Energy Conservation and Demand Control Using Distribution Automation Technologies
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T.L. Wilson, Senior Member, IEEE
D.G. Bell, Member, IEEE
PCS UtiliData
Spokane, WA 99217 USA

Abstract: In 2002, two Pacific Northwest Utilities placed new distribution automation technology solutions into service at four substations with a total of ten distribution feeders. These solutions use commercial-off-the-shelf control technology to closely control distribution voltages to reduce energy usage and control demand. The first system at Inland Power and Light Company, a cooperative in Eastern Washington, went into service in April 2002, and the other three at Clatskanie PUD in Oregon went into service in November 2002. Avista Utilities is installing this new technology at the time of this writing. This paper presents the results of the ongoing operation and tests at these four rural substations. It will also describe the results that other utilities could expect when this technology is used to implement demand control, load management and conservation voltage regulation.

Keywords: AdaptiVolt™, Adaptive Voltage Control, Conservation Voltage Regulation/Reduction (CVR), Conservation Voltage Reduction Factor (CVRf), Demand Side Management (DSM), Dispatchable Demand Control, Line Regulator and Interface Controller (LRCCI), Line Voltage Monitor (LVM), Programmable Logic Controller (PLC), SCADA, Substation Data Concentrator and Controller (SDCC),

1. Introduction

Rural utilities such as Inland Power and Light Company (Inland) in Spokane, Washington and Clatskanie People's Utility District (Clatskanie) in Clatskanie, Oregon have traditionally set voltage regulator controls or on-load tap changer (LTC) controls to assure that end-of-line voltages would be kept above minimum levels during heavy load periods. This has often resulted in voltages above nominal levels and excess energy usage during off-peak periods. In some instances, these voltages could be high enough to damage equipment and shorten the expected life of appliances such as lamps and heating elements.

Traditionally, there have been several difficulties in controlling distribution voltage levels closely enough to be used as load management, demand response or conservation tools. Under-voltage conditions (under the ANSI C84.1-1995 low limit of 110 volts on a 120 volt base) are believed by some to damage customers' equipment.[i] (In 2002, the California PUC rejected a move to use distribution voltage reduction as an energy conservation measure primarily because of end-of-line voltage concerns.)

Typical implementation of distribution voltage control as a load or demand management tool involves operators physically going to distribution substations to change regulator settings. Newer regulators have communications capabilities that allow a SCADA system to issue a single step level voltage reduction signal or download new bus voltage set-points.

These traditional approaches require significant amounts of engineering and capital to prepare a distribution system for the use of voltage control as a demand or load control tool or an energy conservation tool. Computer modeling of the distribution lines is usually required. In addition, distribution lines often require enhancements such as load balancing, re-conductoring, and the addition of capacitors.

2. Description of AdaptiVolt™ Systems

An AdaptiVolt™ (Adaptive Voltage Control) system consists of several different components, each having its own unique function. Figures 1 and 2 show the simplified architectures of two typical systems, Inland and Clatskanie.

- AdaptiVolt™ Core (Core) and associated microprocessor - The Core is the software that runs all the main algorithms for managing the distribution line voltages. This includes determining tap change requirements, selection of the controlling voltages and determination of capacitor

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[i] There is much research that shows no damage to equipment or overheating of motors until much lower voltages are reached and sustained.

switching requirements to manage voltage and reactive power. The Core may run on the same hardware platform as the substation data concentrator and controller (SDCC).

- Deployment Software Modules – Each distribution system is unique. The deployment software modules allow the configuration of the system to match the architecture of the distribution system. They accommodate different manufacturers of regulators, load tap changers, power monitoring equipment and communications equipment.
- Line Voltage Monitors (LVM) – The line voltage monitors are installed at the end of distribution feeders and at critical loads on all three phases. There can be multiple line voltage monitors on a single feeder. The system will select the controlling voltage based on the configured rules and the critical LVM selection algorithms.
- Line Regulator and Capacitor Control Interface Units (LRCCI) – Line regulator and capacitor controllers and interface units are microprocessor-based units located at mid-line regulators and at switched capacitors located on the distribution lines.
- Field Communications Links – The field communications links provide two-way communications between the LVMs and the LRCCIs. These links can be licensed or unlicensed radio, power line carrier, broad-band or internet TCP/IP, satellite, fiber-optic, hard-wire or other suitable communications link.
- Substation Data Concentrator and Controller (SDCC) – The SDCC is a microprocessor-based unit that performs communications functions within the substation, data interface and data storage functions. It may function as a substation remote terminal unit (RTU) or it may communicate directly with an existing RTU. The SDCC may be located on the same hardware platform that the Core resides on.
- Substation Communications Links – The communications links within the substation may be both local area network (LAN) and remote input/output directly connected to the SDCC platform and the Core platform. If it is a LAN, it may use any number of protocols including Modbus, DNP 3.0, Modbus Plus®, DF1, ControlNet® or UCA.
- Feeder Monitoring Devices – The feeder monitoring devices monitor the feeder kWh, kVARh, kW, kVAR, current and voltage of each feeder. Usually these are specialized power monitoring devices.
- Operator Interface – The operator interface allows an operator to determine the status of the system, turn it on and off, and in some cases to manually operate regulators, LTCs and capacitors. The operator interface can be as simple as selector switches, pilot lights and diagnostic LEDs or it can be a personal computer (PC) based graphic user interface (GUI).
- Data Acquisition Unit – Data acquisition is optional with the system. If data collection is required, it can be collected either on a remote master unit via telephone or satellite link or it can be collected by a PC in the substation.

In currently operational AdaptiVolt™ systems, both the SDCC and Core units are PLC based and they communicate with each other via a local area network (LAN).

