Ameren Illinois

Conservation Voltage Reduction Pilot Project

ICC Docket 10-0568

November 1, 2013

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Introduction

On December 21, 2010, the Illinois Commerce Commission ordered Ameren Illinois, in docket 10-0568, to conduct a pilot Voltage Optimization project to determine the benefits of wider adoption of Ameren Illinois' Voltage Optimization program.

The Illinois Commerce Commission order suggested that the pilot project was to be instituted on a heavily loaded feeder that was able to support a significant reduction in voltage in order to maximize the cost-effectiveness of the pilot project. The commission further suggested that Ameren Illinois design a number of tests using industry best practices that can be used to ensure the demand response capabilities of the pilot project will actually work.

Background

Conservation Voltage Reduction (CVR) is a reduction of voltage along a distribution feeder for the purpose of reducing electric power demand and energy. By reducing the voltage along the feeder a few percentage points, but keeping the delivery voltage in the acceptable range of 114-126 volts (Figure 1), demand and energy are reduced while still providing adequate voltage for customer usage. In addition, losses in lines and transformers are slightly reduced under the lower-voltage condition.

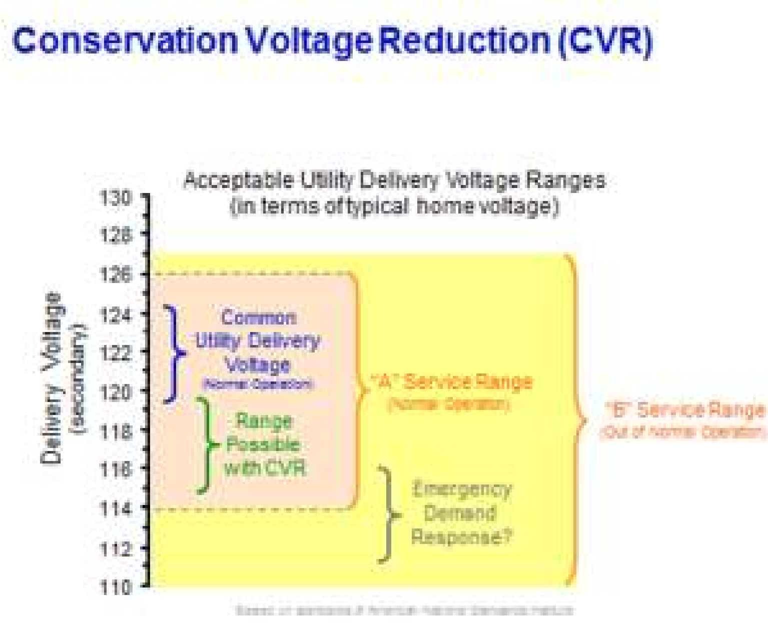


Figure 1

CVR Primer

The CVR concept involves modification of the load-tap-changing transformer (LTC) or distribution circuit voltage regulators' mid-band set points to manage voltage levels within an acceptable range over the whole circuit in order to reduce line losses, reduce peak demand, and reduce customer energy consumption. The concept of CVR is illustrated in Figure 2 below, showing the voltage drop along a conceptual distribution line. Distribution circuit voltage generally declines as the distance from the substation increases because current flowing in the line causes losses. Some of the current provides energy to the loads, but some of the current is only magnetizing current, predominantly for motors and transformers. Magnetizing current carries no net energy. In fact, it can be provided by passive capacitors placed along the distribution circuit, reducing the amount of magnetizing current that has to be supplied from the substation. Reducing magnetizing current from the substation reduces losses, and actually frees capacity in the lines for delivery of load energy. However, reducing losses, especially from reducing magnetizing current, reduces the voltage drop all along the line. With properly-sized capacitors in place, the voltage at the LTC can be reduced slightly, reducing the average delivery voltage along the line. The voltage reduction is not uniform, and is usually greatest near the substation, as the voltage closer to the end of the line was already near the bottom of the standard delivery range.

