WHITE PAPER / **DISTRIBUTION VOLT/VAR CONTROL**

A SYSTEMATIC APPROACH USING DISTRIBUTION DATA TO OPTIMIZE THE GRID

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The wealth of data being monitored on the electric distribution system is opening new opportunities for cost savings and improved energy usage efficiency. Applying a combination of two voltage control concepts into a sophisticated algorithm applied systemwide is creating value for utilities and their customers.

PAIRING CONCEPTS FOR SYSTEMWIDE IMPROVEMENTS

As current electric utility regulators' models are evaluated for change, one major focus area is creating increased value for utility customers. This raises questions: How will this value be created? Where will it come from? How can this value be tracked and quantified? Many utilities across the country and the world are looking at new technology solutions to address these challenges.

The concepts of volt/VAR optimization (VVO) and conservation voltage reduction (CVR) have been researched extensively, and the U.S. Department of Energy (DOE) has partnered with multiple national laboratories, universities and dozens of utilities to evaluate the benefits as VVO and CVR are emerging as methods to bring value to the customer in the form of energy usage reduction and the associated cost savings. This paper explores some of the benefits and challenges of implementing VVO and CVR into a new systemwide distribution operating model.

Studies have estimated that VVO could potentially save 2% to 3% of annual U.S. electricity consumption. While VVO concepts have been used for decades, only recently have regulators begun to emphasize power quality, energy efficiency and reliability savings. More capacitor banks and voltage regulators are being installed to resolve multiple efficiency issues, including low voltage, high voltage, power factor at the load, as well as power factor at the sub-transmission bus level. More advanced VVO systems use network-based feedback to these devices from a centralized control system that evaluates voltage and VAR flow on a system level as opposed to localized device control. As utilities continue to build out the grid's communication infrastructure, implementing these centralized algorithms systemwide becomes possible. The benefits of VVO are further enhanced by pairing with the benefits and control of a CVR scheme.

VOLT/VAR OPTIMIZATION

VVO is the practice of tightly controlling voltage and volt-ampere reactive (VAR) flow of an entire system to reduce energy losses and shave peak demand.

CONSERVATION VOLTAGE REDUCTION

CVR is reduction of the service voltage at the customer connection to reduce energy usage. Most electrical equipment loads consume less power at a lower voltage.

A DOE evaluation of CVR schemes found that, on average, a 1% reduction in voltage at the customer connection point correlated to a 0.8% reduction in energy usage. By pairing VVO with CVR, utilities are utilizing as many assets as possible to reduce the system and end point voltage. The more distribution system assets used to support VVO and CVR control schemes, the greater the value to the utility and customer.

Together, VVO and CVR have more recently been referred to as Distribution Volt/VAR Control (DVVC). This paper presents DVVC as an example of the dual-use system, but may reference the individual benefits of each technology for clarity. DVVC is often implemented as a control algorithm programmed to achieve optimal distribution voltage profiles and VAR flows on the distribution system.

These control systems can be run as a third-party application algorithm that might interface with either a distribution management system (DMS) or an energy management system (EMS). Alternatively, the algorithm can be embedded directly into the DMS or EMS. The choice of whether to run a third-party application or an embedded application should be evaluated based on each utility's existing systems. The interface with these management systems can often be difficult to implement, and the technology is new, so a knowledgeable and experienced third party may be needed to help with the challenges.

Some of the factors affecting each implementation scenario could include expected life span of current DMS/EMS implementation, number of automated distribution assets, urgency of implementation and existing dedicated resources. For example, if a utility recently went through a management system upgrade, it may be more challenging to implement the algorithm if it was not included in the original scope of work. The complexity of these systems might require additional engineering resources for implementation, with reductions in resource requirements after the control algorithm has been implemented systemwide. However, DVVC will not be a "set it and forget it" algorithm. Given how dynamic the distribution system is, this algorithm will require consistent maintenance and upgrades, just like many other systems within the utility.

BENEFITING FROM COST SAVINGS AND OPTIMIZATION

There are many operational benefits that can be realized from DVVC. Because DVVC is a data-driven algorithm, it requires the investigation and verification of assets, equipment settings and operational configurations, which if addressed properly can benefit many other groups within the organization.

