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UE-190274/UG-190275 (*consolidated*)
Witness: Jason L. Ball

BEFORE THE WASHINGTON
UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, **Complainant,** **v.** **PUGET SOUND ENERGY,** **Respondent.**	**DOCKETS UE-190529 and UG-190530 *(consolidated)***
In the Matter of the Petition of **PUGET SOUND ENERGY** **For an Order Authorizing Deferral Accounting and Ratemaking Treatment for Short-life UT/Technology Investment**	**DOCKETS UE-190274 and UG-190275 (*consolidated*)**

EXHIBIT TO TESTIMONY OF

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WASHINGTON UTILITIES AND
TRANSPORTATION COMMISSION

Volt-VAr Optimization Benefits

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Using Secondary VAr Controllers to Enhance Integrated Volt-VAr Optimization Benefits

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***Abstract*— Grid modernization efforts are on the rise for many utilities in the US with major investments seen in the distribution networks where conventional visibility and control has been scarce. Primary drivers for such investments include the increasing energy efficiency of the grid and managing uncertainty seen with rapid adoption of EVs, and solar PV by end users. Integrated Volt-VAr Optimization (IVVO) has been used to achieve energy efficiency objectives in the past by few utilities. Newer technologies such as Secondary VAr Compensators (SVCs) are providing new and cheaper avenues for utilities to enhance the energy efficiency goals in addition to providing distributed visibility and control. Through a pilot project and field testing performed at Xcel Energy in Colorado, this paper quantifies the benefits of SVCs in coordination with IVVO assets in enhancing energy savings (3.3%) and demand reduction (4.2%). The LCoE for an SVC solution is much lower (0.5 – 1 cts/kWh) than conventional approaches for providing social and environmental benefits (reduction in CO_2 emissions) in addition to achieving the grid modernization benefits of increasing resilience and reliability of the network.**

Keywords— Energy efficiency, Load Tap Changer, Capacitor Banks, Secondary VAr Compensators, Volt-VAr Optimization

I. INTRODUCTION

A wave of grid modernization efforts is whizzing through many utilities in the US to tackle problems associated with uncertainties on the grid due to an increase in newer types of loads such as EVs and rapid adoption of intermittent sources such as distributed solar PV [1]. In addition, many states are moving towards approaches that allow them to achieve energy efficiency through technological alternatives that are much cheaper than the conventional routes of building new generation plants. To realize these alternatives, utilities are channeling more investments in the distribution grid specifically to add sensing, measurement, control and automation, which has conventionally not been present for distribution networks. All these efforts ultimately are geared towards increasing reliability, resilience, situational awareness of the grid and achieve a cleaner means of generating and transmitting power to end users.

One manner of achieving energy efficiency is through Demand Side Management (DSM) sometimes called Demand Response (DR) [2]. Demand response requires customer participation to enable utilities to control their loads such as heaters, HVAC etc. at times of peak demand. Demand side management requires the necessary communication infrastructure where a third-party system can help utilities reduce demand by communicating with loads either directly or through automated metering infrastructure (AMI). While, DSM or DR has been shown to be quite successful for some utilities, it does depend on consumer participation, their availability, and suffers from the consumer behavior, which can be highly unpredictable.

The other method of achieving energy efficiency is through the implementation of Integrated Volt-VAr Optimization (IVVO) [3]. This mode of control resides on the utility-side of the meter (as opposed to the consumer side in the case of DR). Energy efficiency and demand control is achieved by automating primary grid assets such as Load Tap Changers (LTC), Line Voltage Regulators (LVRs) and Cap Banks. In many cases, the IVVO equipment is controlled through a software that may reside in an Advanced Distribution Management System (ADMS) platform among other suite of applications. To achieve energy savings, the IVVO system optimizes the settings of the various assets to reduce energy consumption generally through Conservation Voltage Reduction (CVR). A reduction in voltage causes the energy consumption of the system to reduce but the end consumers do not experience this change. Neither are the end consumers required to participate in this program. However, end consumers do reap benefits of reduced electricity bills. This mode of control is under full utility control and is not hostage to the unpredictability that accompanies DR programs. However, achieving voltage reduction even through IVVO may not be possible on several distribution feeders due to the nature of the circuit (sensitive industrial loads) or the sheer length of circuits (long rural circuits). Further, there is an upfront investment that the utility needs to make in order to automate equipment and have a communication infrastructure to then remotely control these assets.

