

DEMAND SIDE MANAGEMENT AND ENERGY CONSERVATION USING DISTRIBUTION AUTOMATION TECHNOLOGIES

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Introduction

The unique marriage of evolving utility distribution automation technology with control techniques used in process and manufacturing industries found in the UtiliData® AdaptiVolt™ technology brings to the electric utility industry a unique and powerful tool to control voltage, demand, shave peaks, reduce reactive power requirements and implement CVR to conserve energy. “Real-time” voltage feedback and closed loop control allows voltage and reactive power to be managed by the utility as they require without fear of customers experiencing unacceptably low or high voltages.

AdaptiVolt™ has been deployed at four substations in the Pacific Northwest for over a year. The first installation went operational in April, 2002 at Inland Power and Light Company’s Half Moon Substation. Three more went operational at Clatskanie People’s Utility District’s Clatskanie, Delena and Wauna substation in November, 2002. At the Half Moon substation data showed that moving two capacitor banks would improve the ability to reduce overall average voltage. This was done with a further improvement in performance. As of the writing of this paper a fifth is being deployed at Avista Utility’s Francis and Cedar Substation in Spokane, Washington as part of the Northwest Energy Efficiency Alliance “Distribution Efficiency Initiative”.

Testing of the systems has been ongoing and the collected data shows significant energy conservation results, demand reduction and power factor improvement. There have been no low voltage complaints. Future applications are being considered some of the largest utilities in the world and at military bases and at industrial facilities.

AdaptiVolt™ Overview and Architecture

Historically CVR has been implemented using two different strategies. The first method is Line Drop Compensation (LDC) and the second is Voltage Spread Reduction (VSR). Most utilities use a combination of these two strategies when they implement CVR. This usually requires enhancements to the distribution lines such as load balancing, reconductoring, and addition of capacitors. Utility engineers tend to be conservative and the LDC settings or voltage bandwidth settings on distribution LTCs or regulators are often made very conservatively to assure that the end of the line voltage never droops below a preset value. In addition, daily changes in temperature, day-of-the-week, etc. can lead to load changes that reduce the effectiveness of CVR settings. Annual review of circuit load, models and settings is required to maintain effective “legacy” CVR.

In fact, in many utilities the distribution LTC or regulator controls are set so that the nearest customer never has voltages above 126 volts and the end of line voltage droops and rises as loads vary. The reasons for this are many. Lack of engineering resources to perform the required studies or prepare the distribution line models design the line upgrades are often a major reason.

Another is the lack of capital resources or the inability to justify the capital and expenses needed to upgrade distribution.

AdaptiVolt™ was developed as a direct response to the West Coast energy crisis in late 2000 and early 2001. PCS UtiliData had been applying PLC systems in substation and distribution automation and SCADA systems for several years. After attending regional energy conservation forums and interviewing a retired CEO of a Pacific Northwest IOU, we decided to see if we could apply our then current technology to help with energy conservation. Our research indicated that we could add industrial process control to our distribution automation designs and provide an automated conservation voltage reduction system. (After consideration we felt that the concept was unique so we initiated a patent search and based on the results of the search a patent application was submitted.)

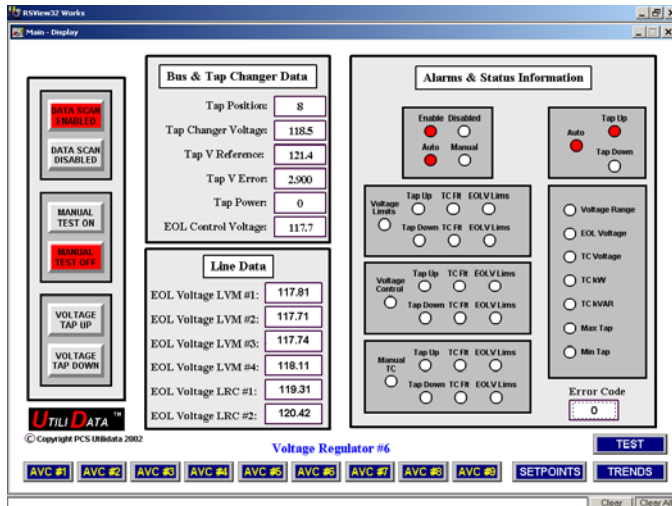


Figure 1 - AdaptiVolt™ Operational Screen

In a typical AdaptiVolt™ deployment no additional distribution regulation equipment is normally required if there are existing station regulators or on-load tap changers. If there are existing mid-line regulators or switched capacitors they are also put under control of the system. The main components are the Substation Data Collector and Controller (SDCC), the Adaptivolt™ Core (Core), the Line Voltage Monitors (LVM). Additional components may include Line Regulator Controllers (LRC) and additional LVMs. If data collection and monitoring is required a substation PC, Master Control Console (MCC) or SCADA Master may

be included.

