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Using Time Series Analysis to Integrate DA FLISR and CVR Systems

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SUMMARY
As the electrical grid becomes more advance and additional control systems are being implemented on the distribution system, more advanced study methodologies must be deployed.

These deployed systems can be active or passive. An active system receives feedback of current system conditions, usually to a centralized intelligence system, and make decisions based upon current system configuration. In a passive system the control system does not receive live feedback on actual system conditions and control parameters are set using a specific set of static conditions. These are studied and designed for a certain system conditions and operating outside these static conditions can produce unknown results.

POWER Engineers has been performing Conservation Voltage Reduction (CVR) studies on Puget Sound Energy's (PSE) medium voltage system using Synergi Electric distribution models. CVR systems provide energy reduction to end-customers by reducing the voltage across the distribution system. This energy reduction is achieved by delivering voltage closer to the rated voltage that equipment is designed to utilize, thus allowing it to run more efficiently.

The methodology currently deployed for these CVR systems is a passive system where the distribution model is studied, and settings are developed based on its normal configuration. When the distribution system must be re-configured for maintenance or operational needs, current practice is for the CVR system to be disabled and regulation returned to a more traditional setting that will provide adequate voltage for customers on the feeder(s).

PSE is also deploying Distribution Automation (DA), Fault, Location, Isolation, and Service Restoration (FLISR) systems. The FLISR system is an active system and automatically re-configures to restore customers during fault conditions. The main purpose of the FLISR systems is to provide reliability improvements to PSE reliability indices and improve customer satisfaction.

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Deployments of the passive CVR and the active FLISR systems are more commonly being implemented on the same feeder(s). This is primarily because both programs currently target a highly residential feeder topology. The highly residential feeder topology provides the largest benefits to both programs.

Having both systems on the same feeder presents issues. The CVR system is designed for the system to be in a normal configuration to provide the maximum voltage reduction that can be delivered to customers, thus the largest energy reduction. While the FLISR scheme is an active system that reacts to system faults and reconfigures outside of its normal configuration to restore as many customers as possible.

The business case to deploy these systems individually is strong, but together they present unknown system conditions that must be studied. This paper shows that by performing a time series analysis, solutions can be derived for the effects of running both systems simultaneously on the distribution systems.

KEYWORDS

Time Series Analysis, Distribution, Synergi, Big Data, Conservation Voltage Reduction, Distribution Automation, Smart Grid

Introduction

As electric customers and regulatory bodies push for a modern grid that is more reliable, safer, greener, and efficient, traditional study methodologies are unable to provide the holistic view required to operate a distribution grid with these concurrent systems deployed. According to the Smart Grid System Report prepared by the U.S. Department of Energy, annual smart grid investments into the transmission and distribution systems rose 41% to $4.8 billion from 2014 to 2016. This number is expected to rise to $13.8 annual spend in 2024[1].

Depending on the roll out of these smart grid systems, study methodology can take a few different paths. Traditionally, planning engineers would manage these studies by selecting which systems are implemented and could do traditional one-off studies to determine which selected systems would provide the desired benefits when activated. As investment grows, multiple systems need will to be implemented on the same feeder(s). This creates problems as there are different styles of systems being rolled out.

One type of system is an active system, which receives feedback from devices in the field and can use this information to make corrective actions. The other style of system is passive, which is designed for a certain normal static configuration. Operating these systems outside of a normal configuration can provide unknown results and possible adverse results to the electric grid. One possible solution can be to manage both systems by deploying Advance Distribution Management Systems (ADMS). However, ADMS can take years to deploy before it provides the holistic management that multiple deployments in the same area require. Meanwhile, utilities are still receiving pressure from their customers and regulators to deploy the smart grid systems as soon as possible.

One way to address the need to deploy multiple smart grid systems and obtain a holistic view of operational performance is to perform a time series analysis. These studies allow the integration of multiple systems while utilizing historical data provided by intelligent electrical devices (IED) to analyze system performance. This allows planning engineers to make an informed decision on whether the systems can work holistically or whether to develop a plan to mitigate the adverse operational performance that is created by deployments of multiple systems.

Modernization Deployments

PSE is in the midst of rolling out multiple systems to modernize its electrical distribution system, which includes a DA FLISR and a CVR system. Deployments of both systems are encouraged by both customers and regulators.

The DA FLISR system spans multiple feeders and often multiple substations. It is an active system that is currently studied in the traditional methodology of worst-case scenario (peak loading) to ensure optimal operational performance. The purpose of this system is to respond to faults on the distribution grid and reconfigure to minimize the number of customers experiencing an outage based upon the feedback from field devices and decisions made by the centralized intelligence system. The DA FLISR system provides reliability benefits to customers served by these systems and improves PSE reliability indices.

A side benefit of this system is the IED devices provide large amounts of “Big Data” that can be utilized in time series analysis. This benefit is addressed later in this paper.