Newer distributed technologies for managing voltage on the distribution grid provide relief and an alternative to enhance the benefits that can be achieved from regular IVVO programs. One such technology is called the Secondary VAr Compensator (SVC) that is connected in shunt to the low voltage side of the service transformers (208V, 240V or 277V) and provides tight voltage regulation by modulating its reactive power. An SVC acts autonomously once a setpoint voltage has been dispatched to it. As SVCs are connected in shunt, they improve the feeder-wide voltage profile. Generally, a few SVCs (10-15 SVC/feeder) can improve the minimum voltage on the feeder by 1% - 3%. This is in addition to the existing voltage margin, which on some distribution circuits can be nearly 0%. Further, due to their distributed architecture, SVCs don't suffer from a single point of failure and are easily scalable to achieve higher improvements and even support different use-cases such as PV hosting capacity increase.

Through a pilot project and extensive testing performed at Xcel Energy in Colorado, this paper provides benefits of voltage support, voltage visibility, energy savings and peak demand reduction achieved by using SVCs in coordination with primary IVVO equipment such as LTC and Cap Banks. Before delving deep into the pilot project, the next section covers Xcel Energy's vision specifically for IVVO.

II. AGIS PROJECT AND IVVO AT XCEL ENERGY

In 2016, Public Service Company of Colorado (PSCo) launched its "Our Energy Future" strategy—a new plan consisting of ten different initiatives that will pave the way for an interactive, intelligent, and efficient grid. One component of PSCo's plan is the Advanced Grid Intelligence and Security (AGIS) initiative. The AGIS initiative comprises: Advanced Distribution Management System (ADMS), Advanced Meter Infrastructure (AMI), a Field Area Network (FAN), Integrated Volt-VAR Optimization (IVVO), Fault Location Isolation and Service Restoration (FLISR), and the Geospatial Information System (GIS) [4].

Working together, the AMI meters will measure and transmit voltage and power quality data, which will be used by the IVVO application within the ADMS to automate and optimize the operation of the distribution voltage, and the Field Area Network (FAN) will facilitate the flow of information between the AMI meters and the IVVO devices to the Company's software and hardware support system. Those three components of the AGIS initiative will be rolled out between 2016 and 2022 and will require an estimated capital investment of $562 million.

As the focus of this paper is the IVVO application, the next sub-section describes PSCo's plan for IVVO deployment.

A. *Integrated Volt-VAR Optimization (IVVO)*

PSCo plans to deploy intelligent field devices to 67% of its customers by implementing IVVO on 472 feeder lines within the Denver metropolitan area. The four principal utility equipment components of IVVO include capacitors, Secondary VAr Compensators (SVC), voltage sensing devices, and Load Tap Changers (LTC). PSCo plans to install new capacitors on all 472 feeders and 4,350 SVC devices on a subset of those feeders. Further, currently PSCo has the capability to monitor voltages at the substation but does not have the capability to constantly monitor voltage levels throughout its feeders. As a result, the PSCo must operate at a higher voltage than would otherwise be required to ensure the appropriate voltage at the end of a long feeder. The proposed IVVO application will allow voltage to be monitored along the entire length of the feeder and at selected end points, allowing PSCo to utilize lower voltages across the system. The IVVO is expected to initially produce a 2% overall system voltage reduction but may be able to expand to a 5% reduction on certain feeders through secondary static VAR compensators (SVC). The projected energy savings from IVVO are expected to be approximately 71 GWh in 2019, rising to 340 GWh in 2022. In addition, the reduction of distribution losses will save an additional 9 GWh by 2022. The IVVO project will reduce peak demand by over 1%, amounting to an annual demand reduction of 44.5 MW in 2022.