A voltage survey is first performed and end-of-line and critical load sensing locations are determined. With this information AdaptiVolt™ can be installed to control substation

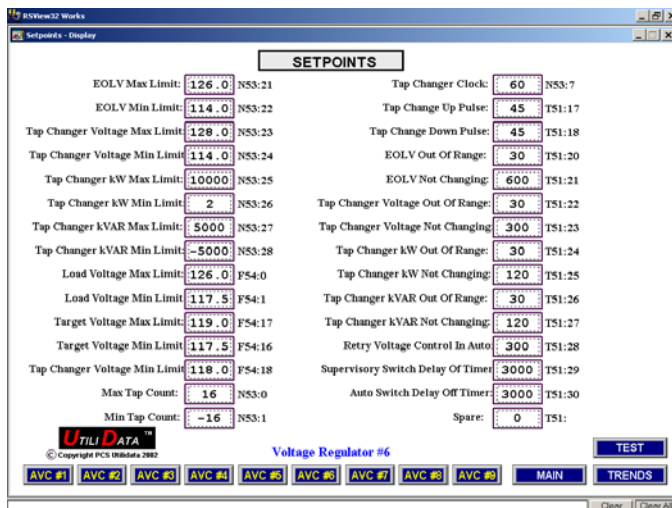


Figure 2 - AdaptiVolt™ Set Point Screen

regulators, on-load tap changers, mid-line regulators and switched capacitors. Experience at the stations where AdaptiVolt™ has been deployed shows that at least 80% of the benefit of voltage control can be attained upon the initial installation of AdaptiVolt™. The need for recondoring, additional regulators, capacitors and load balancing can then be easily determined by studying actual operating data that AdaptiVolt™ provides.

The SDCC monitors the feeder kWh, kvarh, kW, kvar, current and voltage. It stores interval data for collection by a master. The master, while not strictly

necessary, is used to store historical data on system performance and can be used to change set points and monitor system operation.

The AdaptiVolt™ algorithms run in the AdaptiVolt™ unit. The unit communicates with the LVMs, the LRCs and line switched capacitors via DNP3.0 or Modbus. Currently both the SDCC and the Core units are PLC based and they communicate with each other via a local area network (LAN).

Figure 2 shows the general configuration at the Half Moon substation. 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 LRCs are installed at each line voltage regulator. Communications protocol is DNP3.0. Fiber Optics is used between the AdaptiVolt™ and the station regulators. The LRCs communicate with the mid-line regulators via fiber. Communications between the station and the LRCs and the LVMs is via VHF radio. Fifteen minute interval data is archived to the central MCC for data publication and evaluation via dial up line and a cell phone installed in the substation.

At Clatskanie PUD there are three substations with six (6) feeders as shown in Figure 3. Each feeder has its 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 LRC is via DNP3.0 over UHF radio link. Clatskanie PUD has a SCADA system and existing SDCC units. Data is archived on the SCADA Master then sent to the MCC for data publication and evaluation via daily email.