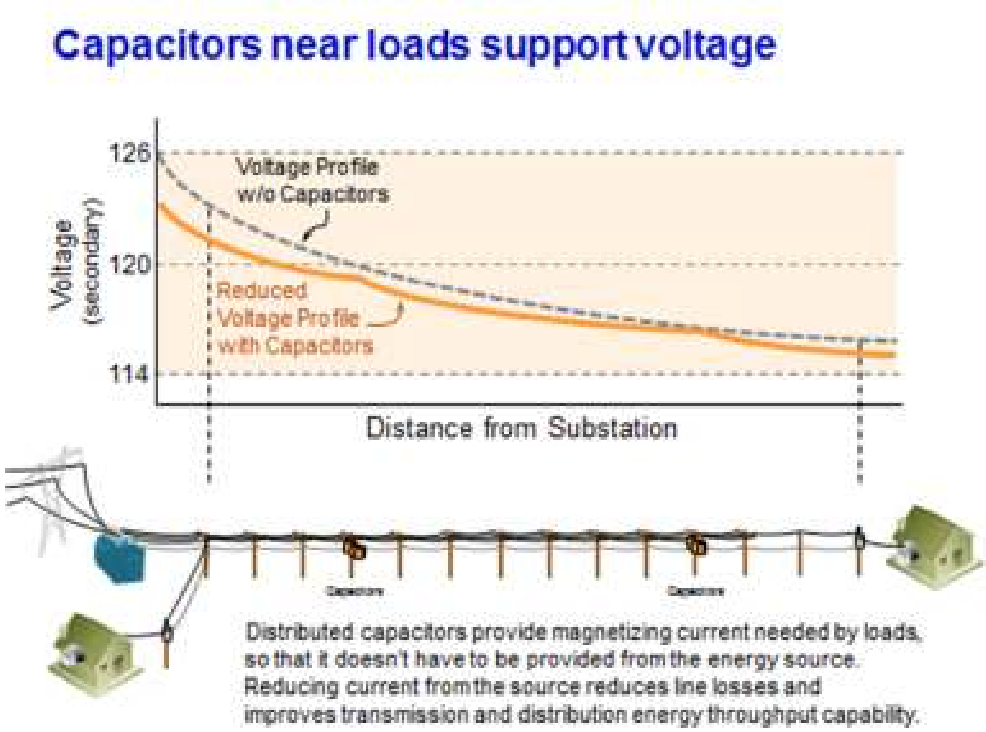


Figure 2

Test Circuit Characteristics

In order to meet the guidelines that the Illinois Commerce Commission established for this CVR pilot project, Ameren Illinois chose to implement the CVR project in two substations that involved different circuit configurations (Urban and Rural/Urban)

The University substation in Peoria, Illinois, represented urban distribution design which includes a 69/13.2 kV LTC transformer rated at 20 MVA. This substation serves three distribution circuits with a total connected customer count of 4,011 customers, or a customer density of 125 customers per mile. The University distribution circuits cover 31.2 miles of line and utilize fixed and switched capacitor banks, and 13 voltage sensing locations that were deployed as a part of this project. No voltage regulators are deployed on this circuit. The system characteristics and circuit configurations are depicted in Table 1 & Figure 3 below.

Base characteristics	**Circuit 1**	**Circuit 3**	**Circuit 4**
System Voltage	69 kV/13.2 kV	69 kV/13.2 kV	69 kV/13.2 kV
Residential	91%	96%	92%
Circuit Miles	11.6	8.3	11.3
Average Customer Density	103 Customers/mile	147 Customers/mile	135 Customers/mile
Substation Control	LTC	LTC	LTC
Switched Capacitor Banks	1	1	1
Fixed Capacitor Banks	1	1	2
End of line Voltage Monitors	4	4	5