Polling of LVMs using the standard communication architecture occurs on a 5 to 15 second basis. Architectural modifications allow longer acceptable communication signal latencies. Filtering and other algorithms allow adjustment of the substation bus voltage to maintain proper delivery voltages without undue wear on the regulator or LTC contacts. Normal operation on tap changers with a correctly tuned system will be in the range of 10 to 15 operations per day.

The architecture of this new distribution automation technology lends itself well to integration into a SCADA system for remote operation capabilities. On its native PLC platform, it can operate as an IED connected to an existing substation RTU. This is how the system is used at Avista Utilities. It can act as an RTU such as it does at Clatskanie PUD. It can act as a stand-alone system as it does at Inland Power. The architecture and algorithms can be migrated to other intelligent programmable substation automation platforms.

The system provides distribution system visibility to SCADA systems and it provides information that can be used for engineering, planning and operational use. The speed with which distribution system voltage can be changed is dependent only upon the speed of the SCADA communications system and the physical characteristics of the LTCs and/or regulators. Thus the system provides both dispatchable demand control[i] and a tool for responding to system emergencies.

2.1. Inland Power and Light Company

The Inland Halfmoon Substation is located in a rural area north of Spokane, Washington. It feeds rural load, suburban load and a small amount of light commercial load. Figure 1 shows the general configuration of the system. There is a single transformer with four distribution feeders. The bus is regulated by three (3) single phase voltage regulators. Two of the feeders have banks of three (3) single phase mid-line voltage regulators at approximately the midpoint of the feeder. LVMs are installed at the end of each feeder and LRCCIs are installed at each mid-line voltage regulator. The communications protocol is DNP 3.0. Fiber optics are used between the SDCC and the station regulators. The LRCCIs communicate with the mid-line regulator controls via fiber-optics. Communications between the station and the LRCCIS and the LVMs is via VHF radio. The SDCC and the Core communicate via a DF1 LAN. Each feeder power monitor communicates with the Core via a remote I/O LAN.

Fifteen minute interval data is archived to the central Master Control Console (MCC) at PCS UtiliData's offices for data publication and evaluation. Communications are via dial up line and a cell phone installed in the substation.

Inland Power financed the project using the Bonneville Power Administration (BPA) Conservation Augmentation (ConAug) program. The ConAug program is designed to allow BPA to purchase kWh of energy reduction. Therefore measurement and verification of the system results are required by BPA.

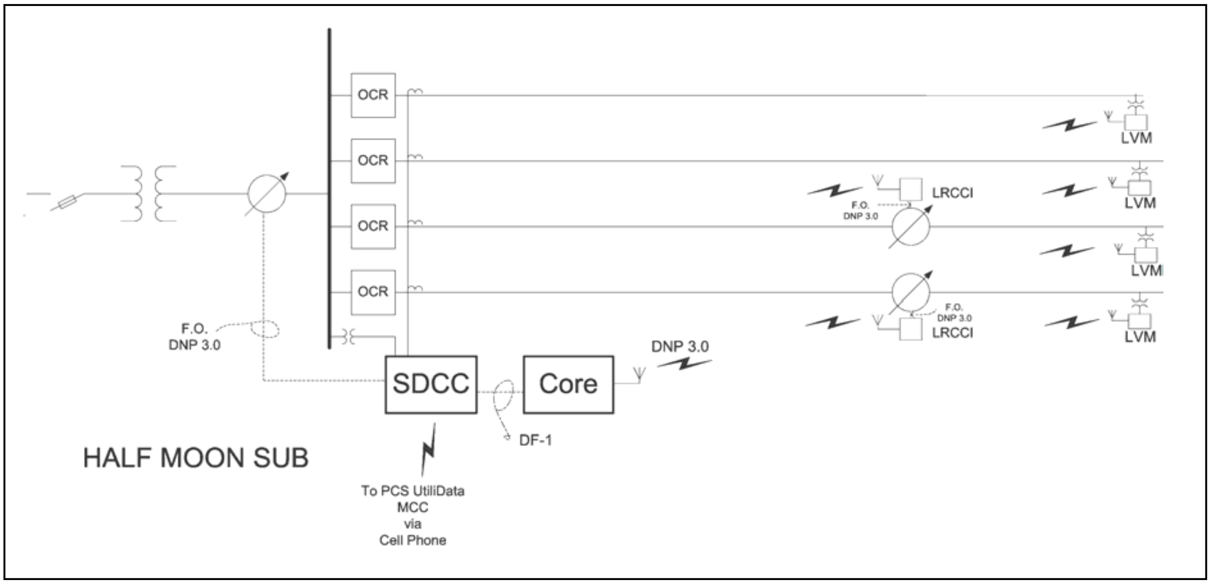

Figure 1 - Halfmoon Adaptive Voltage Control Simplified Architecture

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[i] Dispatchable Demand Control is demand control that can be dispatched by the utility system operator and can provide demand reduction within 10 minutes of the dispatch order.

2.2. Clatskanie PUD Systems

At Clatskanie there are three substations with six (6) feeders, as shown in Figure 2. Each feeder has it own bank of three (3) single phase regulators. LVMs are installed at the ends of each feeder. There is one mid-line voltage regulator. Communications with the LVMs and the one LRCCI is via DNP 3.0 over UHF radio links.

Clatskanie had an existing SCADA system. The SDCC units were part of the SCADA system prior to installing the remaining components of the Adaptive Voltage Control system.

On one Clatskanie substation feeder, a single phase LVM unit is located on a different branch of the feeder than the the LVM that monitors voltage on the other two phases. The data from the LVM is communicated to Delena sub then to Clatskanie sub via the SCADA system communications links.

Data is archived on the SCADA Master then sent to the MCC for data publication and evaluation via daily email.

The three systems at Clatskanie were installed as a BPA/Regional Technology Forum (RTF) demonstration project.