The vision highlighted in the AGIS project especially associated with the IVVO deployment was tested through a pilot project conducted at the Englewood substation and is a focus of this paper.

III. ENGLEWOOD SUBSTATION PILOT DEPLOYMENT

The Englewood Substation is in the state of Colorado, United States. Fig. 1shows the one-line diagram from the Synergi model. There are four feeders connected to this substation (1685, 1686, 1687 and 1688), whose nominal voltage is 13.2 kV (L-L). All 4 feeders are regulated by a single Load Tap Changer (LTC) at the substation, and the LTC is gang operated base on phase C voltage. The LTC has a band center of 124V with a bandwidth of 2V. There are four (4) 1200 kVr Fixed Cap Banks (FCB), twenty (20) 1200 kVar Switched Cap banks (SCB).

The feeders are predominantly residential with a peak load of 37.1 MW and average load of 20.1 MW. The maximum length of the feeder (from substation till end of line) is 5.74 miles. The feeder has 69% overhead service transformers and 31% pad-mount service transformers, with 63% transformers in the 15 – 50 kVA range. The historical load profile and the substation voltages by phase are shown in Fig. 2.

A. *Secondary VAr Compensators (SVCs)*

Xcel Energy had the objective of testing SVCs on the Englewood substation. SVCs are utility-owned devices that tightly regulate the voltage locally (on the secondary side of service transformers) and feeder wide (on the primary MV side). SVCs are shunt connected on the secondary (208V – 277V) side of the service transformers and are generally single-phase but can be designed to be three-phase as well. The tight regulation is accomplished by injecting VArs when the sensed voltage drops below a configurable set-point and removing VArs when the voltage rises above the configurable set-point. These devices are dynamic, fast-acting and can inject variable amounts of reactive power (e.g. 1 kVAr increments up to 10 kVAr) on a sub cycle basis. Xcel Energy tested the SVC product offered by Varentec called ENGO as shown in Fig. 3.

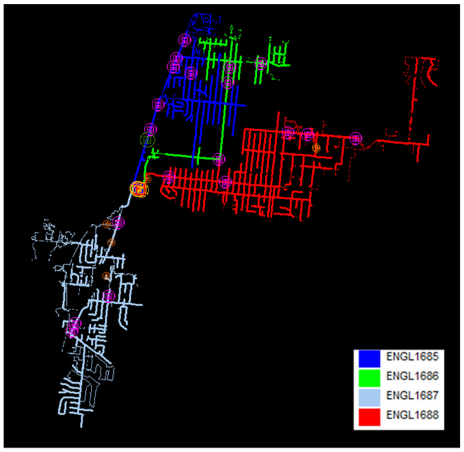

Fig. 1. Circuit diagram of the Englewood feeders

Several SVCs deployed on the distribution grid act autonomously once they have a set-point command. All the SVCs can communicate wirelessly (cellular or mesh radio) and managed by a central software platform that can help in dispatching utility defined set-points; and help to collect, visualize and report data. This software platform can be either hosted in the cloud or deployed on utility premises behind utility firewall to ensure cybersecurity. This software platform can also act as a gateway to communicate with operational and enterprise systems such as Advanced Distribution Management Systems (ADMS). One example of such a software platform is the Grid Edge Management System (GEMS) also offered by Varentec Inc. as shown in Fig. 3

Fig. 2. Yearly substation MW and voltages by phase

GEMS™ ENGO® ENGO deployed on a Pole

Fig. 3. SVC Solution in the Market: ENGO (0 – 10 kVAr) and GEMS software platform offered by Varentec

The collective action of SVCs helps to control grid voltage and thereby unlocks a simple grid-edge VVO/CVR scheme that increases system efficiency; provides feeder level dynamic VAr control [5]; and supports the penetration of solar PV by tapping down the substation Load-Tap-Changer set-point or Feeder Head-Regulator(s).