Table 1 – University Substation Circuit Characteristics

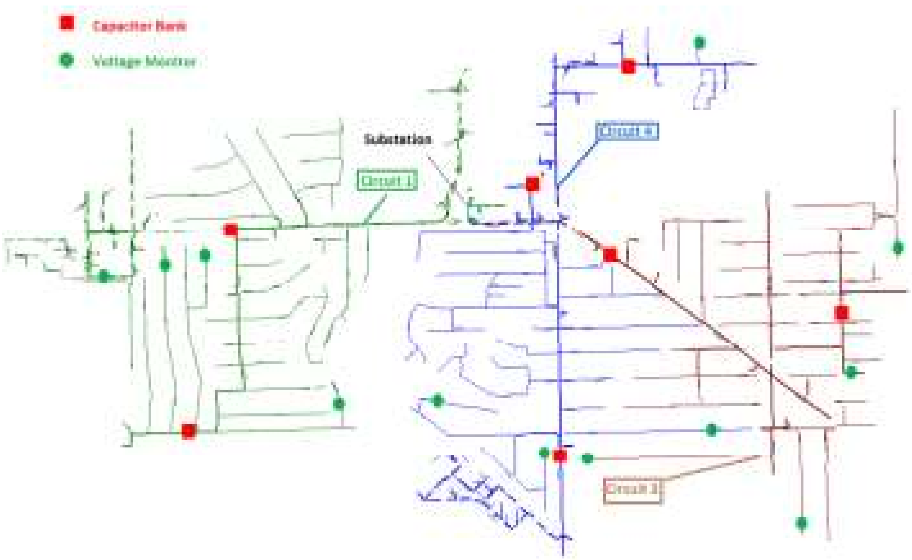


Figure 3 – University Substation and Circuit - Urban Configuration

The Mt. Zion Rt. 121 substation represented the rural/urban distribution design which includes a 138/13.09kV transformer rated at 22MVA. The transformer serves 2 distribution circuits. The CVR project test circuit covers 100.8 miles of line connecting with 1,659 customers, a customer density of 16 customers per mile. The circuit utilizes fixed and switched capacitor banks, 6 sets of voltage regulators and 6 voltage-sensing locations that were deployed as a part of this project. The system characteristics and circuit configurations are depicted in Table 2 & Figure 4 below.

Base characteristics	**Circuit 173**
System Voltage	69kV/13.09kV
Residential	92%
Circuit Miles	100.8
Average Customer Density	16 Customers/mile
Substation Control	Voltage Regulator
Switched Capacitor Banks	3
Fixed Capacitor Banks	2
End of line Voltage Monitors	6

Table 2 – Mt. Zion Substation Circuit Characteristics

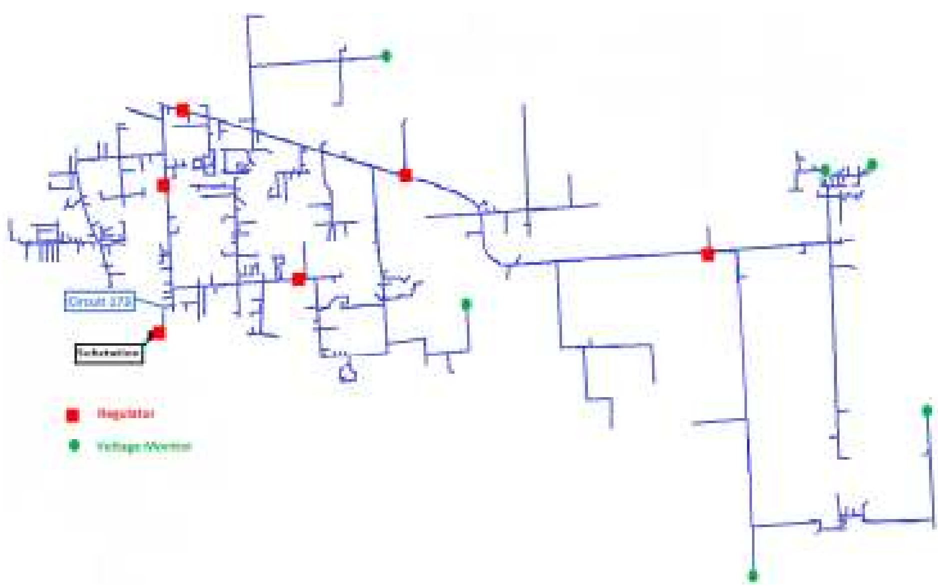


Figure 4 – Mt. Zion Substation and Circuit Rural/Urban configuration

Methodology

The CVR project implementation included the installation of new voltage regulator controllers with two-way radio communications, installation of voltage sensors at end of-line locations, modifications to the LTC controller at the University substation, to provide remote control capabilities, and implementation of automatic voltage control using Ameren's new Advanced Distribution Management System (ADMS) system.

The Urban test (University Substation) involved three circuits and included varying the mid-band set point on the load-tap-changing transformer (LTC) for 24-hour periods at voltage reduction levels of 0% (normal), 2% and 4% voltage reductions.

