Industrial Voltage Optimization at Large Industrial Facility Brings Energy Savings

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ABSTRACT

Less is more when it comes to eating healthy and the same can be said of alternating current (AC) voltage inside industrial plants. By using active voltage regulation which incorporates voltage monitoring at the load, an industrial facility can save energy and better protect their equipment and systems.

In the early spring of 2007, Plum Creek Timber Company (Plum Creek), Flathead Electric Cooperative (Flathead Electric), and the Bonneville Power Administration (BPA) teamed up with PCS UtiliData (PCS) to evaluate Plum Creek's Medium Density Fiberboard (MDF) facility in order to optimize its distribution voltage. Based on the November 2007 evaluation, the facility implemented the *AdaptiVolt*™ voltage optimization system - resulting in a voltage reduction between 1.9% and 4.8%. This reduction provides over 6,000,000 kWh per year of energy savings.

This paper will describe the results of the evaluation, commissioning, and the measurement and verification (M&V) of the *AdaptiVolt*™ system installed at the facility. It will also address some key factors that were discovered during the evaluation, resulting in a modification of the evaluation processes and extending the M&V period another 11 months.

Some of the factors are the influence of the distribution system's characteristics on energy savings (i.e., the effects of an unbalanced distribution system), the unique M&V techniques used to determine the system's potential, and the various setbacks that nearly eliminated the energy savings produced by the project.

Background

In October 2006, Plum Creek and PCS approached Flathead Electric and BPA to fund an assessment of Plum Creek's MDF facility to consider industrial voltage optimization (IVO). The goal was to assess the operating voltages provided throughout the facility, focusing on the end-of-line voltages, and to determine what the end-of-line voltages are when compared to the system-rated voltage. Flathead Electric and BPA approved funding and launched the detailed assessment in the spring of 2007.

To assist industrial facilities in assessing the potential for energy efficiency projects and the development of M&V plans, utilities together with BPA have provided funding for feasibility studies. In addition, these studies provide a list of energy efficiency measures (EEM) and technical estimations of a potential project's costs, the simple payback, and the development of an M&V plan, which outlines the steps that will be used to measure and verify the actual energy saving achieved at the project's completion.

The IVO project consisted of five major steps: Project feasibility study, development of the M&V plan, project implementation, system commissioning, and post M&V. These steps and the resulting information are necessary for an industry to be eligible and apply for utility energy efficiency programs and incentives, when offered.

This IVO project qualified for energy efficiency incentives by Flathead Electric and subsequently approved by BPA; the incentive rate was $0.17/kWh for first-year savings up to 70% of the project's incremental costs. Based on the significant energy savings produced by this project, Plum Creek received incentives that covered roughly 65% of the project's total cost.

Timeline

Spring 2007		PCS began Plum Creek's MDF facility feasibility study
July 2007		Study completed and included project's M&V plan
October 2007		Plum Creek approved capital funding for project and submitted project to Flathead Electric
October 2007		Flathead Electric approved project and submitted to BPA
December 2007		BPA also approved project for incentives
January 2008		Project implementation began
September 2008		Project completed, commissioned, and post-M&V initiated
September 2009		Post-M&V of project was completed

Note: Just after the start of the post-M&V process, the nation's economic downturn had an affect on the facility; resulting in a significant reduction to the facility's operation. This caused the post-M&V process to also be negatively affected. At the time of post-M&V, the facility had returned to 80% of normal operations and was expected to return to full operation sometime around the 3rd quarter of 2010.