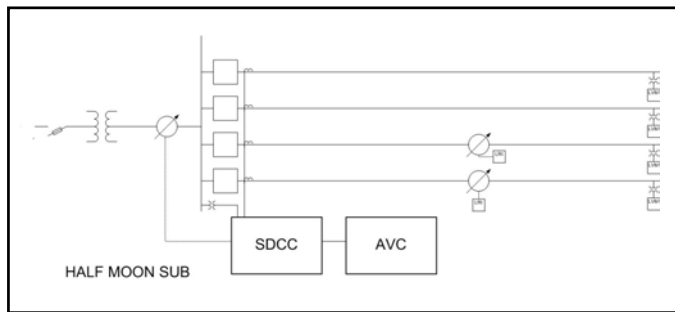


Figure 3 - Half Moon Substation

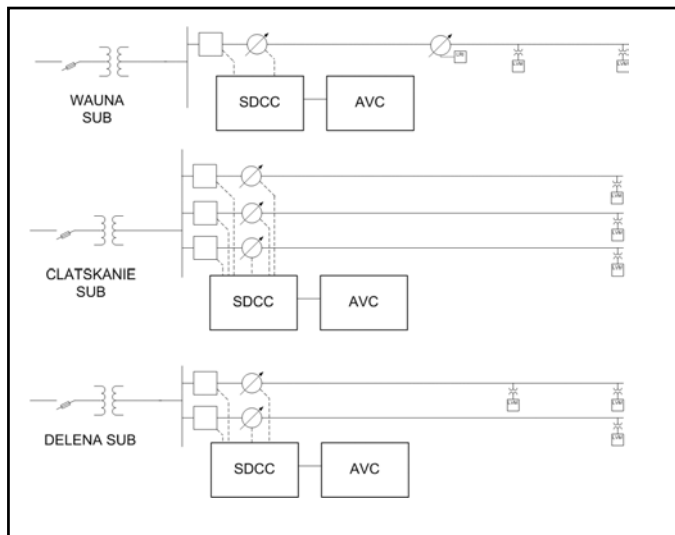


Figure 4 - Clatskanie PUD Substations

The Avista Utilities Francis and Cedar substation has single phase regulators in 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 Half Moon is approximately 10 Mw. The total peak for the three Clatskanie PUD 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.

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 correctly tuned AdaptiVolt™ will be in the range of 10 to 15 operations per day.

Initial deployment requires a survey of voltages at the end of the feeders and at critical loads. It also requires a communications survey to assure a strong communication system if radios are the selected means of communications. Other means of communications such as a wide area network, LAN for a localized system, broad band systems, power line carrier and other communications systems can be used. Multiple LVMs can be installed on each feeder to allow for feeder reconfiguration. This all leads to the benefit that feeder load growth can occur and be extensive periodic load profile studies are not required.

The architecture of the system and the distribution automation technologies used lend 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 such as it is at Avista Utilities or it can act as an RTU such as it is at Clatskanie PUD. It can also act as a stand-alone system as it is at Inland Power. The architecture and algorithms can be migrated to other intelligent programmable substation automation platforms.

The system provides greater 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 regulators. This provides both “dispatchable” demand control and the potential for using management of distribution voltage levels as a tool for responding to system emergencies.

Modes of Operation

The three main modes of AdaptiVolt™ operation are Conservation Voltage Regulation Mode, Demand Control Mode, and Emergency Mode. The operating results obtained with each mode are different and the reasons for operating in the different modes vary from utility to utility. Modes can be selected from the utility’s central dispatch center to meet current operating requirements.

Conservation Voltage Regulation/Reduction (CVR) is the operation of a distribution system so that the customers’ utilization voltages is 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 with the objective of reducing energy usage.

While CVR has been implemented by some electric utilities over the past 25 to 30 years it has not come into widespread acceptance. Some of the reasons for this are skepticism among engineers that reducing voltage conserves energy and a lack of understanding of the effect of voltage reduction on utilization equipment, reluctance of utilities to reduce revenue, difficulty in implementing CVR using “legacy” technologies and the annual costs of maintaining “legacy” technology CVR. Perhaps the biggest reason is the concern that customers will experience unacceptably low voltages. In March, 2002 the California Public Utility Commission rejected

the proposal to reduce voltage as a measure to help meet the energy crisis citing low voltage risks as a major factor in the decision. AdaptiVolt™ uses end-of-line voltage feedback as the control variable and assures no low voltage at the end of lines.

In CVR mode the utility keeps voltages at controlled low levels to conserve energy 24 hours a day. A measure of effectiveness of CVR is the Conservation Voltage Reduction factor (CVR_f). A simple equation for CVR_f = % energy saved ÷ % voltage reduced within the allowable service voltage ranges and over time. CVR_f will vary depending upon several factors, type of customer, loads served, climate, geographical service area and others. Various papers indicate theoretical CVR_f ranging from 0.4 for industrial customers all the way to 2.5. Actual testing with AdaptiVolt™ at Inland Power and at Clatskanie PUD shows actual CVR_f from .5 to 1.9 using measured test data. Energy savings have ranged from 3.7% to 7% on different feeders based on the voltage reduced and CVR_f.