2.3. Avista Utilities System

The Avista Utilities (Avista) Francis and Cedar substation has single phase regulators on each feeder. There are two main differences between this deployment and the earlier deployments. The substation is located in an urban area so the feeders are much more heavily loaded. For example, the peak load at Halfmoon is approximately 10 MW. The total peak for the three Clatskanie substations is approximately 10 MW. At Francis and Cedar the peak load on each feeder is approximately 10 MW. An additional difference is that a PC is installed in the substation to collect system performance data. This is due to the security requirement that no outside lines be connected to the station.

The system at Avista is being installed as part of the Northwest Energy Efficiency Alliance's (The Alliance) "Distribution System Efficiency Initiative."

3. Requirements for Deployment

To date, no additional distribution regulation equipment or capacitors have been added to any of the deployments of the AdaptiVolt™ systems. Both Inland and Clatskanie upgraded existing regulator controls to allow for DNP 3.0 communication capability even though the systems could have operated with the older style regulator controls. At Avista no changes are planned to any equipment, nor will any regulation equipment be added to the system.

Initial deployment of the system requires a survey of voltages at the end of the feeders and at critical loads. If radios are selected as the means of communications, a communications survey is needed to assure a strong communication system. With this information the system can be installed to control substation regulators, LTCs, mid-line regulators and switched capacitors.

4. Operational History

4.1. Inland Power and Light

As the first deployment of this technology, the Inland system began operations in April 2002. Initial operation was delayed by the assignment of a radio frequency that was already in use at a neighboring water utility. Additionally a minor redesign of the LRCCI units was required to allow the radio modems used on the project to handle the DNP 3.0 messaging from the Cooper CL-5 regulator controls on the mid-line regulators.

When the system began operating, an analysis was done to determine what if any if any changes should be made to optimize energy conservation using data the system was collecting. The data showed that lightly loaded Feeder 4, which feeds preponderantly rural loads, had a continuous leading power factor. At that time, a 50 kVAR fixed capacitor bank was located on Feeder 4. Feeder 2b (that portion of Feeder 2 down-stream from the mid-line regulator) also had a 50 kVAR fixed capacitor bank installed. The mid-line regulator on Feeder 2 was always operating well above the low end steps. Analysis also showed that end-of-line voltages for Feeder 1a and Feeder 3 were almost always the critical voltages that controlled the system. Based on this data, PCS UtiliData recommended that Inland consider moving the 50 kVAR capacitor banks from Feeder 4 to near the end-of-line on Feeder 3 and moving the 50 kVAR capacitor from Feeder 2b to Feeder 1a near the mid-line regulator.

Inland decided to wait until the end of the first year of BPA performance testing to make the recommended modifications. At the end of one year of testing the results showed that the conservation being obtained was less that what had been contracted for between Inland and BPA. At that time the two parties agreed to allow the testing to run for another year after Inland made the recommended capacitor bank moves. Inland also lowered the end-of-line voltage set-point to 116.5 volts from its initial very conservative set-point of 117.5 volts.

4.2. Clatskanie PUD

The three Clatskanie systems began operation during February 2003. The radio communications system was redesigned based on the experience at Inland.

Three operational issues have been encountered at Clatskanie. The first issue encountered was when one of the Siemens MJXL controllers was replaced. The firmware in the replacement MJXL had a newer version as shipped from the factory. The new firmware did not have the same DNP 3.0 addressing and was not compatible with system communications as installed. This issue was solved with appropriate version control measures. The second and third issues had to do with invalid kWh and kVARh values being read from the Cooper Form 6 controllers. There were two underlying causes, the first being that the utility did not connect the metering potential transformers to the Form 6 controls and instead were using “phantom” phase voltages. This was corrected by connecting the potential transformers. The second Form 6 issue (remaining at the time of this writing) is the 32-bit kWh values being read from the Form 6 controllers seem to have and extra bit set in the low order word.

Fortunately these issues have not prevented the system from operating nor have they prevented data collection that shows the results of system operation. BPA metering is available at each of the three substations. Using this data, energy conservation results have been determined for each station. When the remaining issue with the Form 6 kWh data is resolved, energy conservation analysis by feeder will be possible.

4.3. Avista Utilities

The Avista system is scheduled for commissioning and initial operation in January 2004. At of the time of this writing, final factory acceptance testing of the system is underway.