Facility Description

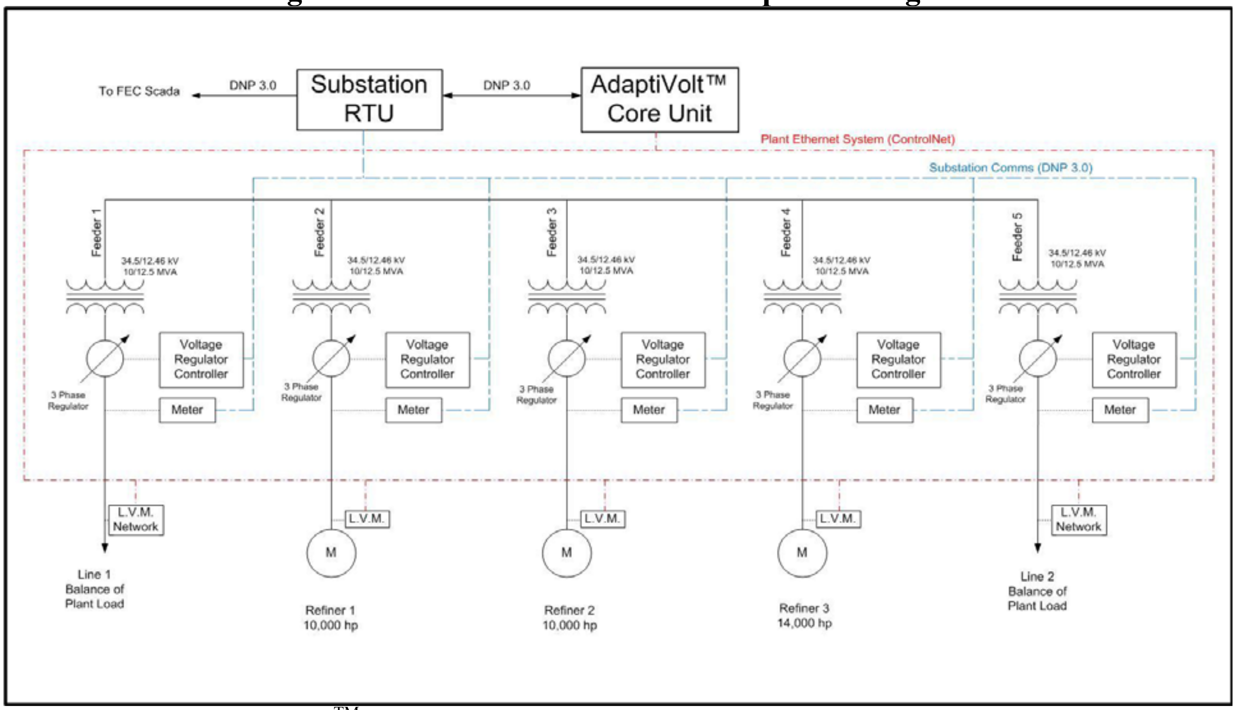
Plum Creek's MDF facility is located in Columbia Falls, Montana, and is part of a five-facility campus that produces various lumber products which include MDF, dimensional lumber, and plywood. The MDF facility consist of two production lines, Process Line #1 (line #1) and Process Line #2 (line #2) with each line having separate process systems and some shared auxiliaries. Line #1 has two 10,000 hp thermal mechanical pulping plate-type refiners (refiner) and line #2 has one 14,000 hp refiner. All three synchronous motors are manufactured by ABB and refiners are manufactured by Andritz.

The Plum Creek campus, which includes the MDF facility, purchases all of its electrical power from Flathead Electric. BPA provides wholesale power to Flathead Electric and co-funds conservation programs offered by Flathead Electric to their members. Due to requirements of the contract between Flathead Electric and BPA, only the power to line #2 is provided by BPA to Flathead Electric. The power to line #1 is provided by other Flathead Electric resources. Because of this arrangement, BPA and Flathead Electric provided incentives based on the energy savings achieved on line #2. Even with this restriction, as mentioned earlier, the incentives covered 65% of the total project costs for both lines #1 and #2.

The facility's power is supplied from Flathead Electric's Tamarack Substation. There are five 12.47 kV feeders from the substation to the facility, one for each of the three refiners and two process lines. The process line loads are consistent with typical industrial facility loads, that include lighting, HVAC, compressed air (line #2), and induction motors from fractional to 800 hp.

Figure 1 is a simplified, single line diagram of the Tamarack substation as it relates to the voltage optimization (VO) system. The diagram does not include equipment not directly associated with the VO system.

Figure 1 – Tamarack Substation Simplified Diagram



Note: AdaptiVolt™ Core Unit is the voltage optimization control unit provided by PCS.
Source: Wilson, Benson, & Bell

Industrial Voltage Optimization

Industrial Voltage Optimization (IVO) is the application of advanced VO controls to a dedicated feeder for an energy intensive facility. VO, also referred to as conservation voltage regulation (CVR), is the practice of operating electric distribution systems at voltages in the lower half of ANSI standard C 84.1 and CAN3-C235-83 (R2000)[1] allowable voltage levels. Operating in the lower half of the allowable voltage band increases the efficiency of many of the utilization devices [Chen, Shoults, & Fitzer]. Typical industrial equipment such as motors, variable frequency drives (VFDs), transformers, and lighting systems, have lower electrical losses, therefore are more efficient when operated at or close to their rated voltage.

Applying IVO to a dedicated utility feeder[2] for an industrial facility results in energy savings occurring throughout the entire facility, or customer-side of the utility meter. This is why in some IVO applications, the actual IVO system will be purchased by the facility but installed

[1] For a nominal 120 volt system, ANSI standard is 114 to 126 volt delivery at the service entrance and CAN standard is 112 to 126 volt delivery at the service entrance. IVO typically operates 114 to 120 volt for a nominal 120 volt system.

[2] A distribution system feeder placed into service with the sole purpose of serving a single customer. A non-dedicated feeder or shared feeder serves multiple customers.

upstream of on the utility-side of the meter. The IVO system will control voltage prior to the meter while the actual energy savings occurs within the facility; thereby resulting in the facility receiving financial benefits from the energy savings.