Demand Control is the operation of AdaptiVolt™ by the utility system to reduce load for a short period. It can be used as a Demand Side Management (DSM) tool by utilities. It can also be used to reduce demand for short periods either to meet system resource shortages or for “peak shaving” to avoid demand penalties, reduce peak demand charges or to avoid demand ratchets. AdaptiVolt™ based Demand Control can be dispatched from a utilities operations center via SCADA control or energy management software. Demand control and peak shaving algorithms can also reside directly in the substation AdaptiVolt™ and can operate independently.

DSM actions to reduce load with AdaptiVolt™ are dispatchable within seconds the only limit being the latency of the communication system and physical design of on load tap changers and regulators. Using AdaptiVolt™ as a DSM tool reduces energy by all customers on a substation without turning off customer loads and forcing them changing their living patterns.

Using AdaptiVolt™ Emergency Mode voltage can be raised or lowered in time of emergency. Voltage can be lowered to ANSI “B” range in time of energy supply or system stability crisis (110v at service point) within seconds. Emergency Mode can be used to lower voltages to help restore service after outages. It can be used to raise voltages to aid during system stability crisis when there is too much generation in an area after transmission line losses or to help customers recover heat inertia after winter peak shaving occurrences.

Applications and Results

Results to date at the four substations where AdaptiVolt™ has been operational for over a year are highly encouraging showing significant energy conservation, peak demand reduction and power factor improvement. At Inland Power Bonneville Power Administration (BPA) financed a portion of the project under their Conservation Augmentation Program. At Clatskanie PUD BPA approved the project for financing under their Conservation and Renewable Discount (C&RD) program. The Pacific Northwest Regional Technology Forum (RTF) has classified the project at Clatskanie PUD as a Demonstration Project.

At Inland Power tests were run for one month periods during different seasons of the year. During the test periods the system was turned on for one day and then was off for one day. Originally the test period was to have run for one year, however BPA has extended the test period for an additional year to obtain more data. During the rest of the time the system was left on so that BPA would receive the benefit of the energy conservation. At Clatskanie the system test consists of one full year of one day on and one day off operation.

Demand Side Management and Energy Conservation Using Distribution Automation Technologies

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Some results from the Inland tests are shown in the following tables and charts at the Half Moon substation. The tests show a clear reduction in energy consumption, Kwh, a clear reduction in peak demand, Kw, and an unanticipated but not unexpected reduction in reactive power requirements, Kvar by the system with AdaptiVolt™ operational.

Result	Interpretation
1.013	CVRf: $\% \Delta \text{energy} / \Delta V$
1.237	CVRf: $\% \Delta \text{energy} / \% \Delta V$
5.23	Mean ΔV Volts RMS
1377.69	Total ΔE kWh/day

Table 1 - Half Moon Fdr #1 May, Sept 2003

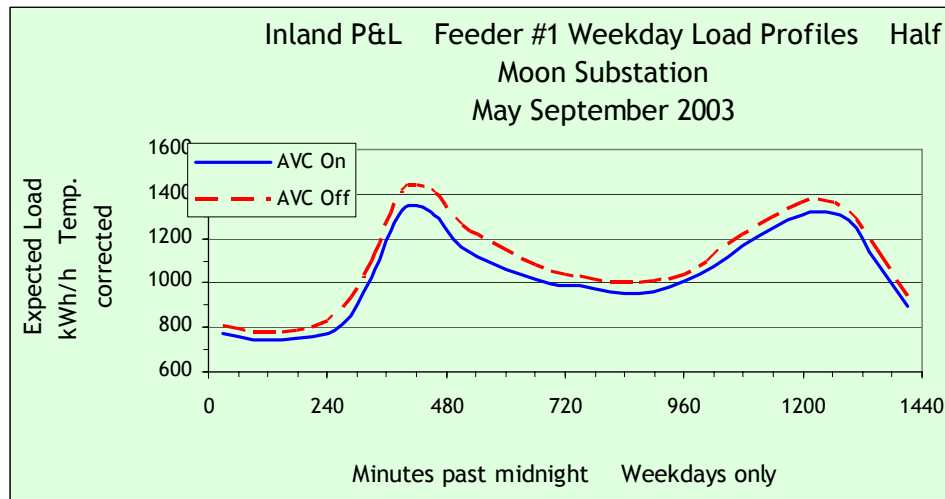


Figure 5 - Half Moon Fdr #1 May, Sept 2003

Feeder	May and September 2003	
	% Energy Conserved	
	Week Day	Week End
1	5.30%	2.86%
2	5.70%	5.40%
3	3.76%	3.36%
4	4.20%	5.34%
5	6.70%	1.97%
6	6.15%	4.35%