The main driver for DVVC is usually cost savings for the customer, realized primarily through reduced energy consumption. These energy savings are realized by first lowering the average system voltage, then smoothing out the feeder voltage profile to reduce the voltage drop from the substation to end-of-line (EOL). For lowering average system voltage, feeders without any existing low-voltage issues can see the most energy savings. For circuits with low-voltage problems, DVVC can increase the EOL voltage to reduce violations, but this will lead to reduced energy savings. The financial savings in the system come from a combination of lowering EOL voltage, reducing energy consumption, smoothing out the feeder voltage profile, optimizing VAR flows and reducing system losses. This allows for additional feeder load-carrying capacity as well as overall operational efficiency gains.

To smooth voltage profiles and reduce voltage drop, utilizing more automated equipment like line capacitors and voltage regulators on the feeder will result in increased savings.

Average energy reduction is usually about 2% to 3% on a systemwide basis. Each individual feeder may see reductions of up to 4%, depending on existing properties of the feeder.

DVVC OPERATIONAL BENEFITS

- **Reduced feeder energy consumption.**
- **Increased power factor at the substation bus.**
- **Lower VAR demands from the sub-transmission or transmission levels.**
- **Lower system losses.**
- **Optimized asset control for line and substation capacitors, LTCs and voltage regulators.**

Feeder length, conductor size and distribution of load all affect the voltage profile and potential energy savings. DVVC systems that use only automated distribution capacitor control often have lower energy reduction than systems also using voltage regulators and substation load tap changers (LTCs).

Depending on the regulatory environment, DVVC also could be implemented for peak shaving — it would turn on peak as a demand response mechanism to reduce energy consumption during peak demand, when potential savings have the greatest financial impact. The system also can be implemented as normally on with operational control to disable the algorithm when required. Since voltage drop on the feeder scales with the load level, the largest difference in voltage from substation to EOL is seen at peak loading, and therefore less savings can be seen from lowering average voltage at peak. Because the electric system is designed to maintain voltage for the end customers during these periods of large voltage drop, the average system voltage can be lowered more during off-peak periods, and the utility can see the largest energy savings during these times. However, energy savings realized during peak demand can have larger financial impacts.

DVVC also enables a centralized distribution power factor (PF) control, which can find optimal capacitor and tap changer configurations mathematically to optimize systems. Many DVVC systems allow for