The IVO system used in this project was based on the *AdaptiVolt*™ Volt/VAR Optimization system, a system that has been installed at utility distribution substations in the U.S. and Canada. Typical VO systems rely on line-drop compensation for voltage control. Line-drop compensation uses a model of the distribution system to compute fixed resistance and impedance settings in the voltage regulator controllers [Wilson, Benson, & Bell]. While this approach can work for radial distribution feeders with known or predictable load patterns, it does not work for industrial loads with varying load patterns dependent on a facility's operation. For the line-drop compensation approach to work, a model would be required for every predictable variation of a facility's load.

The *AdaptiVolt*™ system provides a closed loop feedback control system that measures actual voltage at or near the end-of-line or critical loads. By using actual measurements and not models, the system is able to respond to changing system operations to maintain the voltage in the lower half of the allowable range while ensuring the system does not experience a low voltage condition. A significant secondary benefit comes from the additional equipment protection provided by the system.

Motors that are properly sized for an application tend to be more efficient when operated at nameplate voltage. For the motors operating at less than 100% of full load, the motor will still maintain its efficiency even when operated at less than nameplate voltage. Most motors are operated below 100% of full load or are only required for deliver 100% of full load for very short periods of time [DOE].

Project Results

Project feasibility study. This was designed to evaluate the overall potential for the IVO project to save energy. The study focused on the key systems and variables that had the potential to restrict or prevent the project from saving energy.

The goals of the study were to:

1. Evaluate the substation and facility infrastructures for IVO application.
2. Evaluate the current condition and the potential impact on the facility distribution system.
3. Determine the end-of-line low voltage points under various operating conditions.
4. Conduct voltage disturbance tests to determine potential savings on the refiner motors.
5. Estimate potential CVR factor and energy savings.

The study showed the project had strong potential for energy savings but did require some modifications to one of the distribution feeders and an addition of a key variable.

Evaluate the substation and facility infrastructure for IVO application. The evaluation of the substation and facility infrastructures for IVO application focused on determining if the current substation and communication infrastructure was sufficient to implement IVO, or if those systems would require modification. If significant modifications were required, such as the installation of new voltage regulators or load-tap transformers, the project may not have been cost effective.

The study showed the substation contained the equipment and communication systems required to implement IVO. The facility's existing SCADA system had sufficient communication capacity with the substation to allow for communication with the IVO controls.

The study also confirmed that the substation had appropriate voltage regulation and load-tap transformers, which are both required to implement IVO.

Evaluate the current condition and potential impact on the facility distribution system. The evaluation of the current condition and potential impact focused on verifying the facility's distribution system, particularly the process feeders (feeders 1 & 5), were in good condition and did not require modification to implement IVO.

Evaluation of the facility's distribution system found the phase-to-phase loading on feeder 5 was not balanced. If left uncorrected, the voltage on feeder 5 would only be reduced 0.86% instead of 2.50% for a balanced feeder; thus reducing the potential energy savings by 65.60%. Therefore, the facility corrected the issue by balancing single-phase loads between the three phases; thus allowing the study to estimate the voltage reduction at 2.50% instead of 0.86%.

Determine the end-of-line low voltage points under various operating conditions. The facility's distribution system drawings were evaluated to determine the locations most likely to have the lowest voltages. The analysis looked at loading, size of conductor, and locations farthest from the substation based on conductor length. From the analysis, the monitoring points were selected.

The voltages, current, demand, and kVAR were measured and recorded at each monitoring point. This included the voltage at the large motor terminals for feeders 2, 3, and 4 and at 5 (five) separate locations on feeders 1 and 5. The same variables of each feeder at the substation were measured and recorded during the same period to determine the conditions along each feeder. During the monitoring and recording period, approximately 60 process variables were recorded for a variety of operations within the facility. This data allowed the comparison of substation voltage to end-of-line voltage and the normalization of voltage and power variations based on the process variables.

Conduct voltage disturbance test to determine potential savings. Voltage disturbance tests were conducted on the large refiner motors to determine the potential effects on motor demand (kW) by implementing IVO.

The test consisted of manually reducing the voltage regulator setting at the substation during steady state operation of the refiners for a period of 6 (six) hours, monitoring and recording the key variables (voltage, demand, and kVAR), and then returning the voltage regulator to its original set point and monitoring and recording the key variables once again. This allowed the documentation of the actual energy savings when the refiners were operated at the reduced voltage during steady state conditions. This test also allowed for documenting the affects the reduced voltage would have on various refiner operating parameters such as motor temperature, exciter field, and armature current.