The Rural/Urban test (Mt. Zion Substation) involved one circuit and included modification to all voltage regulator mid-band set points (six sets), including the substation feeder regulator, for 24-hour periods at levels of 0% (normal) 2% and 4% voltage reductions.

Data was collected at the test circuits' feeder heads as well as the feeder heads for the comparable circuits via Ameren Illinois new SCADA system.

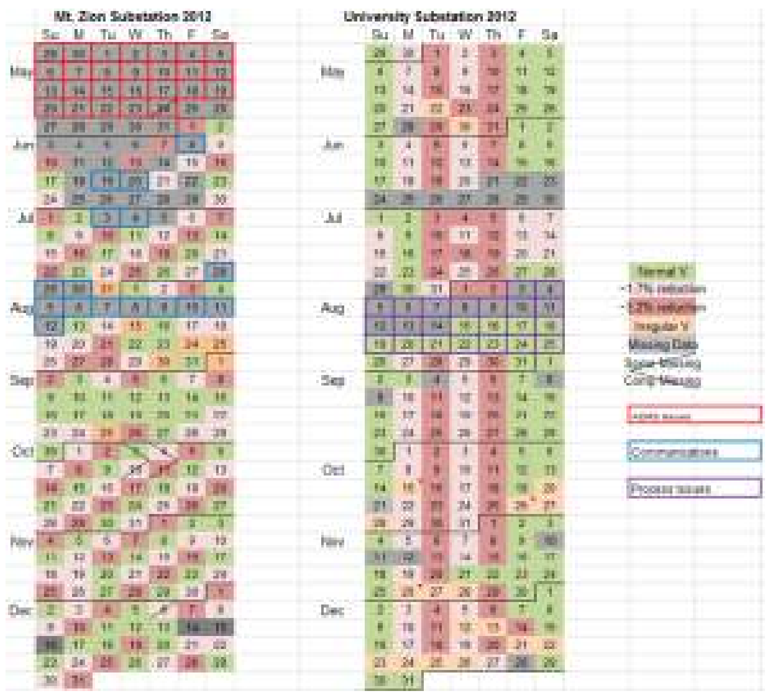
To provide an analysis platform for comparison of test data from the test circuits, Ameren Illinois identified "comparable" distribution circuits whose loading characteristics were similar to the test circuits. The distribution substation that was chosen for comparison to the University substation (Urban design) was Hines transformer #1. The distribution circuit that was chosen for comparison to Mt. Zion circuit 173 (Rural/Urban design) was circuit 174, fed from the same substation transformer.

Testing began on April 30, 2012 and concluded on July 31, 2013. The test procedure included varying the LTC or Voltage Regulator mid-band set points once every 24 hours. Switched capacitor bank switching was allowed to occur based on the time and temperature settings that had previously existed on both test locations. From April 30, 2012 till January 7, 2013, manual mid-band voltage changes to the LTC at the University substation were deployed due to the lack of remote control capabilities between the substation and the Distribution Dispatch Organization (2% voltage reduction was implemented on Monday and Wednesday, 4% voltage reduction was implemented on Tuesday and Thursday, and 0% voltage reduction was implemented on Friday through Sunday). From January 7, 2013 through July 31, 2013, the ADMS system modified the mid-band voltage setting for each day of the week, on the University substation LTC. On the Mt. Zion test circuit, mid-band voltage changes were performed on all Voltage Regulators (six sets), including the substation feeder regulator, for 24 hour periods at levels of 0% CVR, 2% CVR and 4% CVR. These mid-band voltage changes were performed utilizing the ADMS system from April 30, 2012 through July 31, 2013. Mid-band voltage modifications for both test locations were conducted between 9:00am and 9:30am.

During the CVR testing, voltage sensors were used to ensure that sufficient voltage was provided to Ameren Illinois' customers. These voltage sensors provided cellular paging notification whenever the voltage dropped to alarm limits. The alarm points that were utilized for these experiments were 119 volts, 118 volts and 117 volts as sensed from the secondary side of distribution transformers located at predicted voltage low points across the test circuitry. On seven different days the voltage sensors provided low voltage alarm notification on the Mt. Zion circuit 173-2 voltage regulator during a 4% CVR test. These low voltage notifications typically occurred between 1:30pm and 4:30pm. A signal was sent to this voltage regulator location to raise the voltage regulator mid-band set point back to 2% voltage reduction which alleviated the low voltage alarm condition. It should be noted that no customer voltage complaints were ever received during any of the CVR project testing sequences.