Note: Feeder 5 and 6 are the sections of Feeders 1 and 2 beyond the mid line regulators.

Table 2 - Half Moon Energy Conservation Results

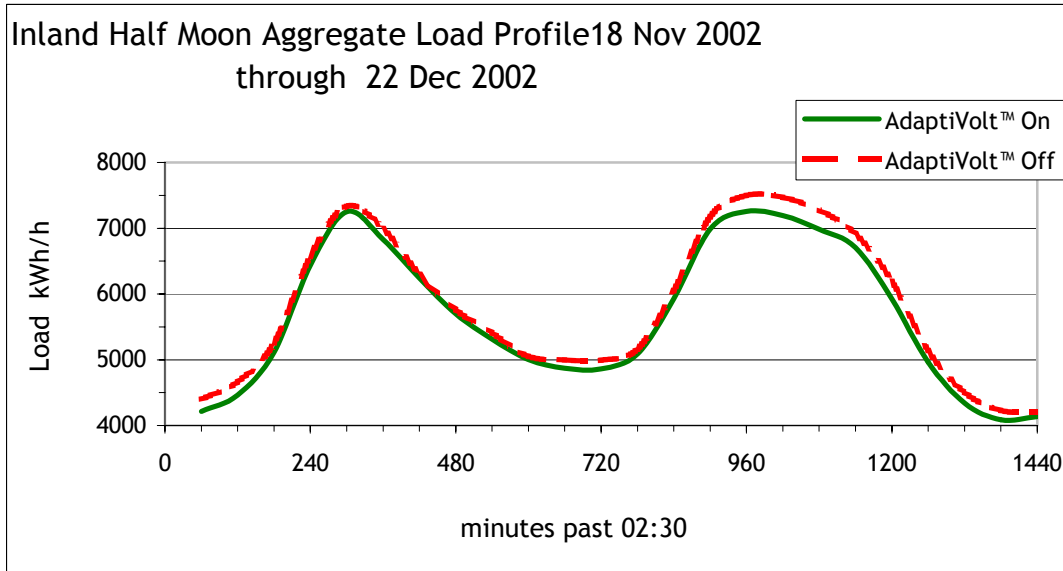


Figure 6 - Half Moon Aggregate Load Profile, Nov/Dec 2002

Performance Summary Worksheet			Reporting Period					
UtiliData® AdaptiVolt™			18 Nov 2002 through 22 Dec 2002					
Inland Power & Light Half Moon Substation								
Estimated 30-day savings for Half Moon Sub			109770 kWh					
Estimated mean CVR factor, demand weighted by feeder			1.09 %E / %V					
Half Moon Feeder	Estimated CVR Factors		Expected Load Profile Results			Peak Demand Reduction		
	per Volt (%E / V)	per %Volt (%E / %V)	AdaptiVolt™ On kWh/day	AdaptiVolt™ Off kWh/day	ΔE (Off-On) kWh/day	DVRf	Peak Demand	% Demand Reduced
1	0.81	0.98	20389	20759	369	1.32	26.00	2.25%
2	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%
5	0.40	0.50	20640	21011	371	0.57	20.00	1.88%
6	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 3 - Half Moon Nov/Dec 2002 Results Summary

The following graph and table show results from the first six months at Clatskanie substation. Of a metering problem which has since been corrected only the total station Kwh was available from BPA metering.