Estimate potential energy savings. The potential energy savings was calculated by first determining the Conservation Voltage Regulation Factor (CVR_f) of the system. The CVR_f is a measure of percent energy savings per percent voltage reduction. CVR_f is calculated as:

$$CVR_f = (\Delta E\%)/(\Delta V\%)$$

Each feeder was analyzed to determine the CVR_f based on the actual kW loading and types of loads on that feeder. The key variables were identified that were required for creating operating and time based models for statistical evaluation of the feeder and the effect on the CVR_f. Statistical evaluations were used to determine the how the CVR_f varies on each feeder depending on variations in the process [Bell]. This allowed estimating the energy savings potential for a full year even though the actual voltage reduction and CVR_f may vary depending on variations in the process.

When the CVR_f was calculated for the refiners (feeders 2, 3, and 4), the CVR_f exceeded the theoretical maximum value based on the voltage of those feeders. During the initial analysis it was not clear why the CVR_f was so high or which of the key variables may be driving it. Further analysis of the model showed that during some periods of operation, the CVR_f was reasonable and during the times the model showed the CVR_f high, none of the key variables changed or changed very little. This required stepping back and reevaluating the models and key variables against the actual process.

Review of the actual process variables identified the mass flow rate of raw materials (wet wood) into the refiners, which is a key variable, was assumed constant for a given product while data from the process showed it varied proportionally to both refiner and process load based on the characteristics of the raw materials. The affect of this key variable was significant on the operating model for the refiners (feeder 2, 3, and 4) in determining their CVR_f. The affect of this key variable on the overall process line loads (feeder 1 and 5) operating models was small and did not significantly affect the CVR_f for those feeders.

M&V plan. The M&V plan for measuring and verifying the energy savings was structured to allow comparing voltage and demand in IVO regulation mode against standard voltage regulation mode. In standard voltage regulation mode, the voltage is regulated based on substation voltage and not end-of-line voltage. The plan required 12 weeks of monitoring the voltage and demand while cycling between IVO regulation and standard voltage regulation every 2 weeks based on the standard operating cycles of the facility. This allows for accurate comparison of the energy usage in both modes and for a variety of product mix.

In September 2008, with the IVO system commissioned, the M&V plan was implemented. At this same time, Plum Creek decided to reduce operations at the facility due to the slowdown in the lumber market. This was the first reduction in operations at the facility since it was built over ten years ago. The shift in operating cycles and product mix was significant. The facility historically operated at over 8,300 hours per year with a fairly consistent mix of products and it was reduced to about 3,800 hours per year with no long-term predictability in the product mix. Where the original M&V plan only required 12 weeks of data to determine annual savings, the reduced operating hours and varying product mix would not provide sufficient data in that same period. This required a significant change to the M&V plan.

The M&V plan was modified to extend the data collection period up to one full year. The mill planned to return line 2 to normal operations as soon as the lumber market supported it followed by line 1. The goal of the new plan was to collect enough data to accurately determine annual energy savings but not simply require one full year of data if it was not needed. If the facility returned to full operation or the product mix was more consistent during the year, the M&V plan would be completed earlier.

Due to the continued reduced operation and more frequent product shifts throughout most of 2009, the M&V period lasted 11 months. During this time, the data for both regulation modes and a variety of product mixes was collected. Based on the data, the actual real CVR_f was determined and energy savings could then be verified. Line 1 was still operating about 3,800 hours per year while line 2 was about 6,900 hours per year by the end of the M&V period and they were scheduled to return to full operation in mid-2010. Based on the current hours and the schedule to return to full operation on line 2, the measured energy savings listed for line 1 is based on 3,800 hours per year and line 2 is 8,040 hours per year. The calculated full load energy savings is based on both line 1 and line 2 operating at full production. The results of post-M&V are shown in Table 1.