Data Collection

Analysis of the data obtained for the CVR project revealed several days of missing data. Research into this issue revealed that there were a number of factors that affected the data collection process. Table 3 depicts three main factors (ADMS issues, Communications issues, Process issues) that affected the data collection process.



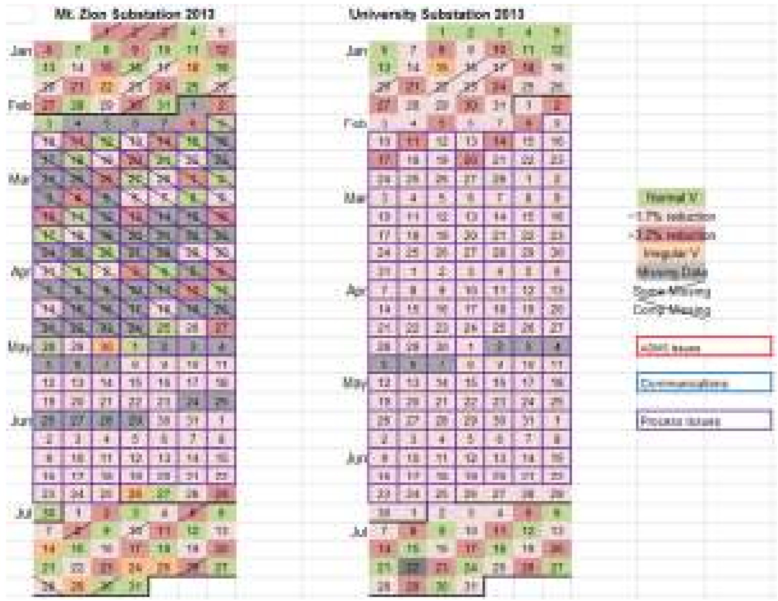


Table 3 – Data Collection issues

Analysis Methodology

Conservation Voltage Reduction results are usually characterized by a CVR factor:

$$\text{CVRf} = \frac{\text{\% Change in Power}}{\text{\% Change in Voltage}}$$

The above equation can be described by:

CVRf = Percentage Change in Power Consumption for each % Change in Voltage.

The CVRf is utilized to determine a distribution circuits load sensitivity as it relates to voltage reduction across the distribution circuit. There are many methods that can be utilized to estimate the CVRf characteristic and are summarized as follows:

- Dynamic Measurement

  (reduce voltage, measure contemporaneous load change)

- Test-Day Comparison

  (compare hourly load on a reduced-voltage test day with a similar day or sequential day with normal voltage)

- Regression Methods (all of which may be referred to as “Day On – Day Off”)

  Dimensions:

  - Annual versus Seasonal or Monthly

- Hourly versus Daily
- Comparable Feeder versus Weather
- Voltage state dummy variable versus %ΔV variable
- Ordinary Least Squares versus Robust Methods
- Handling of outliers

Ameren Illinois chose to enlist the Electric Power Research Institute (EPRI) to provide analysis support for its Conservation Voltage Reduction Pilot. EPRI uses Regression Methods to create voltage-sensitive models of test-feeder loads based on either weather variables or a suitably comparable feeder. EPRI defined to Ameren Illinois three regression methodologies that have been utilized in industry as follows:

- **Comparable Circuit Method**

  (Model equation that utilizes comparable feeder load, voltage state, time variables)

  <u>CVRf calculated from the voltage-state variable</u>

- **Weather Method**

  (Model equation that utilizes weather data, voltage state, time variables)

  <u>CVRf calculated from the voltage-state variable</u>

- **Protocol #1**- Develops 48 separate regression models, two for each hour of day

  (Model equation that for each day/hour when CVR is turned on)

  (Model equation that for each day/hour when CVR is turned off)

  (Three temperature ranges regressed separately)

  <u>CVRf calculated by averaging the average difference between the models</u>

Discussion with EPRI about Ameren Illinois Conversation Voltage Reduction Pilot allowed EPRI and Ameren Illinois to determine that the best method to perform the analysis of the project was to utilize the Comparable Circuit Regression methodology.