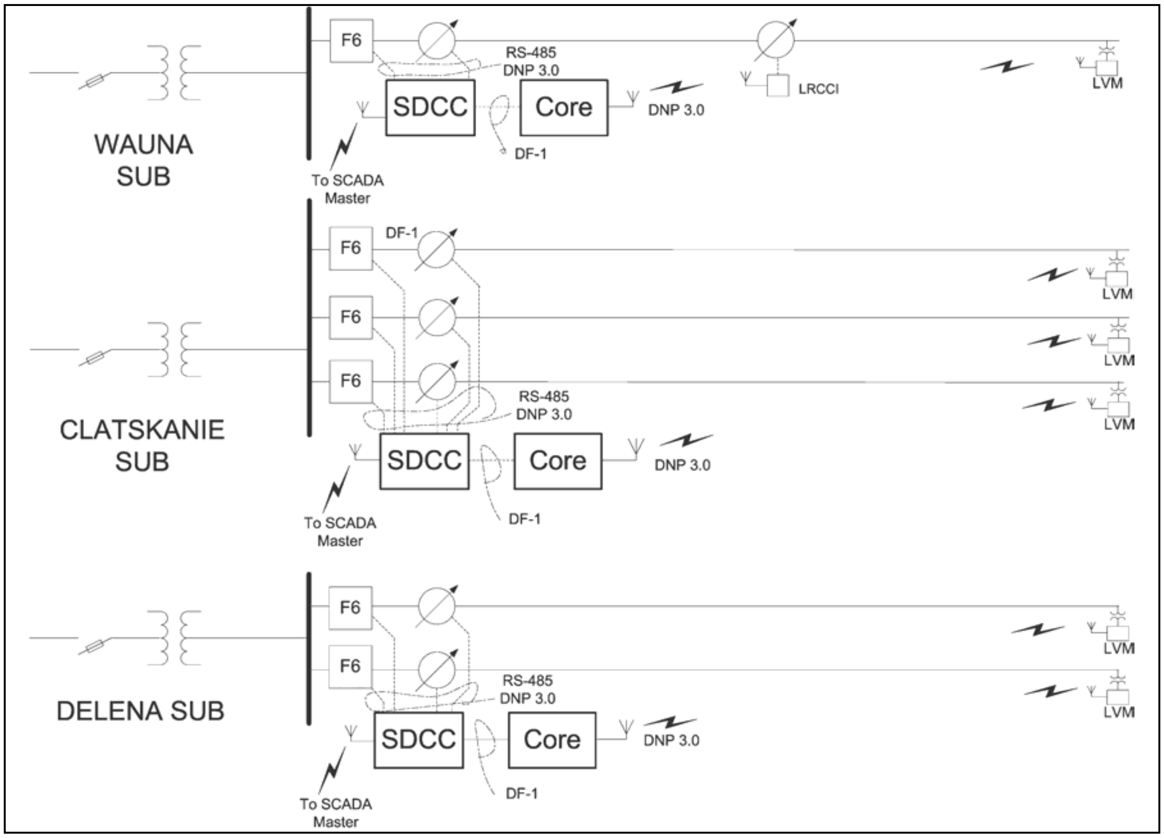

Figure 2 - Clatskanie Adaptive Voltage Control Simplified Architecture

5. Test Design

Testing of these first systems is critical to determine their effectiveness in energy conservation and demand control.

Because of the intelligent capabilities of the systems, they were set up to turn themselves on and off on alternating days. In other words, on one day the system would control the end-of-line voltages to the set point. The next day the system would only monitor and record voltages and load data. At both Clatskanie and Avista the test period is scheduled for one year of alternating day on/off operation. At Inland the alternating day testing is run in one month periods. Testing is scheduled to be finished by Feburary 2004. The months that the testing is not being performed the system is left on to control end-of-line voltages to allow maximum energy conservation to occur.

At Inland and Clatskanie, 15 minute interval data is recorded. At Avista, both 15 minute interval data and 15 second interval data will be recorded. The 15 second data is being recorded to allow a better understanding of the distribution system's response to tap changes.

Temperature data is available from the National Weather Service from Deer Park, Washington for use with the data from Inland. The Clatskanie SCADA system has a weather station connected to it. Temperature data from the weather station is recorded along with the load and voltage data. At Avista an RTD temperature sensor is being installed at the substation as part of the system.

5.1. Collected Data

The following minimum data is collected, and used for analysis:

- Per phase regulator or LTC output voltage per phase from the system regulators, LTCs, LCCIs or feeder power monitors.
- Per regulator or LTC step-position from the system regulators, LTCs or LCCIs.
- Per phase feeder end-of-line voltage from the system LVMs or LCCIs.
- Per feeder period kWh total or per phase from the feeder power monitors or LCCIs.
- Per feeder period kVARh total or per phase from the feeder power monitors or LCCIs.
- System on/off information from the system.
- System time from the system.
- Period average temperature from the system or from a local weather station.

Additional data such as phase current, power factor, etc. is also available but not required for analysis of energy conservation, demand control and reactive power requirements.

6. Evaluation Methods

The evaluation methods used on the data has evolved over time since data was first available from the Halfmoon substation. Methods used began as simple visual inspections of initial available data comparing daily total energy use with Adaptive Voltage Control "on" with daily total energy use with Adaptive Voltage Control "off". Classical Gaussian statistical methods such as evaluation of the means of energy use for "On Days" and "Off Days" and simple regression methods were used.

Key points in the evaluation methods were to compare demand on a uniform basis by operation on alternate days and exposure to the same environment. Also evaluation methods were to take advantage of prior knowledge of the demand processes and the resulting signals, such as daily periodicity, the known utilization device efficiency vs. voltage and customer demand behavior. Finally the results were to be applied only within bounds of observations.

6.1. Time Series Analysis

After study of the available methods, Time Series Analysis[1] with temperature compensation was chosen to compare and evaluate energy use with Adaptive Voltage Control "on" and "off." Unlike the analyses of random observation samples that are analyzed with most other statistical methods, Time Series Analysis is based on the assumption that successive values of data observations represent consecutive measurements taken at equally spaced time intervals. The use of Time Series Analysis is especially suited to evaluation of these systems because of the repeated daily, weekly and seasonal patterns of load cycles.

6.2. Temperature Compensation

A linear dependence of energy on temperature has been assumed for these evaluations. The temperature component is used to estimate load profiles for the 'typical' temperature profile. Daily hourly temperatures are arranged in ensembles. An ensemble contains the temperature data from the same hour for all days under consideration. The temperature profile for the 'average' day is computed from the ensemble of hourly temperature data. The values for temperature dependence of the loads were regressed by linear least squares. (Linear dependence of energy use on temperature has been used extensively in the past in well known energy conservation evaluation methods[2]. An example is in PRISM®[i].)

6.3. Robust Statistical Methods[3]

The initial system evaluation efforts used conventional least squares regression analyses. Most previous studies of energy conservation data have used these methods. The use of least squares regression methods for model parameter estimation from experimental data can only be properly justified if the experimental data meet these specific criteria:

- The probability density of the stochastic process component in the experimental observations is Gaussian;
- The data exhibit homogeneous variance over the range of observations (the data are homoscedastic);
- The number of observations is large enough to establish the validity of the first two statements.

The load profile data that PCS UtiliData has collected to date do not satisfy any of these criteria:

- The probability density, as estimated by discrete histograms, is bimodal and heavy-tailed, and almost certainly will fail standard tests for Gaussianity;
- The magnitude of 'scatter' around some estimated regression line (e.g. for a temperature abscissa) clearly varies over the range of observations (the data are heteroscedastic);
- In analyses to date the data sets for any selected regression are small, so that the effect of outliers is exaggerated.