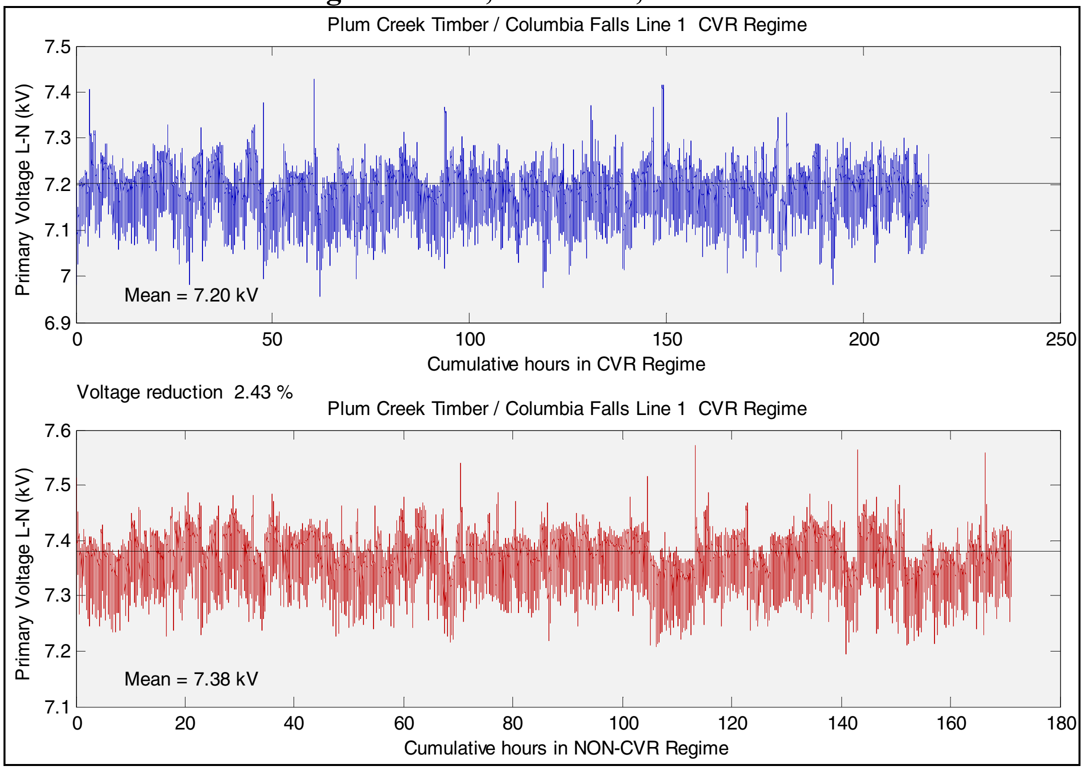
Table 1 - Post Commissioning IVO Results

	Line 1			**Line 2**	
	Process Load Feeder 1	**Refiner #1 Feeder 2**	**Refiner #2 Feeder 3**	**Refiner #3 Feeder 4**	**Process Load Feeder 5**
Average Voltage Reduction	2.42%	3.33%	3.06%	4.82%	2.42%
Real Energy CVR_f	.88	2.16	1.83	.97	1.03
Reactive Energy CVR_f	15.97	1.36	2.11	1.02	3.26
Demand Reduction	2.13%	7.19%	5.60%	4.68%	2.49%
Measured Energy Savings (kWh)[1]	627,000	1,216,000	957,600	1,976,491	1,191,750
Calculated Full Load Energy Savings[2]	1,327,000	2,573,000	2,027,000	2,305,714	1,390,260

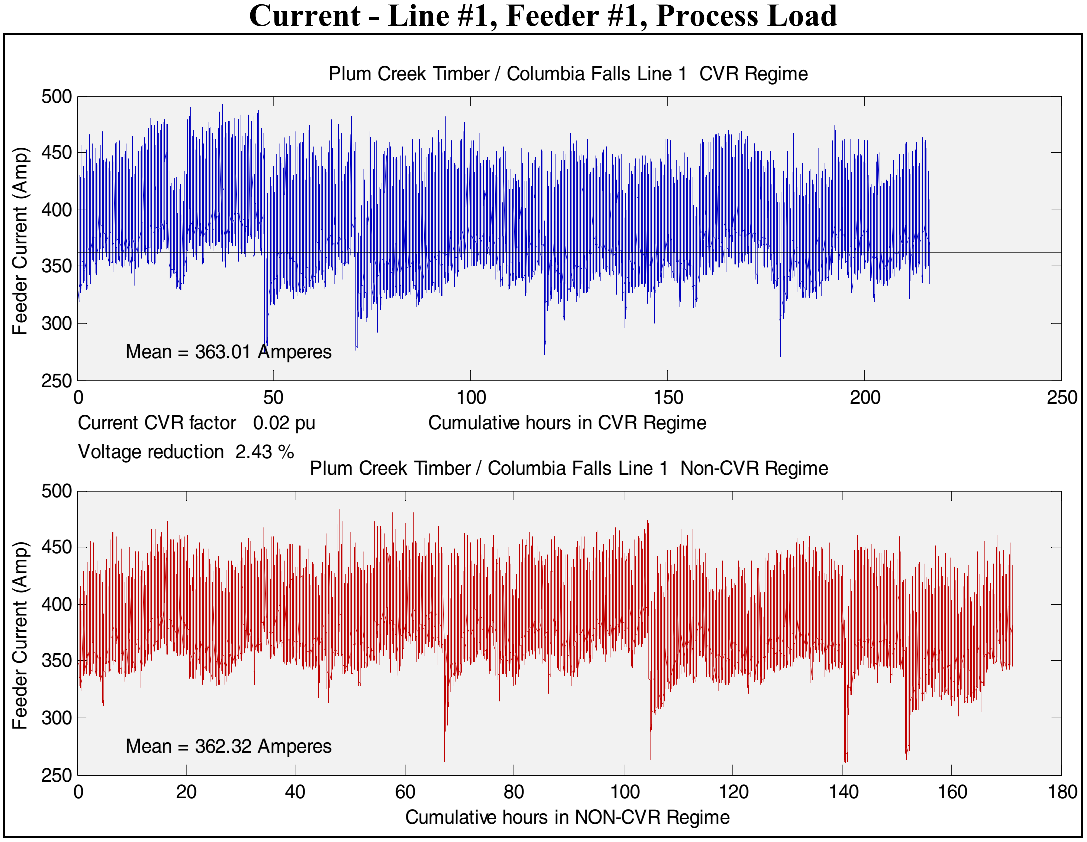
1 Measured Energy Savings based on 3800 operating hours for line 1 and 6900 hours for line 2
2 Calculated Full Load Energy Savings based on 8040 operating hours for line 1 and line 2

