated. The green arrows indicate dates when CVR was enabled.

Figure 15: Season Long Demand

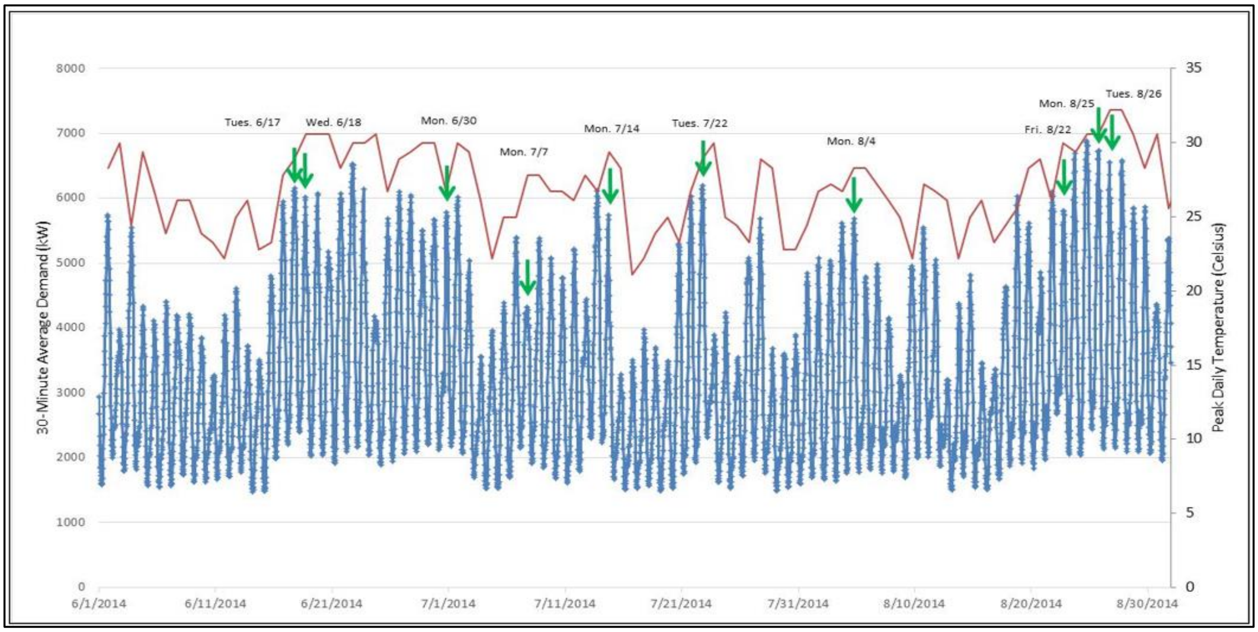
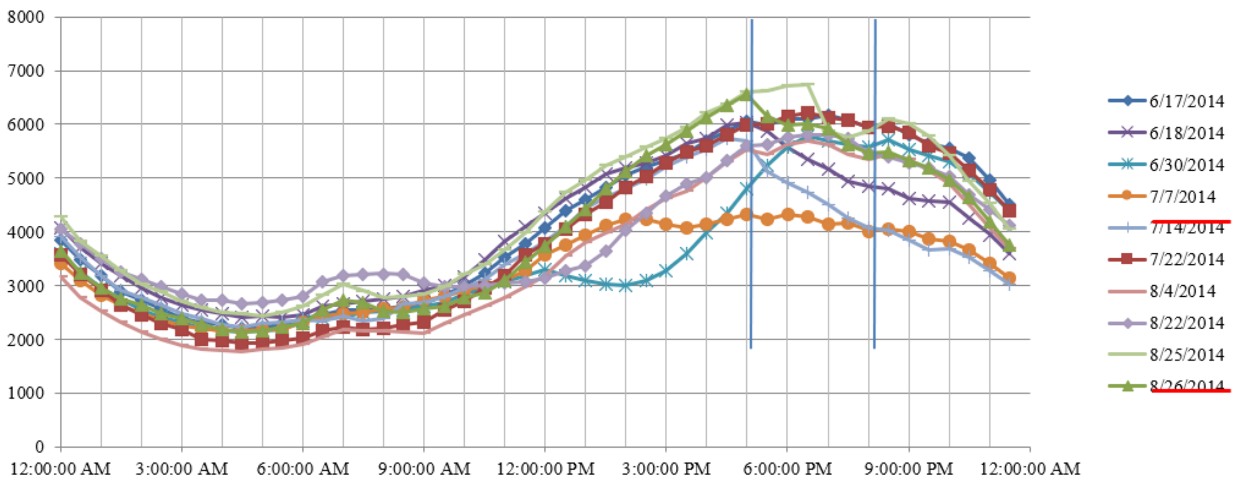