Thus, the CVR feeder loads were analyzed with a statistical regression procedure that used the comparable feeder as a key independent variable along with time-of-day and day-of-week variables. Holidays and other feeder events were also associated with dummy variables. Hours were eliminated from the analysis if any of the required data items was missing or clearly in error. Though two different voltage-reduction levels were tested, the initial analytic procedure obtained a single average impact per percent of voltage reduced. The data were analyzed monthly and seasonally.

Results

The analysis revealed some issues that may occur with the comparable-circuit method. Correlation between the paired circuits was well above 95% (see Figure 5 below) for most of the initial summer of the test, while load was dominated by air conditioning, providing a seemingly solid basis for a model of the test feeder. CVRf was found to be around .8 in the summer months. However, the correlation between the paired circuits fell apart in late summer and into the fall. Interestingly, the problems occurred for different reasons on the different pairs.

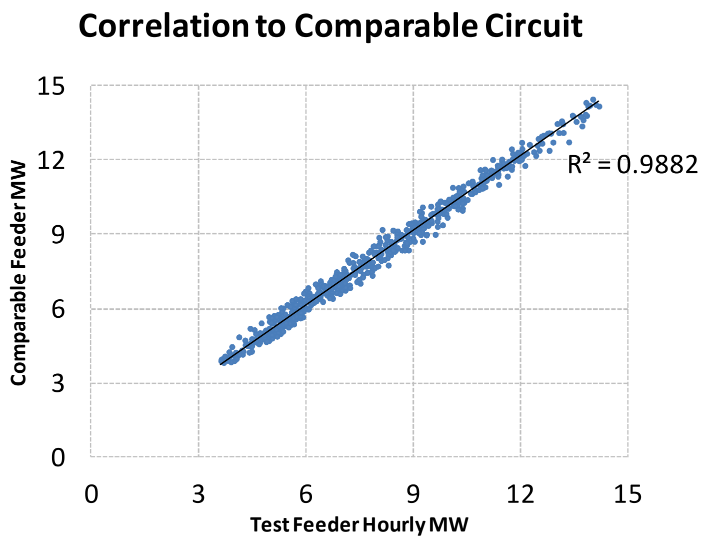


Figure 5 - Both pairs of circuits exhibited strong correlation in the summer months. This graph is a scatter of the loads for the University feeder and its comparable feeder during the month of July, 2013.

- Analysis of September through November for the University circuit revealed that the comparable circuit had picked up about a megawatt of additional load in late September, returning to normal in early November. Inquiry into the logs indicated that a segment of an adjacent feeder had been switched onto the comparable feeder. While this clearly affected the raw correlation between the two circuits, this was overcome by adding a binary dummy variable that indicated the hours when the extra load was present.

- Similarly, the raw correlation between the Mt Zion 173 circuit and its comparable circuit fell apart in late August, but not in a dependable, steady way. Rather, it seemed that a difference of a megawatt or two would arise between the circuits at odd intervals. Here we suspected some unusual load activity, and a search turned up the presence of several large agricultural loads on both the test feeder and the comparable feeder. The loads are termed “large” in comparison to the other loads on the feeder, especially in the fall when weather was mild. The solution to this issue was to obtain the hourly meter reads on these customers and subtract them from the total feeder loads. This is less than ideal, but it raised an important issue for CVR testing.

University CVR Results			
Month - Year	CVRf	KW/%ΔV	Comment
May-12	1.37	85	
Jun-12	0.79	55	
Jul/Aug - 2012	0.75	76	
Sep-12	1.12	63	Load shift in
Oct-12	1.48	74	Comp Feeder
Nov-12	0.91	48	"
Dec-12	1.16	68	
Jan-13	0.8	50.5	
Feb-13	N/A	N/A	
Mar-13	N/A	N/A	
Apr-13	N/A	N/A	
May-13	N/A	N/A	
Jun-13	N/A	N/A	
Jul-13	0.71	56.5	