The following graphs show the pre and post operating conditions for voltage, current, and demand for feeders 1 and feeders 4. These graphs are representative of the differences in voltage, current, and demand on the process loads (feeders 1 and 5) and the refiner loads (feeders 2, 3, and 4) while operating in IVO regulation mode and standard voltage regulation.

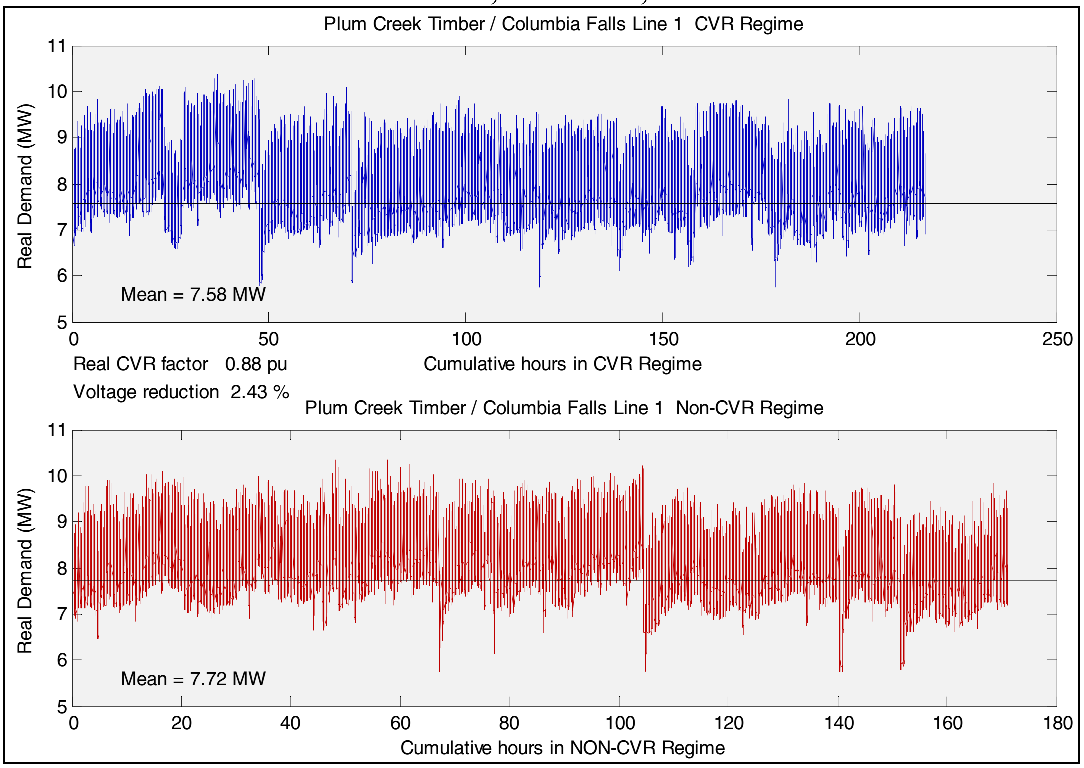
Voltage - Line #1, Feeder #1, Process Load