B. SVC Location and Sizing

1) Locations

An iterative load flow technique is used to deploy SVC devices in the feeder with the first device deployed at the location with lowest voltage and subsequent devices deployed at the new lowest voltage in the system. This process automatically selects and installs the SVC at the locations with low voltage problems.

2) Sizing

The number of SVC devices depends on the type of application. A rule-of-thumb for SVC sizing depending on application is as follows:

1) Voltage Support: 2 – 5 SVCs per feeder
2) Energy Savings: 7 – 13 SVCs per feeder
3) Demand Reduction: 15 – 20 SVCs per feeder
4) PV Hosting Capacity: 20 – 30 SVCs per feeder

a) Energy Savings

Based on field experience, a more precise metric has been developed for energy savings application. By deploying 4 times the average energy of the system, we can ensure a critical mass of SVC devices. Further, a metric called BCM_{ES} is used that is given by

$$BCM_{ES} = \frac{0.3 \times \#SVC}{V_b\% \times MW_{avg}}$$

Where, #SVC is the number of SVCs, $V_b\%$ is the voltage boost achieved by placing SVCs in the system, MW_{avg} is the average MW of the substation

The constraint used to choose the number of SVC devices for Energy savings is as follows:

$$BCM_{ES} < 1\ \underline{AND}\ V_b\% > 1\% \tag{1}$$

The above constraint is not strict and should only be used as a rule-of-thumb.

b) Demand Reduction

Another metric called BCM_{PD} is developed to assist in the sizing of SVCs for the demand reduction use-case.

$$BCM_{PD} = \frac{V_b\%}{\#SVC/MW_{avg}}$$

The constraint that can be applied to choose the number of SVC devices is

$$BCM_{PD} > 0.3\ \underline{AND}\ V_b\% > 1.5\% \tag{2}$$

C. SVC Placement for Englewood

Using the guidelines mentioned in the previous section, the location and sizing of the SVC, a total of 153 SVC devices were selected to provide two use-cases namely energy savings and peak demand reduction. The total number of SVCs chosen was higher than the optimal as one of very objectives of this pilot test was to compute the optimal number of SVCs required. The final locations of the 153 SVC devices are shown in Fig. 4.

TABLE I. SVC PLACEMENT ON ALL FEEDERS BY PHASE

	ENGL 1685	ENGL 1686	ENGL 1687	ENGL 1688	Total
Phase A	42	31	2	12	87
Phase B	15	26	3	11	55
Phase C	0	2	2	7	11
Total	57	59	7	30	153

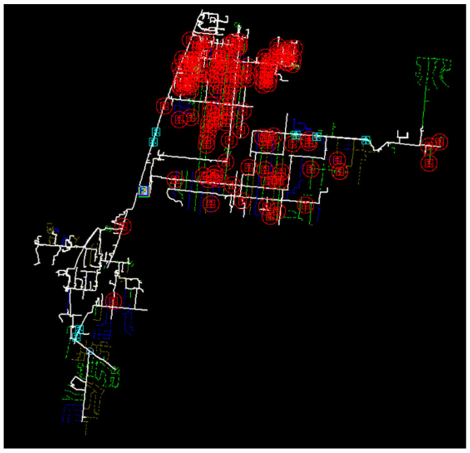

Fig. 4. 153 SVC placed on the four Englewood feeders

IV. PILOT TESTING AND TECHNICAL RESULTS

Several tests were conducted to validate the value of SVCs acting in coordination with the primary assets. The description of these tests along with their corresponding results are given next.