These systems' data are clearly candidates for robust regression[ii] procedures, because:

- No generating density is assumed, so estimates of location and scale ('mean' and 'variance' in the Gaussian world) are density independent,
- Large data sets are not needed to establish a particular density;
- Heteroscedasticity does not affect the estimate of the regression line, because scale is not measured by variance, but rather by location-free distance measures,

Inland Power & Light Halfmoon Substation

Estimated 30-day savings for Halfmoon Sub	109770	kWh
Estimated mean CVR factor, demand weighted by feeder	1.09	%E / %v

	Estimated CVR Factors		Expected Load Profile Results			Peak Demand Reduction		
Halfmoon Feeder	per Volt (%E / V)	per %Volt (%E / %V)	AVC On kWh/day	AVC Off kWh/day	δE (Off-On) kWh/day	DVRf	Demand Reduced kW	% Demand Reduced
1a	0.81	0.98	20389	20759	369	1.32	26.00	2.25%
2a	1.55	1.90	6362	6587	225	5.69	33.00	9.01%
3	1.51	1.84	36982	38331	1349	2.32	76.00	3.80%
4	1.14	1.39	10172	10477	305	0.96	8.00	1.55%
1b	0.40	0.50	20640	21011	371	0.57	20.00	1.88%
2b	0.46	0.57	41337	42377	1040	1.17	120	5.26%
Totals	0.894	1.094	135882	139542	3659	1.610	283.00	3.84%

Table 1 – Halfmoon December/November 2002 Results

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[i] PRinceton Scorekeeping Method, a commercial software package, developed by Princeton University and available for sale at http://www.princeton.edu/%7Emarean/

[ii] The same PRISM document referred to in endnote 2 also suggests that robust measures will provide better evaluation of energy conservation.

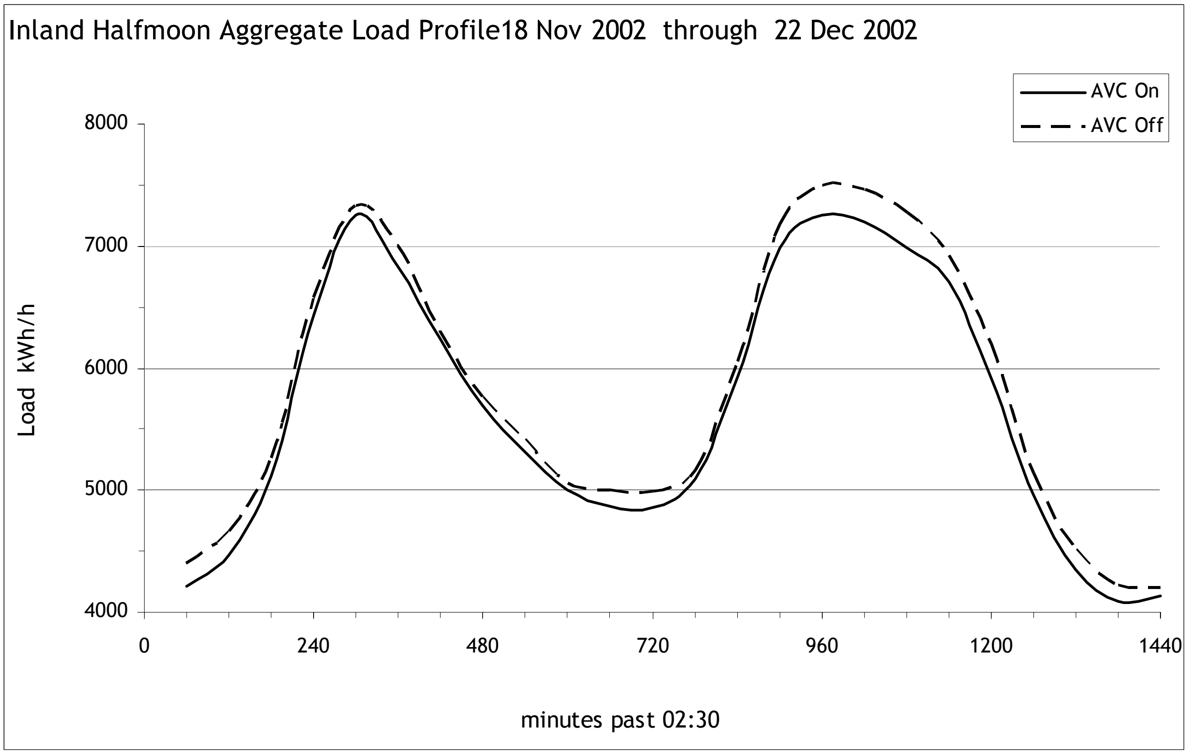

Figure 3 - Halfmoon Nov/Dec 2002 Demand Profiles

- Large data sets are not needed to establish variance-based confidence measures; therefore large data sets are not required.

7. General Discussion of Results

Results to date at the four substations where this technology has been operational show significant energy conservation, peak demand reduction and reduction of reactive power requirements with an associated power factor improvement

7.1. Energy Reduction Results

Conservation Voltage Regulation/Reduction (CVR) is the operation of a distribution system so that the customers' utilization voltages are at the lowest level consistent with proper operation of equipment, within nameplate ratings of utilization equipment, and within levels set by regulatory agencies and standards setting organizations[i] with the objective of reducing energy usage. A measure of effectiveness of CVR is the Conservation Voltage Reduction factor (CVR_f). A simple equation is $CVR_f = \%$ energy saved ÷ % voltage reduced, within the allowable service voltage ranges and over an extended time. CVR_f will vary depending upon several factors: type of customer, loads served, climate, geographical service area and others[ii].