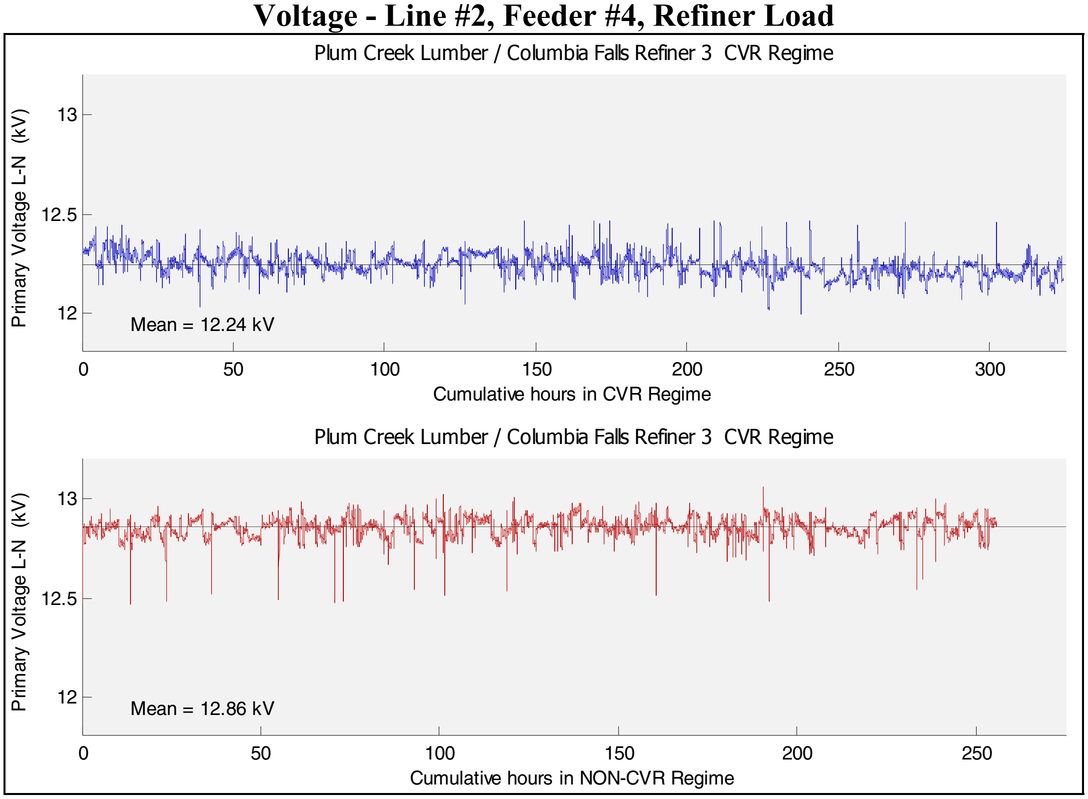
Current - Line #1, Feeder #1, Process Load



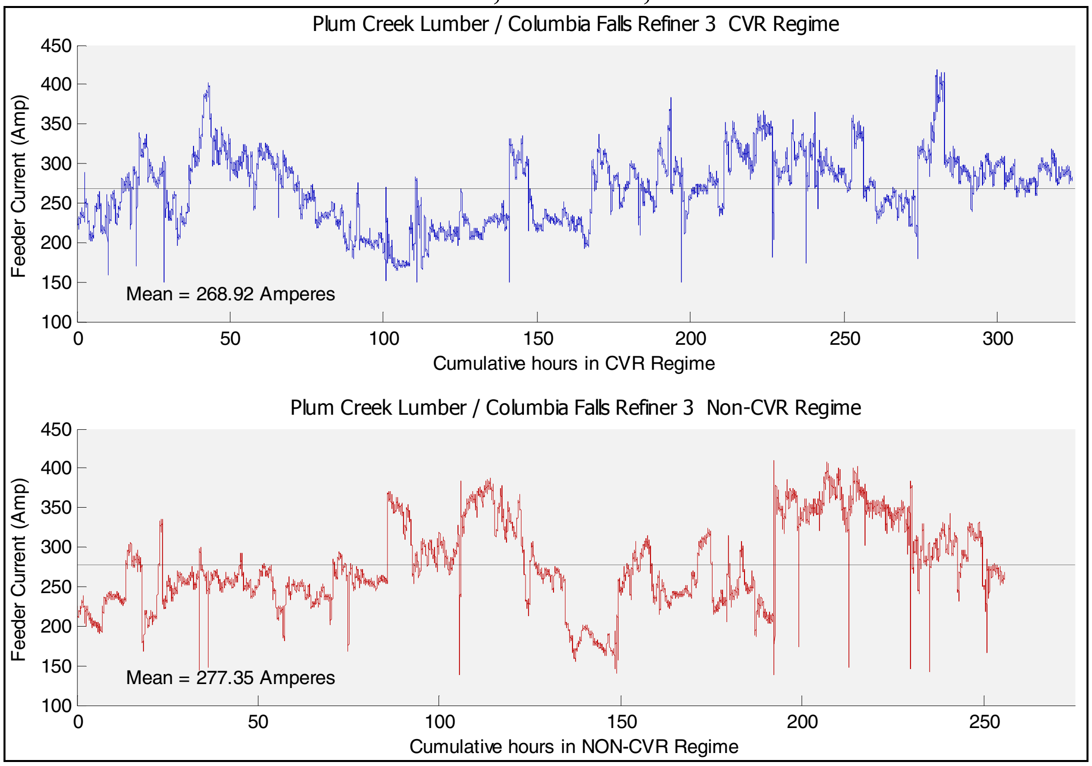
Demand - Line #1, Feeder #1, Process Load