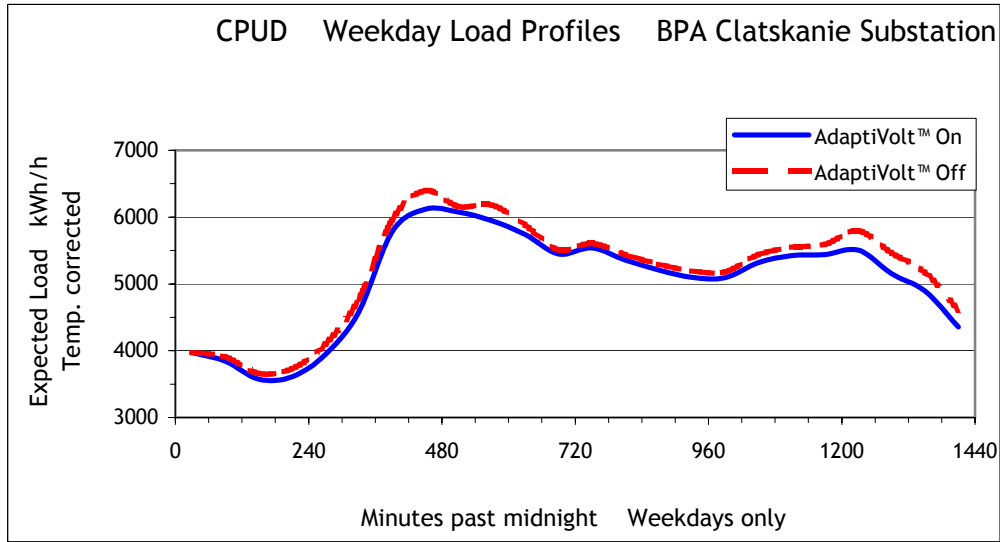


Figure 7 - Clatskanie Sub Load Profile

Result	Interpretation
0.649	CVR: $\% \Delta \text{energy} / \Delta V$
0.781	CVR: $\% \Delta \text{energy} / \% \Delta V$
4.39	Mean ΔV Volts RMS
3545.36	Total ΔE kWh/day

Table 4 - Clatskanie Substation Results Summary

Way ahead

The deployment and effective use of Automated Energy Conservation Systems in the years to come will be based on numerous factors. Among these are the intrinsic requirements for accountability, operational streamlining, guaranteed customer support, sound power supply options, a reliable and technologically advanced grid, flawless regional coordination and planning, and regulatory certainty or direction. Allotted monies, social pressures and the quest for the establishment of a modern power distribution system that best serves the public will continue drive new ideas, methods and technologies that can be brought to bear. Whether the chosen solutions are basic Line drop Compensation, Voltage Spread Reduction, a combination of both methods, smart capacitor control solutions or AdaptiVoltTM; the important point is that one must fully understand the functionalities newly acquired when procuring or embarking on such projects. The author believes that the functionality attained with AdaptiVoltTM by far exceeds expectations, as evidenced by results obtained through continuous operational use at various distribution substations. It is quite obvious that a smart capacitor control solutions will not provide energy savings compared to AdaptiVoltTM and the other more traditional methods. The use of AdaptiVoltTM is proposed to optimize energy conservation and meet the aforementioned factors, while supporting reactive power solutions and increasing overall system stability.

Lessons Learned

As with most distribution automation technology deployments communications issues are key to reliability and success. Communications flexibility built in to AdaptiVolt™ is key to the success of this technology. The current deployments of AdaptiVolt™ use licensed radio to communicate from remote LVMs and LRCs to the AdaptiVolt™ units in the substations. The terrain at Clatskanie provided some interesting challenges and unique solutions. On one feeder the end of line voltage is sent through the Delena substation and then piggybacks on the SCADA communication system to get to the Clatskanie substation AdaptiVolt™ unit.

In evaluating the performance with regard to energy conservation, demand control and efficacy several different statistical methods were initially used. After much research a time-series statistical method was settled upon that seems to be somewhat unique in evaluation of distribution system conservation and demand control. The method has been favorably reviewed by independent academic experts in the field. The method takes into account the physical nature of the system and the social factors which affect load and load cycles and periodicity and appears to provide correct models.

We also found that temperature plays a very large role in load and demand levels. We have found that by keeping track of temperatures as well as interval data on the feeders we are able to use regression analysis to correct or compensate for temperatures and weather dependency. As a result we have designed temperature data collection capability on all AdaptiVolt™ deployments.

Testing has turned up two unanticipated results. The first is that we believe that we are seeing energy conservation effects for space heating. We did not expect this because space heating is a process type load. Nevertheless we are seeing data that would indicate that CVR has a positive impact on space heating loads.