A. *SVC ON/OFF Testing*

In this test procedure, all SVCs connected to all the feeders are turned ON and OFF on alternate days. During the DAY ON/OFF test, the LTC Set-Point is fixed. The Day ON/OFF testing demonstrates the benefits to improve voltage margin and grid edge voltage support provided by SVCs. When SVCs are turned OFF, they still monitor voltage but do not inject VArs. This test was conducted for 2 weeks. The minimum voltage captured over the entire period as a function of distance is depicted in Fig. 5 divided into Day OFF (left) and Day ON (right) period. This figure shows that SVCs provide a minimum voltage improvement of 1.71% across all feeders. Further, there is one limiting node that has overloading. Upgrading the transformer at this location or placing an additional SVC can improve the system wide voltage to 2.4%.

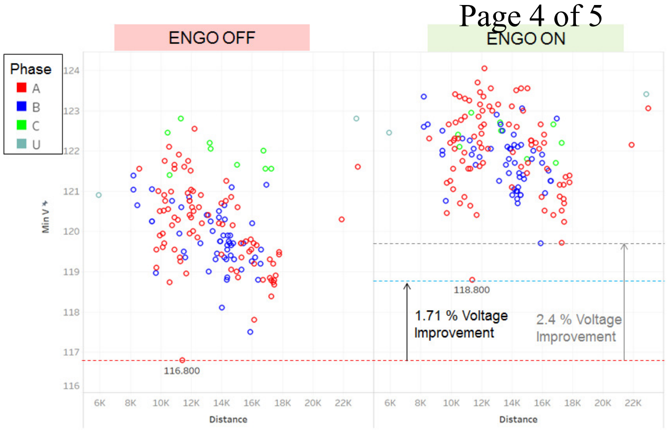

Fig. 5. Minimum voltage improvement of 1.71% (and 2.4% after fixing overloaded transformer) observed with SVCs

B. *SVC Number Optimization Testing*

With different number of SVCs turned ON in the system, the system voltage was reduced by 5%. The results of this testing are provided in Table II. The results clearly show that even with 86 SVCs, the system can be reduced by 5%. With 68 SVCs, the system can be reduced by 4%. 153 SVCs allow 5% reduction at higher peak MW levels validating that SVCs provide a scalable solution.

TABLE II. SVC NUMBER OPTIMIZATION

No. of SVCs Turned ON	LTC Voltage Reduction %	Peak MW	Min. SVC Voltage*
68	4%	32.9	113.9 V
87	5%	33.1	114.4V
104	5%	33.6	113.9 V
153	5%	34.8	114 V

*Disregarding one overloaded transformer

C. *CVR Voltage Reduction Testing*

In this test the LTC voltage was reduced periodically to compute the CVR factor for power, CVR factor for energy and the corresponding reduction in power and energy that can be achieved over an entire year. This test was run over a period of around two months. The voltage and corresponding power gathered from the substation is illustrated in Fig. 6.

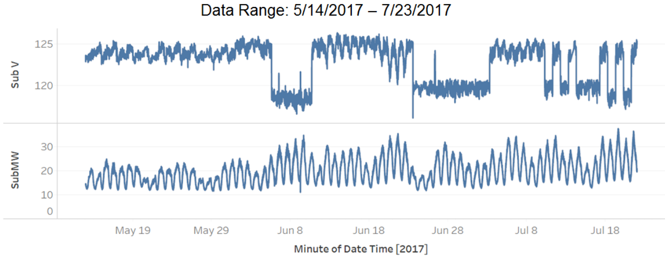

Fig. 6. Voltage reduction events realized over a period of 2 months

The total number of voltage transitions during the period of testing were 14. Using these transitions, the CVR factor for power was computed to be 0.84 with an error band of ±0.26 (95% confidence). Using single Day CVR ON/ CVR OFF events, the CVR factor for energy was computed to be 0.66 with an error band of ±0.27 (95% confidence). As expected, the CVR factor for power is higher than the CVR factor for energy. These values of CVR factors for power and energy were applied to yearly data to compute the annual energy savings and demand reduction achieved for Englewood.

1) *Energy Savings*

The yearly energy usage for Englewood was computed as 176,164 MWh. Two different scenarios are provided in Table III.