Figure 16 shows demand measurements for these days zoomed into the time of the CVR activation.

Figure 16: Demand Measurements during CVR Activation Times



To determine what the demand would have been without CVR, the analysis looks at the demand on the same feeder without CVR and the impact that factors such as temperature, day of the week, and wind have on demand.

Evaluating the impact of these factors results in an estimate of what demand would have been if CVR had not been enabled. It can estimate what the demand on a similar day (a day with the same temperature, same day of the week, etc.) would have been. This can then be compared to the actual demand.

Table 6 summarizes the impact determined by this evaluation.

Table 3: Impact Determined by Similar Day Evaluation

	Demand Reduction (5PM - 6PM)		Demand Reduction (6PM - 7PM)		Demand Reduction (7PM - 8PM)	
	kW	%	kW	%	kW	%
Substation #1	-62	-1.0%	-193	-3.1%	-213	-3.4%
Substation #2	-94	-1.7%	-238	-4.3%	-215	-3.8%

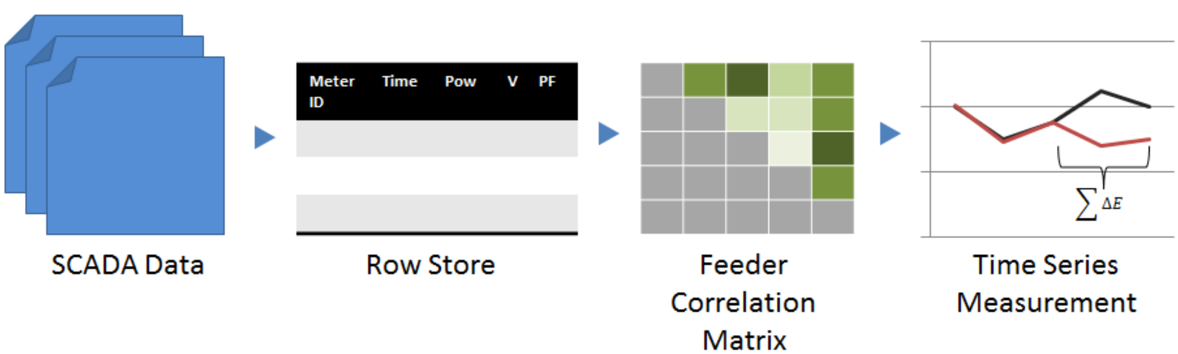
This method leverages the ability of many analytics platforms to perform regression analysis to determine the impact of each of the factors. While not a complex analysis, assistance may be needed from someone familiar with performing this type of analysis.

Similar Feeders Evaluation

Another methodology is comparison of the feeder being tested with other feeders in the system to see which feeders may have similar demand curves. Even if the other feeders do not have more or less demand, the important consideration is whether the shape of the curve is similar.

Figure 17, from an NRECA Report, "Costs and Benefits of Conservation Voltage Reduction,"[5] illustrates the process used to determine which feeders in a system most closely match the one being tested.

Figure 17: Similar Feeders Determination Process



Source: NRECA Report "Costs and Benefits of Conservation Voltage Reduction: CVR Warrants Careful Examination" - MAY 31, 2014

[5] https://www.cooperative.com/programs-services/bts/analytics-resiliency-reliability/Documents/NRECA_DOE_Costs_Benefits_of_CVR.pdf

With this method, historical SCADA data is loaded into a data warehouse that has common attributes across all the substations. Here, the data being compared is power (W), voltage, and power factor. The analyst performs a regression analysis to determine the correlation. In the report, multiple feeders in the system being evaluated have strong correlation with $R^2 > 0.9$.