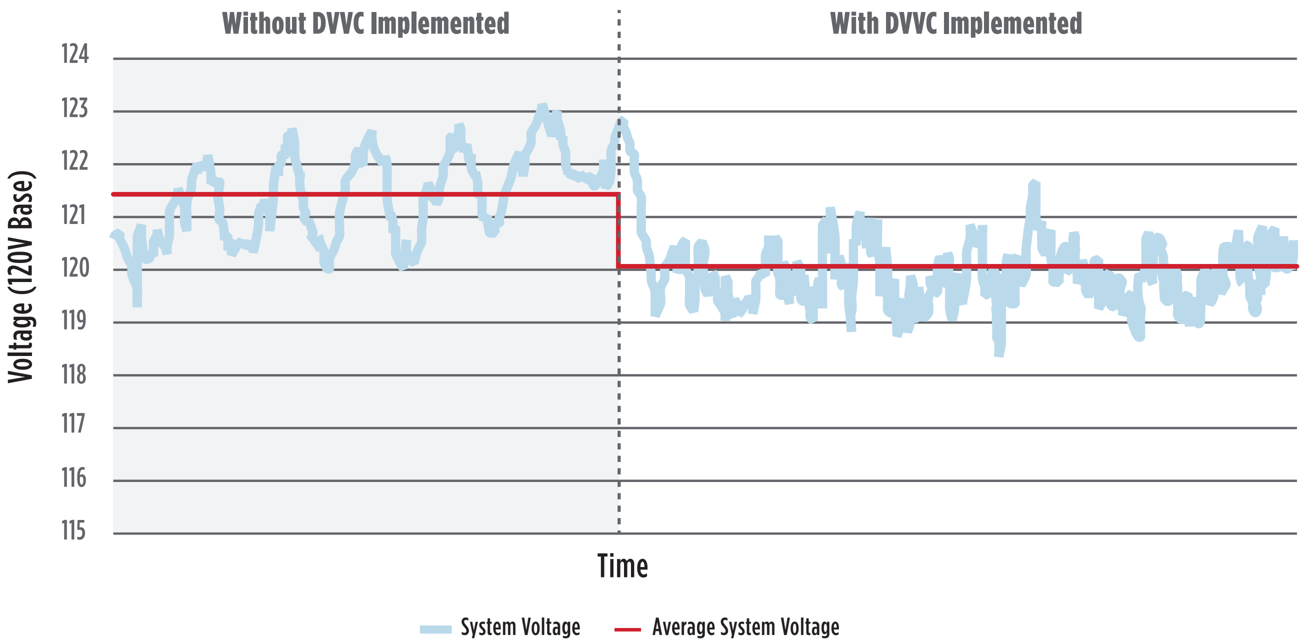

FIGURE 1: *Average system voltage reduction through volt/VAR control.*

programmable input limits of PF (e.g., 0.98 lagging or 0.99 leading as a bandwidth for operation). The algorithm will then review all possible combinations of line equipment settings and select the optimal configuration to achieve an operating scenario within the PF limits.

In most solutions, voltage requirements (i.e., ANSI/IEEE C84.1) also become a limiting factor. For example, if the algorithm finds a solution that would open a capacitor bank, it will only choose that solution if opening the capacitor bank will not cause any localized voltage issues. The utility will need to decide whether the algorithm will prioritize optimizing voltage, which would provide greater financial savings from average system voltage, or power factor. The latter is more common in areas with low PF from large air conditioner or motor loads. The voltage measurements could either be taken from SCADA measurements at the line device or directly from the customer advanced metering infrastructure (AMI) meter.

The PF control on the distribution system is a valuable benefit, as it leads to better operational efficiency as well as provides benefits to better utilize more distributed energy resources (DERs) to the system. Both can be huge drivers for creating value for the end customer.

Another benefit of DVVC systems is better asset utilization and operational tracking. The electric system is currently designed to handle those few peak demand days each year. This means many of the assets are underutilized, called upon only a few days a year to meet that peak demand. DVVC aims to increase this asset utilization by finding new operating configurations and tracking operation frequency. DVVC algorithms can track the number of operations for each asset and could be integrated to create reports for asset management teams to review for asset maintenance, replacement or relocation. Historically, many distribution assets have been neglected when it comes to maintenance, in part because of the cost to monitor the large number of assets. Increased asset utilization can sometimes lead to additional costs to add monitoring or operational intelligence. The benefits of better reliability, power quality and higher efficiency provide a counterbalance to the added operation and maintenance costs.

BALANCING VOLTAGE POSES VARYING CHALLENGES

As with most new technologies, utilities should be prepared to face implementation challenges. Numerous resources must work together for DVVC to achieve slated goals. Data must be aggregated from different platforms — such as geographic information systems (GIS), metering data, system models, EMS, DMS and outage management system (OMS) — to a centralized location for analysis. Engineers, operators and managers all need to understand how this operational technology may affect their business. The initial design will take additional engineering resources for implementation, and after installation, the maintenance and updating of the system will require training a team of dedicated resources.

The system and feeder properties themselves can be some of the biggest challenges. As discussed earlier, the biggest of these is existing low voltage at the EOL. For example, a feeder that supplies 5,000 customers with AMI meters may have multiple customers that experience low voltage during a given day. Sometimes it is a distribution transformer issue, an undersized secondary, or maybe an old cable splice that was never documented. It could be several variables that caused the low voltage, but the meter data shows that the voltage on that feeder cannot be further reduced at that loading level and point in time. While this voltage data has been available to the utility for as long as it has had an AMI system, utilities typically do not investigate the data at the level of detail required for DVVC. The use of a DVVC algorithm and smart meter data can help identify and fix these weak points in the system. A DVVC system can help prioritize maintenance for the distribution system. These investigations take time and often require a lot of work to process and determine the validity of the data. The creation of algorithms to clean and normalize data is essential to the time-effectiveness of the solution.