TABLE III. ENHANCED ENERGY SAVINGS ACHIEVED USING SVCS

# SVC	% Voltage Reduction	% Energy Saving	Yearly Energy Saving (MWh)
68	4%	2.7%	4,679
87	5%	3.3%	5,849

2) *Peak Demand Reduction*

With the help of demand reduction, utilities can defer capital investments in generation assets. At Englewood, using SVCs in coordination with the primary assets, the peak power shaving values are shown in Table IV.

TABLE IV. ENHANCED PEAK REDUCTION ACHIEVED USING SVCS

# SVC	% Voltage Reduction	% Peak Demand Reduction	Peak Power Shaving (MW)
68	4%	3.36%	1.15
87	5%	4.2%	1.47

V. SOCIO-ECONOMIC IMPACT OF PILOT PROJECT

1) *Economic Benefits*

The levelized cost of Energy (LCoE) for the SVC solution was computed to be between 0.49 cts/kWh to 1.02 cts/kWh. This LCoE is extremely cost competitive with power generation alternatives such as Nuclear, Coal & Gas, Renewables and energy efficiency alternatives such as DSM. The graph in Fig. 7 is generated from data obtained from [6] and it shows a comparison in cost between different alternatives.

The reduction in voltage also leads to nearly 7% reduction in losses as many appliances operate efficiently at lower voltages [7].

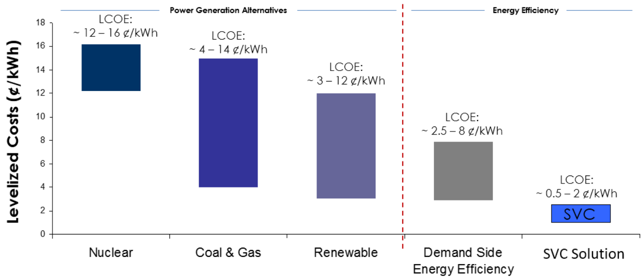

Fig. 7. Levelized cost of Energy (LCoE) for different approaches

2) *Consumer Benefits*

As the voltage is reduced, it leads to reduction in energy consumption for all households connected to the grid. With an average retail price of 8.93 cts/kWh, the reduction in electricity bills was computed to be $486,000 for the entire substation of which $233,000 was attributed to SVCs. On an average (assuming 4000 households), each household saves $120 annually.

3) *Environmental Benefits*

As energy consumption is reduced, less fuel is burnt to produce power resulting in lower CO_2 emissions. The CO_2 emission reduction of 5210 tons (diesel), 4948 tons (coal) and 2620 tons (Gas) can be achieved using the SVC solution.

VI. CONCLUSIONS

This paper presented a novel concept of using SVCs in coordination with LTCs and Cap Banks to achieve many different objectives of IVVO namely voltage support, energy savings and peak demand reduction. It was shown that the SVCs can provide 1.7% minimum voltage improvement to achieve 5% voltage reduction with 87 SVCs and 4% voltage reduction with 68 SVCs. Using this voltage reduction, 2.7% and 3.3% energy savings can be achieved with 68 and 87 SVCs respectively. In addition, it was demonstrated that 3.36% and 4.2% peak demand reduction can be obtained with 68 and 87 SVCs respectively. Finally, it was computed that an SVC solution has an LCoE between 0.5 – 1 cts/kWh which is extremely cost competitive as compared to other generating resources and demand side energy efficiency technologies. Such a solution provides a win-win-win situation for utilities, consumers and the environment. For Englewood, it was shown that the consumers save on an average $120 per annum on electricity bills. The environment benefits as a result of CO_2 emissions reduction ranging from 2620 tons (Gas) to 5210 tons (diesel).

As Xcel Energy integrates ADMS, AMI, FAN into their system, SVC becomes another layer that offers fast control and situational awareness into the system. This architecture promises increase in the resilience and reliability of the network in addition to offering the benefits of enhanced energy savings, peak demand reduction and in the future also providing support to PV penetration.

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