	May and September 2003	
	% Energy Conserved	
Feeder	Week Day	Week End
1a	5.30%	2.86%
2a	5.70%	5.40%
3	3.76%	3.36%
4	4.20%	5.34%
1b	6.70%	1.97%
2b	6.15%	4.35%
Note: Feeder 1b and 2b are the sections of Feeders 1 and 2 beyond the mid line		

Table 2 - Halfmoon May/September 2003 results

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[i] ANSI C84.1 - 1995

[ii] Almost all discussion and estimations make the assumption that in a small range of voltage change CVR_f is linear or near linear. PCS UtiliData's evaluations make the same assumption.

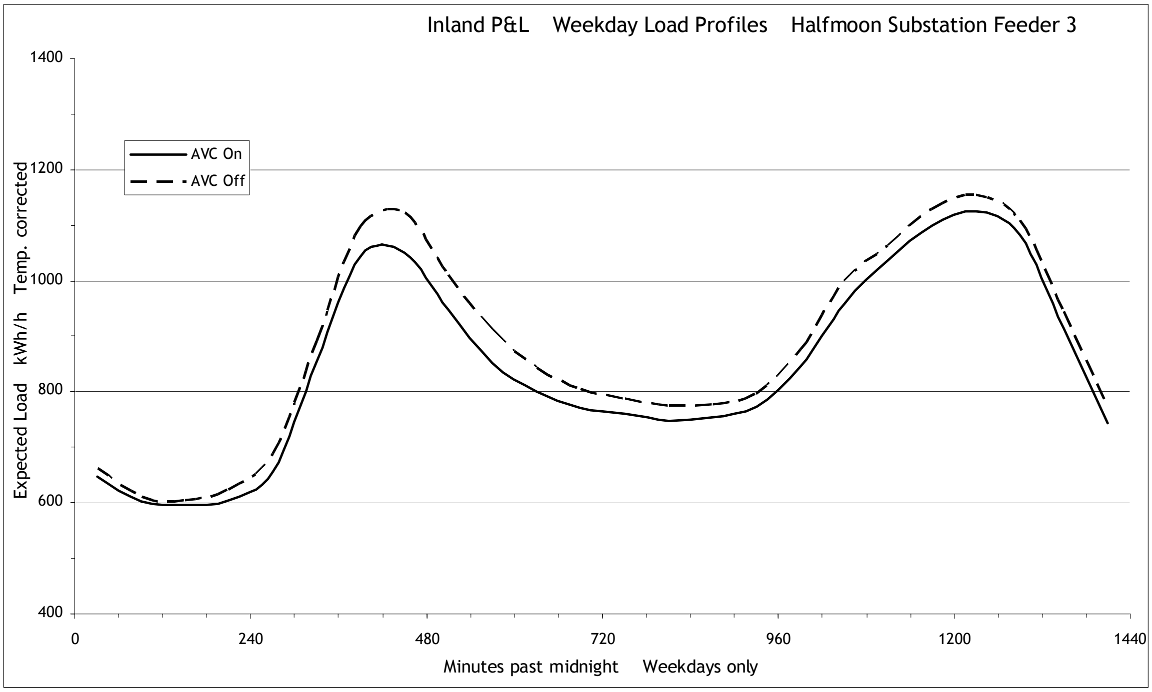

Figure 4 - Halfmoon Feeder 3 May/September 2003 Demand Profiles

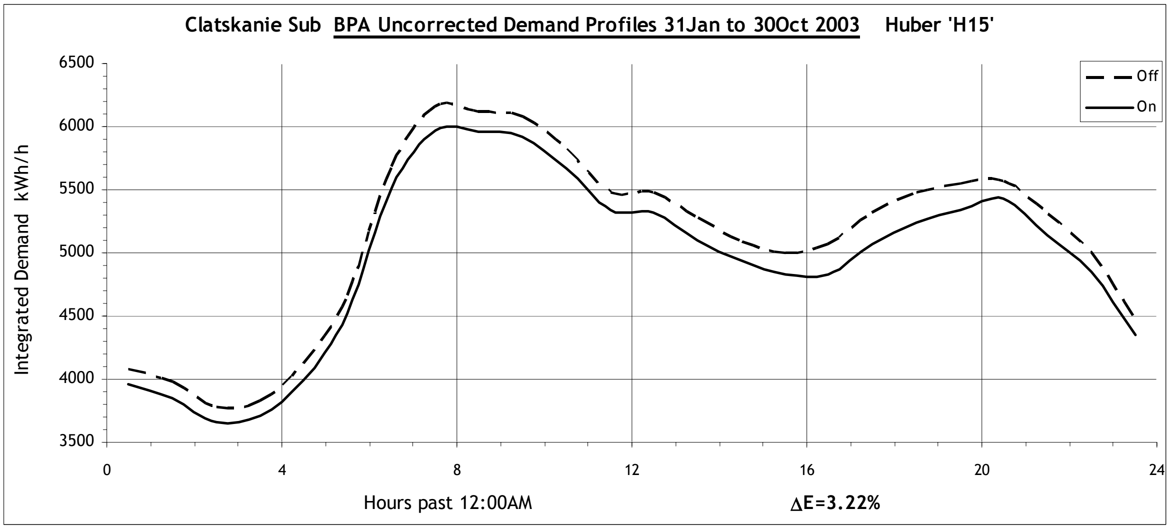

Figure 5 - Robust Demand Profiles for Clatskanie Substation

Various papers indicate theoretical CVR_f ranging from 0.4 for industrial customers all the way to 2.5.[4,5]

Table 1 shows the results for the November/December 2002 Halfmoon tests. Figure 3 shows the November/December 2002 demand profiles. Table 2 shows the Halfmoon May and September 2003 energy conservation results.

Figure 4 shows the Halfmoon Feeder 3 May and September 2003 average profiles.[i,ii]

Figure 5 shows the Robust average demand profiles for Clatskanie substation. The energy savings

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[i] All other feeders show similar results.