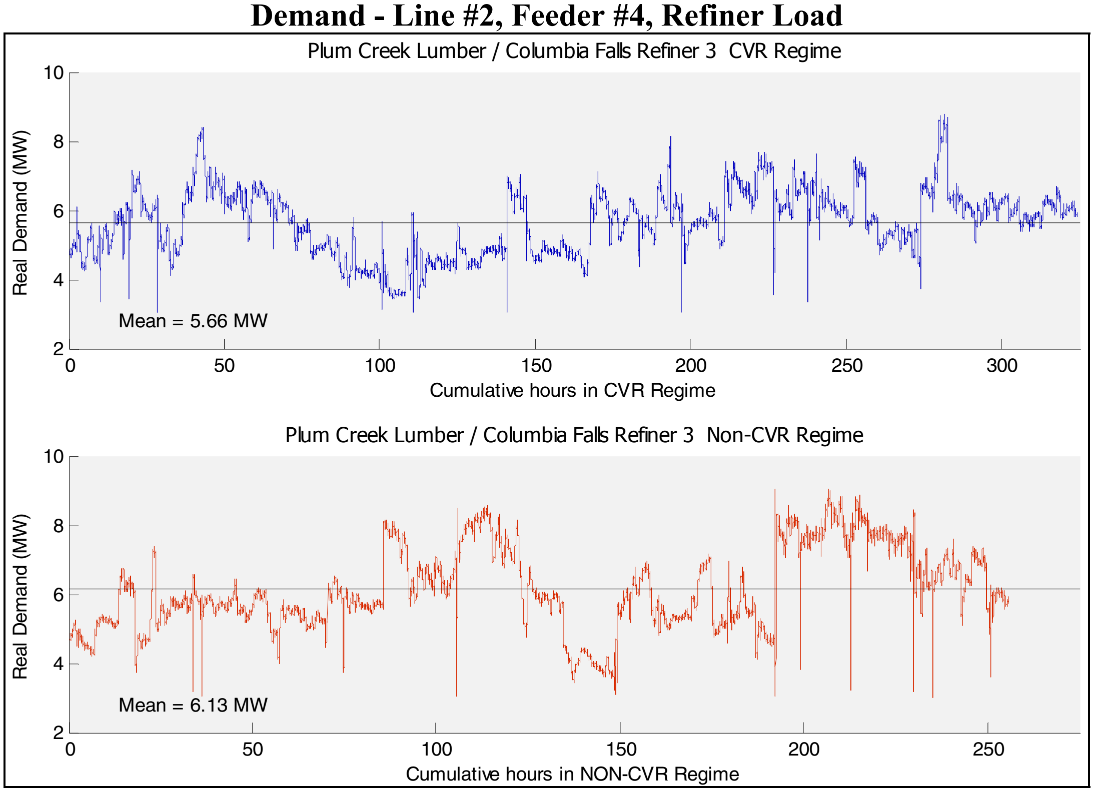
Voltage - Line #2, Feeder #4, Refiner Load



Current - Line #2, Feeder #4, Refiner Load



Demand - Line #2, Feeder #4, Refiner Load



Secondary Benefits of IVO

Prior to the implementation of the IVO system, during ramp down or shutdowns the facility would experience very high peak voltage. Occasionally, these spikes were significant enough to damage or destroy VFDs. Since the IVO system was installed, these occurrences have been greatly reduced. Only one failure has occurred compared to average three to four failures per year. By measuring end-of-line voltage, the IVO system is able to reduce voltage as the process is ramping down, thus preventing voltage spikes.

Current Status of IVO System

The IVO system has been in operation since commissioning in September 2008 and still operates with the original system set points. There have been no significant issues with the system. The system has been shifted to standard voltage regulation on occasion for system testing, maintenance, and to prove energy savings. By shifting between the two modes of regulation during steady state operation, the actual change in demand on the feeders can be seen as a step change in feeder load; thus verifying the savings are real at almost any time.

A minor problem the system has experienced over the last two years is the tap changer position trackers on the regulators. The actual position of the tap changers have occasionally loosened, resulting in the IVO controller assuming the tap changers are near a position limit. This results in the controller defaulting to standard voltage regulation and no energy savings. At this time, the issue does not occur frequently enough to warrant changing the position trackers.

Conclusion

The overall project has resulted in 6,496,574 kWh per year energy savings. When both lines return to full operation, the system will save over 9,000,000 kWh per year. The project demonstrated how energy usage and costs can be reduced on a whole plant basis with a single project at the meter. It also proves VO does work on industrial distribution systems as well as providing important secondary benefits.

IVO will not work at all large energy-intensive facilities, particularly if the facility load is primarily resistive load, instead of inductive load, but most large industrial facilities would be good candidates. Facilities considering significant changes or rebuilding a primary substation should consider IVO. While it can be expensive to implement, depending on the existing substation equipment, it is very cost effective when included as part of a regular substation project.

References

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