Table 4 – University Monthly CVR results

Mt. Zion CVR Results			
Month - Year	CVRf	KW/%ΔV	Comment
May-12	N/A	N/A	
Jun-12	N/A	N/A	
Jul-12	0.82	39	
Aug/Sep - 2012	0.8	25	Aug + Sep 1-9
Sep/Oct - 2012	0.63	14	Sep 23 - Oct
Nov-12	0.86	22	
Dec-12	0.26	7.5	
Jan-13	0.148	14.5	
Feb-13	N/A	N/A	
Mar-13	N/A	N/A	
Apr-13	N/A	N/A	
May-13	N/A	N/A	
Jun-13	N/A	N/A	
Jul-13	0.88	32	

Table 5 – Mt. Zion Monthly CVR Results

The results observed on both the Mount Zion and University feeders, shown monthly in Tables 4 & 5 above, were generally within the range of results estimated by many other electricity providers in the U.S., as shown below in Table 7. However, the Ameren results are variable month to month as the mix of loads changes across the seasons, raising questions as to the estimation method and period of time covered by the various estimates listed in the NEEA report referenced in the table.

The monthly variation in the Ameren estimate is intriguing, but raises questions about the underlying physical differences or statistical variations that might be driving them. For instance, the rural Mt. Zion feeder appeared to have lower voltage sensitivity in winter than in the summer months, while the urban University feeder showed the opposite tendency. During the cooling seasons electric air conditioning dominates on both feeders, but the divergence during the heating season could point to differences in the predominant heating systems in the different areas.[1] On the other hand, the data quality for statistical analysis was different for the two tests, and it cannot be known what effect that might have had on the statistical analysis. Table 3 above shows that the fall/winter voltage variation for the University feeder followed a weekly pattern where the voltage reductions fell on the same days each week. That is, all Tuesdays and Thursdays experienced 4% voltage reduction while all Mondays and Wednesdays were reduced roughly 2%; no Fridays or week-end days experienced any voltage reduction at all. There were no normal voltage days from Monday to Thursday for the entire period. The Mt Zion feeders, on the other hand, were controlled in a precessing "checkerboard" pattern such that over the course of a month each day of the week experienced all three voltage conditions. As a result, the Mt Zion analysis measured and incorporated both weekday and weekend load variation, while the University analysis was estimating weekday load variation based on normal-voltage Fridays and week-end days. While the analysis produced a result for University, the conditions for statistical analysis were not equivalent between the two test areas. However, the true cause of the seasonal divergence has not been definitively determined, and only with a consistent control and measurement schedule can the divergence be confirmed

A question arose whether the impact of voltage reduction on the peak day could be discerned from the statistical analysis. The statistical technique being employed to produce the monthly results was determining a single voltage-sensitivity number for the entirety of each period covered, and was not sensitive to hour-by-hour variations in sensitivity. However, it was decided to estimate the peak sensitivity by narrowing down the hours of each day that were included in the analysis. To estimate the peak sensitivity, the 8 hours around the peak of each day were analyzed for July in both test areas. (By July of 2013 the voltage-control test pattern for the University feeder was the same checkerboard pattern as Mt Zion.) This analysis showed on-peak sensitivity similar to that of the monthly analysis, although the sensitivity at University was somewhat less on-peak than that for the month as a whole. These results are summarized in Table 6.

Table 6 below depicts the substation buss average % demand reduction during peak periods of time as they were assessed over the entire pilot time frame.

[1] Electric resistance heat, while sensitive to voltage while it is heating, is thermostatically controlled such that its total energy usage over time is unaffected by small changes in voltage. Heat pumps, on the other hand, present motor loads to the electric system and may respond to voltage reduction by operating slightly more efficiently. To a lesser extent the same may be true of forced-air gas heating systems' fan motors.

Table 6 – CVR Project Substation Demand Reduction at Peak versus All-Hour Analysis		
Substation	8-hour On-Peak Analysis	All-Hour Analysis
Mt. Zion Substation (July 2012)	41 kW/%ΔV	39 kW/%ΔV
University Substation (July 2013)	47 kW/%ΔV	57 kW%ΔV