[ii] .May and September test data was evaluated together because the weather and number of daylight hours is very similar in the region.

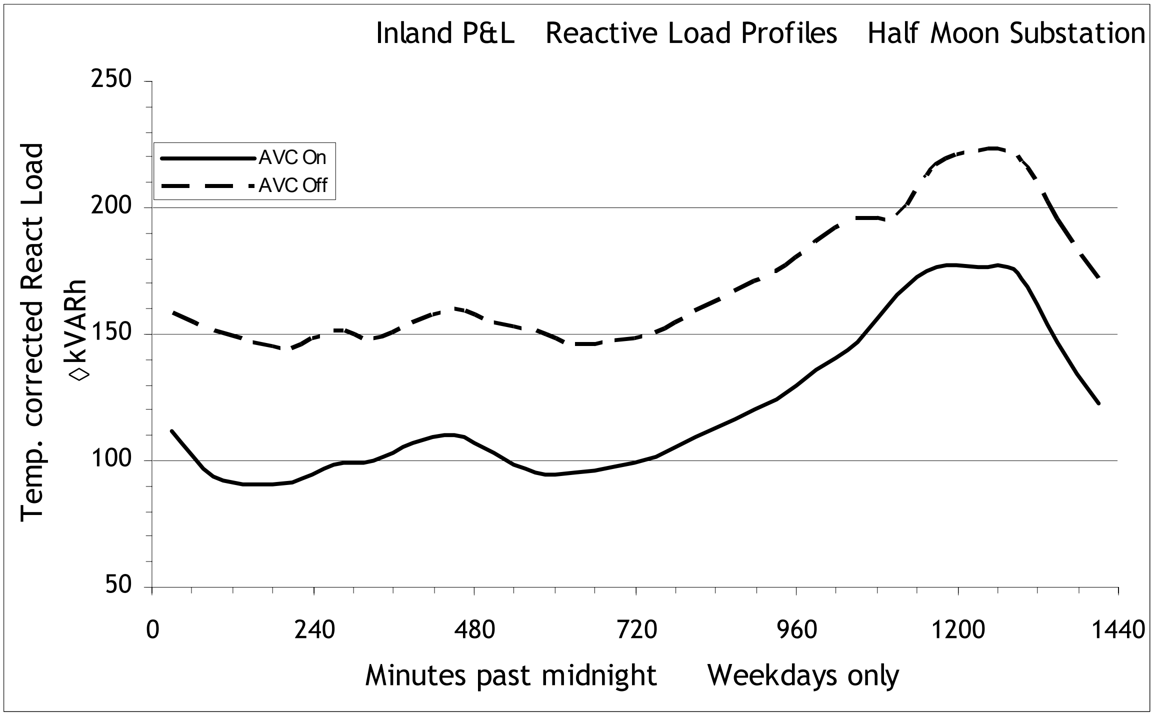

Figure 6 - Half Moon Reactive Load Profile May, Sep 2003

with the system is 3.22% on the total Clatskanie substation load.

7.2. Peak Demand Reduction Results

Peak demand reduction results have also been significant. Inspection of the Inland November/December 2002 profile in Figure 3 shows the difference in peak demand with Adaptive Voltage Control on and with it off during the testing period. The BPA coincident peak demand reduction at Halfmoon was 3.8% during this period. The peak could have been further reduced adding peak shaving algorithms in the SDCC or by dispatching lower end-of-line set point voltages from a utilities operations center via SCADA control or an energy management system during the peak period.

Demand Side Management (DSM) actions to reduce load with Adaptive Voltage Control are dispatchable within seconds. Using AdaptiVolt™ technology as a DSM tool reduces energy by all customers on a substation without turning off customer loads and forcing them to change their living patterns.

7.3. Reactive Power Results

The results also show a significant reduction in reactive power requirements when voltage is lowered. The graph in Figure 6 shows the reactive load profiles on Halfmoon Feeder 3 with Adaptive Voltage Control "on" and "off". The net effect of the voltage reduction on Feeder 3 was a reduction of 50 kVAR on average.

7.4. Economic Results

The economics of applying Adaptive Voltage Control varies depending upon the utility, the density and types of the loads served, the way the utility operates the system and the cost of energy. Economic value that can be measured accrues from energy conservation, demand reduction and reactive power requirement reduction with power factor improvement. Less tangible savings are the improvement of system visibility to the utility, the ability to improve operations and maintenance activities and the value of the data collected. The reduced energy consumed also reduces generation requirements. Along with associated reduction in greenhouse gasses and other environmental impacts, the utility may be able to reduce energy purchase needs, delay generation installation, or sell energy into the market at advantageous times.

Table 3 shows the estimated costs, savings and other economic benefits for three distinctly

***UtiliData*® AdaptiVolt™ Estimated Benefits Comparison Matrix**

	US Naval Station - Pacific Northwest	Electric Cooperative - Rural/Suburban Substation	Investor Owned Utility - Urban Substation
Number of Feeders	10	4	6
Annual Energy Usage	51.0 GWH	38.2 GWH	205.0 GWH
Annual Utility Bill/Value	$ 3,093,043		
Total Installed Cost	$525,789	$328,917	$418,037
CVRf	0.95	1.00	1.00
Energy Savings in kwh	1,694,736 kwh	1,591,667 kwh	8,541,667 kwh
Energy Savings in MBTU	5784 mbtu	5432 mbtu	29152 mbtu
Average Energy Rate	$ 0.0491	$ 0.0350	$ 0.0350
	$ 0.0372	$ 0.0262	$ 0.0062
Energy Saving $	$83,212	$55,708	$298,958
Average Monthly Demand	11609 kw	7928 kw	46803 kw
Demand Reduction	827 kw	879 kw	5187 kw
Average Demand Cost per peak kw	$ 2.77	$ 2.00	$ 1.50
Demand Reduction $	$27,489	$21,096	$93,366
Municipal Tax Savings	$4,982	$0	$0
Annual O&M less non energy benefits	($22,675)	($16,466)	($20,902)
Mbtu/$1,000 Invested	11.00	16.52	69.74
Total Annual Savings	$93,019	$60,358	$392,324
Net Present Value	$ 634,656	$ 533,638	$ 4,839,993
Payback Period	5.9	6.8	1.6
Internal Rate of Return	14%	16%	160%

Table 3 – Economic Comparison Matrix

different types of applications of Adaptive Voltage Control.