Additionally we are seeing a significant reduction in reactive load when voltage is lowered. The graph in Figure 8 shows the reactive load profiles on Half Moon Feeder #3 with AdaptiVolt™ on and AdaptiVolt™ off. Table 5 shows the summary of the reactive load results. This 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 var 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 var support. This indicates that var control should be carefully coordinated with voltage control. Also the author believes that it indicates that voltage control should not be the main reason for capacitor installation and that capacitors should be used mainly for vars.

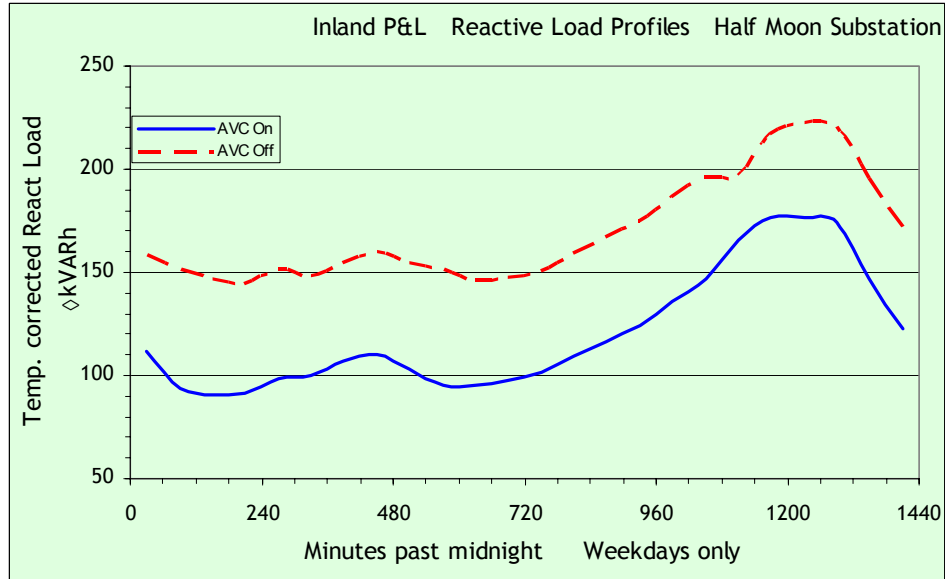


Figure 2 - Half Moon Reactive Load Profile May, Sep 2003

Result	Interpretation
5.33	Mean ΔV Volts RMS
0.706	CVR _f : % Δ energy / ΔV
0.865	CVR _f : % Δ energy / % ΔV
780.88	Total ΔE kWh/day
5.472	RVR: % Δ VARh / ΔV
6.702	RVR: % Δ VARh / % ΔV
0.990	PF AVC On P / S
0.981	PF AVC Off P / S

Table 5 - Half Moon Reactive Load Results May, Sep 2002

Another observation of the test data indicates that CVR_f tends to be higher on suburban residential and commercial loads. This was to be expected. We also see that at Clatskanie substation that has two sawmills has CVR_f that are as good as what we are seeing at Half Moon which has no industrial load. This leads us to believe 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 both CVR_f, energy conserved and demand reduced. This leads us to believe that heavily loaded urban feeders should show good results with AdaptiVolt™. We believe that the results from the upcoming Avista Utilities AdaptiVolt™ deployment will confirm this.

Conclusion

UtiliData® AdaptiVolt™™ is a unique application of distribution system automation technology combined with process and manufacturing industry control techniques. It controls voltage well and allows operation of distribution systems at lower average voltages while assuring no “low

voltage” situations for customers. It provides a powerful new tool for demand side management, conservation, peak demand control, var control and emergency voltage control.

Glossary

AdaptiVolt™ - AdaptiVolt™™ or AdaptiVolt™ler
CVR - Conservation Voltage Regulation/Reduction (CVR)
CVR_f - Conservation Voltage Reduction Factor
DH-485 – An open protocol
LVM - Line Voltage Monitor
IED – Intelligent Electronic Device
OIT - Operator Interface Terminal
PLC – Programmable Logic Controller
PC – Personal Computer
RTU – Remote Terminal Unit
SDCC – Substation Data Collector and Controller
TCP/IP – Transmission Control Protocol/Internet Protocol

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