Utility	**CVR Factor**[22]	**Comments**
California IOUs	0.75	
New York State Electric & Gas	0.6	
Central Florida Electric Cooperative	0.5 – 0.75	0.5 in the summer; 0.75 in the winter
Clay Electric Cooperative (Florida)	1.0	
Progress Energy – Florida	1.0	
Georgia Power	0.8 – 1.7	1.25
Cobb EMC (Georgia)	0.75	
Progress Energy – Carolinas	0.4	
Avista Utilities	1.09	Ongoing pilot project
Clatskanie PUD	1.4	Ongoing pilot project
Inland Power & Light	0.93	Ongoing pilot project
Snohomish PUD	0.65	
Seattle City Light	0.13	Discontinued program
Average	**0.8**	**Mean of all values, equally weighted, with mid point values used for ranges.**

Source: NEEA 1207, *Distribution Efficiency Initiative, Northwest Energy Efficiency Alliance, 2007*

Table 7 – Utility CVR factors

Table 8 provides an estimate of the Kilowatt Hours (KWhr) reduced during the execution of the CVR pilot project. This estimate was computed by counting the total number of days that CVR was implemented at a specific CVR level, multiplying the number of days by 24 hours and then multiplying this value by the average KW/% value for the respective CVR test period.

Month Year	Mt. Zion				KWH saved		University				KWH saved
	Days at 2%	Days at 4%	KW/% at 2%	KW/% at 4%			Days at 2%	Days at 4%	KW/% at 2%	KW/% at 4%	
May-12	0	0	0	0	0		7	10	170	340	110160
Jun-12	0	0	0	0	0		6	5	110	220	42240
Jul-12	8	8	78	156	44928		11	10	152	304	113088
Aug-12	10	7	50	100	28800		0	0	152	304	0
Sep-12	5	1	28	56	4704		7	7	126	252	63504
Oct-12	11	10	28	56	20832		9	9	148	296	95904
Nov-12	11	8	44	88	28512		4	5	96	192	32256
Dec-12	8	7	15	30	7920		6	6	136	272	58752
Jan-13	7	11	29	58	20184		14	7	101	202	67872
Feb-13	0	0	0	0	0		0	0	0	0	0
Mar-13	0	0	0	0	0		0	0	0	0	0
Apr-13	0	0	0	0	0		0	0	0	0	0
May-13	0	0	0	0	0		0	0	0	0	0
Jun-13	0	0	0	0	0		0	0	0	0	0
Jul-13	9	8	64	128	38400		12	9	113	226	81360
		Mt. Zion KWhr saved			194280			University KWhr saved			665136
								Total KWhr saved			859416

Table 8 – Monthly KWhr saved

Costs

The capital costs associated with the Conservation Voltage Pilot were $162,706. This included the purchase cost of hardware (Voltage Regulator controllers, Capacitor Bank controllers, Voltage sensors and Communication equipment). This also included engineering and contractor labor to design and construct the projects infrastructure. This does not include any labor costs associated with manual operations of the equipment at the University substation for the first portion of the testing in 2012, nor does it include any costs associated with analysis and tracking of the project.

The O&M costs associated with the Conservation Voltage Pilot were $25,145. This included the purchase cost of a controller that was initially believed necessary to control the projects test plan.

Lessons Learned

- Understanding the feeder load characteristics (test circuit and comparable circuit) is a critical aspect of performing the CVRf analysis.
- Statistical comparison of a CVR feeder with a similar non-CVR feeder can change in effectiveness from month to month:
  - Load shapes may be similar in hot weather peak months, but may differ in other periods.
  - If the comparable feeder approach fails, then weather data may be useful for use in the regression analysis.
- Large episodic or seasonal loads on a feeder can present challenges for regression analysis.
  - The impact of voltage reduction is small relative to the feeder load. Some individual loads may be large relative to the feeder load, and may present large variations for the circuit.
    - These variations will not be represented in the comparable circuit.
    - These variations may not be daily-weather related.
  - During the testing process, additional load was added to the comparable circuit for the Urban feeder test.
  - Seasonal grain elevator loads on both of the Rural/Urban circuits (test circuit and comparative circuit) created data analysis issues until the seasonal load was identified and addressed.
- Any changes or events that affect load on a feeder might alter the results of the CVR analysis. Ex: changes in configuration, outages, holidays, etc.
- Communication failures with control equipment as well as implementation of a new Advanced Data Management System during the testing process created data retention issues.
- Conservation Voltage Reduction can be implemented on both Urban and Rural/Urban designed distribution systems. Utilization of voltage sensing devices at end-of-line locations is effective in mitigation of low voltage conditions.