Once a feeder is found, the measurements of the feeder with CVR enabled is compared to measurements of a well-correlated feeder. By comparing the two, it is possible to compare the impact of CVR.

The advantage of this approach is that temperature, day of the week, etc. are identical for both feeders. The uncertainty comes in how similar the two are and how much that impacts the evaluation.

Summary of Evaluation Methods

Both methods quantify impact. While both are estimates, these approaches frequently provide good orders of magnitude estimates of the impact. Even if the estimate is off by 10 or 20%, it may still be good enough to prove or disprove the overall merit of CVR for demand reduction on a particular feeder.

At a first level, the critical evaluation is to determine whether the investment in hardware to support voltage reduction is covered by the return in peak demand savings. Unless the cost and benefit are close to each other, there is a good chance that the methods will give a good enough indication.

Where Should I Go from Here?

The first step is to identify categories of issues on your system that could benefit from a Volt-VAR solution, such as:

- Line losses, power factor penalties, or voltage drop issues
- Excess peak demand charges
- Introduction of renewables with potential voltage issues

Basic System Improvements

Issues that fall into the first category (line losses, power factor penalties, or voltage drop issues) are commonly addressed in your construction work plan. So, as you plan common system improvements, consider the economic impact of the line losses and whether there are any penalties. Also, it is beneficial to determine if members are seeing issues with voltage that should be addressed.

Peak Demand

If the issues involve addressing peak demand charges, simple calculations can be useful in considering next steps. Frequently, when demand charges are on the order of $10-$15/kW, there is merit in considering a CVR-based demand reduction. This process often follows these steps:

1. Review your feeder voltage profile at peak demand to determine voltage margin.
2. If the margin is only 1-2V, consider the following to flatten the voltage profile and increase the margin:
    a. Phase balancing
    b. Intelligent capacitors
    c. Load-drop compensation in regulators

    Frequently, upgrades that do not require addition of new regulators can be economically justified as part of a program that reduces peak demand charges.
3. From the above, determine the percent voltage reduction that could be achieved while still maintaining a safe margin.
4. Evaluate the demand reduction that could be seen. It is not uncommon that the ratio of demand reduction to voltage reduction is on the order of 0.7. Estimate how much demand reduction could be achieved by the % voltage reduction in step 3. (For example, a 2% voltage reduction equates to a 1.4% demand reduction with a CVR ratio of 0.7.)
5. Consider the economic benefit compared to the investment.
6. If the program appears beneficial, complete a more thorough engineering analysis to verify the basic assumptions.
7. If the engineering analysis looks beneficial, evaluate the actual CVR factor with a pilot program.
    a. Plan a test with minimal investment in automation to verify the CVR factor.

   b. Install any upgrades and evaluate the effectiveness.

8. If the pilot proves beneficial, consider broader adoption and higher levels of automation to extract additional benefit.

Renewables Support

The first step in considering the Volt-VAR impact of distribution connected renewables is performing analysis appropriate to the breadth of the perspective. The analysis could include:

- Hosting a capacity study to understand the system's ability in general for DER.
- Performing a system impact study to understand the impact of a particular large-scale site.

As a part of these analyses, engineers can consider both traditional system improvements, including line upgrades and capacitors, as well as new tools such as IEEE 1547-2018 voltage and VAR control modes.

About the Author

Jim Weikert, Vice President of Utility Automation & Communications, Power System Engineering

Jim earned a BS degree in Electrical Engineering from the Milwaukee School of Engineering at Milwaukee, Wisconsin and an MBA from Edgewood College at Madison, Wisconsin. He has over 30 years of engineering experience in automation and communications. He regularly assists utilities in creating long-term strategies for smart-grid technologies, communications, and data analytics.

Contact for Questions or Comments

David Pinney, Principal Analytical Tools & Software Products, Business and Technology Strategies: David.Pinney@nreca.coop

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