7.5. Customer and Employee Response

Reports of customer response to the operation of the systems installed at Inland and Clatskanie are primarily anecdotal.

In Inland's service area, a ham radio operator noticed that during certain periods of the year that the performance of his system varied on alternating days. Noticing the voltage differences on alternating days, he contacted Inland and was told of the testing.

Also at Inland a customer noticed that when his heat pump started, his computer UPS alarm would go off. This had not happened before even though there had always been a noticeable dip or "flicker" when the heat pump had started. Review by Inland engineers showed that the heat pump had been installed without an appropriate upgrade on the customer service equipment. Also, the starting capacitors on the heat pump motor had failed at some time in the past. The utility upgraded the service and the customer repaired the starting capacitors.

The author's wife was chatting one day with the wife of a former Inland director who lives on Feeder 2. When the director's wife was asked if she realized that PCS UtiliData had installed a new system on the substation that was serving her house, she responded that she had noticed that there had been, "a noticeable reduction in voltage dips in the last several months." The author's brother-in-law also lives on Feeder 2b. When told about the system he said that he had noticed no difference in the electric service. The Demand Side Resource Manager of Avista lives on Inland Feeder 1b. When told of the Adaptive Voltage Control system he said that he had not noticed the reduced voltage levels. He was later instrumental in obtaining approval to do the Avista project.

At Clatskanie a building inspector was doing a pre-sale inspection when he noted that the voltage in the house was between 114 and 115 volts. When the utility was contacted they explained the testing for energy conservation and the required voltage standards. The owner of an electronic repair shop contacted the utility when he noticed the different voltage levels on alternating days wondering if there was a problem with the system.

Becoming used to the standard voltages lower than 120 volts has been has been one of the main challenges for technical employees at Inland according to their engineers. At Clatskanie, the operations employees used the added visibility provided by the LVMs to help them improve service to the customers. They also used the system's regulators' remote control capabilities during switching operations.

8. Conclusions and Future Directions

Experience at the stations where Adaptive Voltage Control has been deployed leads us to the conclusion that most of the benefit of CVR can be attained upon initial deployment of the system. The need for reconductoring, additional regulators, capacitors and load balancing can then be determined by studying actual operating data that the system provides.

Observation of the test data indicates that CVR_f tends to be higher on suburban residential and commercial loads[i]. Clatskanie substation, which has two sawmills, has a CVR_f that is as high as what is seen at Halfmoon, which has no industrial load. This leads to the conclusion that there is benefit in controlling voltage for industrial loads.

Finally, the data shows that the heavier loaded a feeder is, the generally better the results are for CVR_f, energy conserved and demand reduced. This leads to the conclusion that heavily loaded urban feeders should show good results with adaptive voltage control. The results from the upcoming Avista Utilities deployment should confirm this.

The reduction of reactive power requirements with reduced voltage is significant for several reasons. By reducing voltage the need for capacitors on the system is apparently reduced. This provides the benefits of energy conservation and kVAR improvement. Additionally, when capacitors are installed, they tend to raise voltages. This tends to increase energy usage and, apparently also with it, the need for kVAR support. This indicates that kVAR control should be carefully coordinated with voltage control. The author believes that it also indicates that voltage control should not be the main reason for capacitor installation and that capacitors should be used only to supply kVARs.

The Adaptive Voltage Control systems installed at Inland, Clatskanie and at Avista are a unique application of distribution system automation technology combined with process and manufacturing industry control techniques. The system controls voltage well and allows operation of distribution systems at lower average voltages while assuring no "low voltage" situations for customers. Adaptive Voltage Control provides a powerful new tool for demand side management, conservation, peak demand control, kVAR control and emergency voltage control.

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[i] The higher CVR_f on suburban residential and commercial loads was expected based on earlier studies referred to in the references.

Biographies

Tom Wilson (M' 1972, SM' 1985) is a native of Spokane, Washington. After serving in the US Navy as an Electricians Mate, he earned his BSEE from Washington State University in 1971. While working as a Substation Operations Engineer at Pacific Gas and Electric Company, he attended the University of Santa Clara studying MSEE courses. In 1982 he earned his MBA from Gonzaga University. He worked as an Electrical Engineer for Kaiser Aluminum and Chemical Corporation and as an Industrial Control Application Engineer for Reliance Electric. He is the founder and president of PCS UtiliData, a Spokane, Washington based control system integration firm specializing in substation and utility automation solutions.

He serves on the Western Power Delivery Automation Conference Program Committee (WPDAC) sponsored by Washington State University and also is on the Western Energy Institute (WEI) Service Company Committee.

Wilson has been active in the IEEE serving with the Spokane Section in several offices including Section Chair and IAS Chair. During his tenure as IAS Chapter Chair the Spokane Chapter was awarded the Outstanding Small Joint Chapter Award by the IAS.

David Bell (M' 1992) earned the BSEE (Summa Cum Laude) from Lehigh University in 1980. He has wide experience in instrumentation and control systems in photochemical processing, glass and fiber optics, and electrochemistry. He is presently working on closed loop voltage controller stability and robust performance analysis for electric utility distribution, and cumulant-based system identification in aluminum electrochemistry. He holds two US patents in applied signal processing.

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[1] Wiener, N., "Extrapolation, Interpolation, and Smoothing of Stationary Time Series", Wiley, 1949