In some cases, these challenges may lead to making more conservative assumptions, limiting the initial effectiveness of the algorithm. However, as data analytics tools continue to advance and as the algorithms become more sophisticated, greater visibility into the distribution system will be realized, which will allow utilities to react more quickly to address issues in the future.

FIGURE 2: *Example distribution circuit model for DVVC design support.*

As the system algorithm is implemented, updated and revised, the distribution system will be able to react dynamically. And as more equipment is monitored, it will continue to optimize. It is important to start this process as early as possible to meet the utility's needs as the system grows and becomes smarter.

Existing high voltage can be another challenge for DVVC implementation. To date, much of the electric grid has operated on the higher end of the voltage profile. This was attributable to many reasons, whether to resolve low voltage issues downstream or to allow for more kilowatt-hours to be delivered to the customer. Today, however, the operational focus of utilities is shifting to energy efficiency. The problem is that if the voltage is too high at the distribution substation level — the starting point of the DVVC control — the algorithm will only be able to reduce the voltage a small amount using line devices. This will either push LTCs to their max taps (not able to reduce voltage any more) or it will open all the capacitors to address concerns about high voltage. Without all the capacitors as part of the algorithm, the system may not be able to meet the preset VAR and PF limits. Therefore, for maximum benefit, the whole system must be analyzed, rather than from the low side of the distribution substation down. Again, systemwide data analysis and studies can be used to determine ideal substation voltage, leading to a potentially more efficient and stable system.

There is a constant balance between voltage and VAR demands, creating the real benefit of a tried-and-tested volt/VAR control algorithm. There is a metaphorical "sweet spot" that DVVC can fine-tune and optimize on the system, but it will only optimize to the specifications created by the system engineers. As a result, utilities should conduct preliminary studies to understand the design and challenges of their system, and have the DVVC software vendor demonstrate the optimization to make sure it matches preferred solutions.

A lack of accurate system models is often the biggest obstacle to ideal grid operation. As modeling software, documentation and data management systems improve, creating accurate system models is becoming more feasible. Utilities across the country evaluate these new technologies. Distribution engineers are frequently asked, "Could we run a study or a simulation for DER (distributed energy resources) planning?" A common response: "It depends." It typically depends on the availability of accurate network models for the system or how much work would be required to create or update them. As technology improves, it becomes more essential for utilities to create and maintain these accurate models.

Having these system models benefits all aspects of distribution system design, operation and maintenance. However, the lack of accurate circuit models remains a barrier. Engineers make conservative assumptions because of the general lack of faith in the data's integrity. Now modern technology and data analytics, with accurate network models, will allow DVVC to push the grid into the next generation. Implementing a DVVC program is a great opportunity to dedicate resources to updating these models, as they will become integral in the future automated distribution management systems (ADMS) or distributed energy resource management systems (DERMS).

CONCLUSION

DVVC concepts have been around for decades, but they were always limited in their effectiveness because of a lack of centralized control, network connectivity to distribution assets, and the availability of network models. As the electric utility industry has begun to invest in networks, communication and automation, the building blocks are being set in place to enable these new technologies.

In an environment where the grid is stressed with increasing application of distributed energy to help address renewable portfolio standards, DVVC provides potential solutions to some challenges that are still coalescing. Once a utility has built an AMI system and has network connectivity to distribution assets, preconditioning and DVVC are logical next steps. Many of the benefits increase value and save money for the customer and the utility, and the inherent challenges help encourage the utility to improve its operations and planning for the next-generation grid.

BIOGRAPHY

JENNY REITMEIER, PE, is a section manager for the Networks, Integration and Automation group. Her background includes electric utility SCADA and communications, and substation and distribution automation. She has worked on network systems for centralized recloser and automation, field area networks, as well as project work designing system settings and analysis for DVVC. She has also researched the financial needs and benefits for installing radio networks for distribution field communications.

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