A CVR system is being deployed to reduce the distribution system voltage to the lower end of range A of the ANSI C84.1 standard. Doing this allows for customers on the feeders to experience a reduced demand and energy savings. This energy reduction is achieved by delivering voltage closer to the rated voltage that equipment is designed to utilize, thus allowing it to run more efficiently. Lowering of the system voltage is achieved by implementing restive and reactive (R&X) compensation settings for the substation load tap changers (LTC). These R&X settings adjust the regulation set point of the LTC and allow it to vary based upon the current loading condition of the transformer.

Traditional study methodologies have been utilized to study the distribution system in its normal configuration and verify system performance after these settings are implemented. When the system is in an abnormal configuration these settings are manually removed, and a more traditional regulation setting is temporarily deployed, which accounts for the larger voltage drop and loading that the system may experience.

Selection criteria of where to deploy these systems is also similar. For the DA FLISR system, customer meter count is important for benefits to be realized. For the CVR system, power quality concerns for industrial and commercial customers are important. This leads to both systems typically being deployed on feeders with high residential counts.

As one can see, with similar targets and increased deployments of these systems over the years, they have begun to overlap on the same feeders and substations. This presents issues when studying in the traditional sense as the DA System goal is to reconfigure the feeder to minimize outages while the CVR system is studied to provide maximum energy savings in the normal system configuration.

Performing a traditional static study with both systems active will not accurately represent the true performance of the electrical distribution system. This is because the CVR regulation adjusts with the load profile and the DA FLISR scheme will reconfigure the system adding load and feeder length that wasn't accounted for in the traditional CVR study. These systems together, if not studied properly, can create nonoptimal operating conditions. Therefore, a time series analysis is required to see the holistic picture of these systems integrated over the year using historical data from the Plant Information (PI) system.

Time Series Analysis Setup/Proof of Concepts

As discussed above, a time series analysis was used to provide a holistic study and determine the distribution system response with both the DA FLISR system and the CVR system in operation. This was done utilizing the average value over each individual hour from the IED devices from the PI historical system. Synergi models were used for the winter and summer seasons. The winter model used data from October to March and summer model used data from April to September. The batch analysis feature of Synergi was utilized to perform load allocations and load flows.

Another feature of this study was to determine the benefits of utilizing the existing IED line device's historical data, instead of just utilizing the feeder head data, to see if it provided a more accurate model. Proof of concepts were completed to validate portions of the study prior to completion of the full study. These were:

- Comparing allocations from the normal open point of the feeder instead of the feeder head. Since the DA FLISR system is active and can re-arrange a CVR feeder at any time, we must account for this in the study. For this study, we assumed the worst-case scenario where the CVR feeder is used to restore the entire feeder length. (Refer to Figure 1)

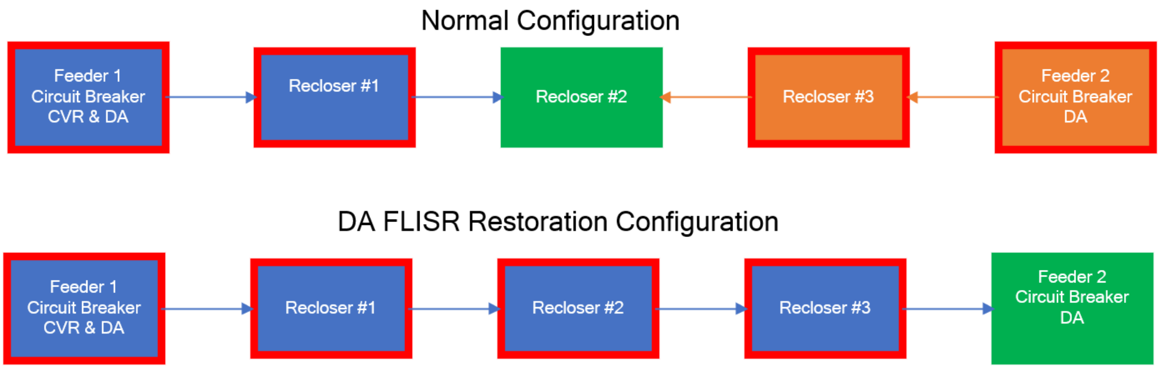

Figure 1 – Normal Configuration and DA FLISR Example

Showing that results weren't affected by where the load was allocated from was an important of proof-of-concept state as the batch-analysis tool does not allow for devices to change states between allocation and load flow. For the proof of concept, the results of running hourly data for an entire month were compared on identified nodes on Feeder 2, between allocating from Feeder 2 circuit breaker and the Recloser 2. The results showed that allocating from the normal open point typically provided a higher load allocation at these nodes although not enough to warrant concern about the results of the study. These results are summarized in Table 1 below:

Allocation Comparison between Feeder Head and Normal Open						
	Average	Max	Average Loading of Node Amps	Peak Loading of Node Amps	Average Deviation Amps	Max Deviation Amps at Peak
Node #1	-6.17%	-8.78%	55	105	-3.4	-9.2
Node #2	-4.84%	-6.53%	39	53	-1.9	-3.5
Node #3	-4.01%	-5.59%	55	60	-2.2	-3.4
Node #4	-3.90%	-5.51%	45	67	-1.8	-3.7
Overall Average	-4.73%	-4.25%			-2.3	-4.9

Table 1 – Allocation Comparison between Feeder Head and Normal Open

- The other proof of concept that was explored was the accuracy gained between including multiple IED line device's historical data versus not utilizing this data and just allocating from the feeder head with its data. This comparison was done using the hourly values of the peak month and the results were compared at the point of the IED devices between including device data in the allocation and not including individual device data in the allocations. The results showed that including these points can provide improvements to load allocations in this instance up to 63% as summarized in Table 2 below:

Benefits Achieved from Utilizing Historical Data				
IED Device	Data Allocation	Average	Min	Max
Device 1	Including Historical Data	0.21%	0.01%	0.61%
	Excluding Historical Data	1.13%	0.01%	6.54%
Device 2	Including Historical Data	0.31%	0.00%	0.56%
	Excluding Historical Data	9.51%	1.36%	1.36%
Device 3	Including Historical Data	0.07%	0.00%	0.38%
	Excluding Historical Data	20.31%	0.01%	63.03%

Table 2 – Benefits Achieved by Utilizing Historical Data

For the overall times series analysis study, a DA system, which has three substations with two of them identified as possible CVR substations, was selected to perform this study. The system includes twelve IED devices, for which their historical data was integrated to improve the overall model accuracy. The normal configuration of this system is below in Figure 2:

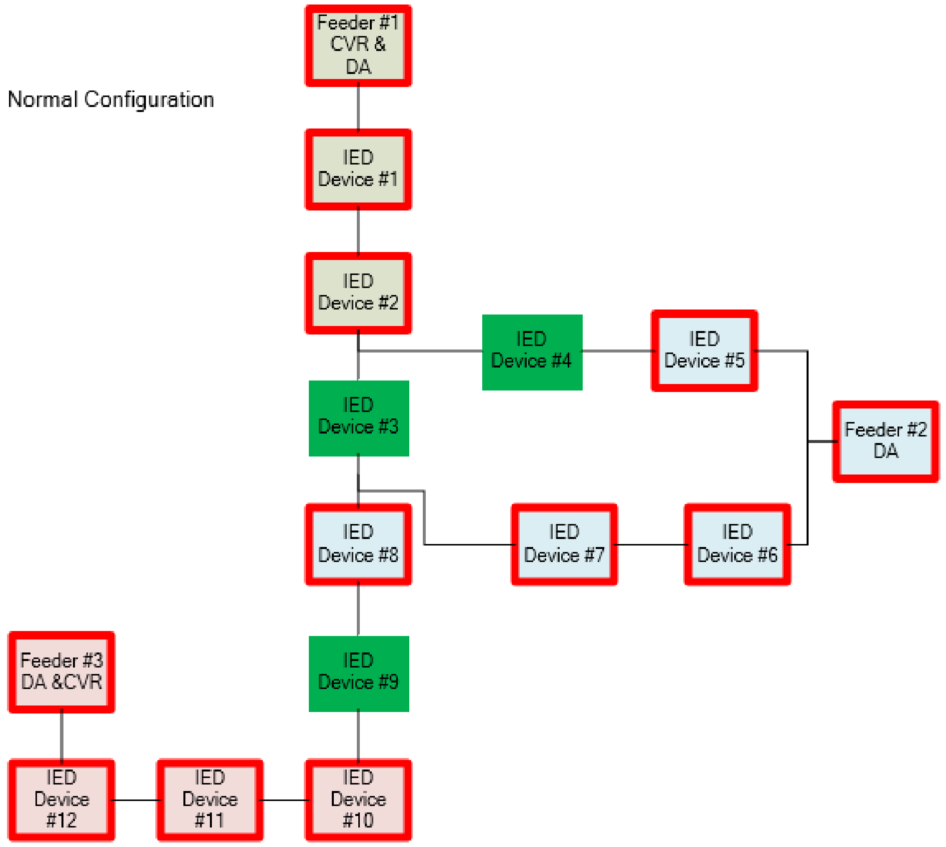

Figure 2 – Normal Configuration

A total of three abnormal circuit configurations were studied as the worst-case scenarios. This being defined as the most amount of line distance and load being added to the CVR system for which it was not designed to accommodate. The first, referred to as the A1 scenario, is where Feeder #1 (DA & CVR), is used to restore Feed #2 (DA) through IED Device #4. The single line of this configuration is below in Figure 3:

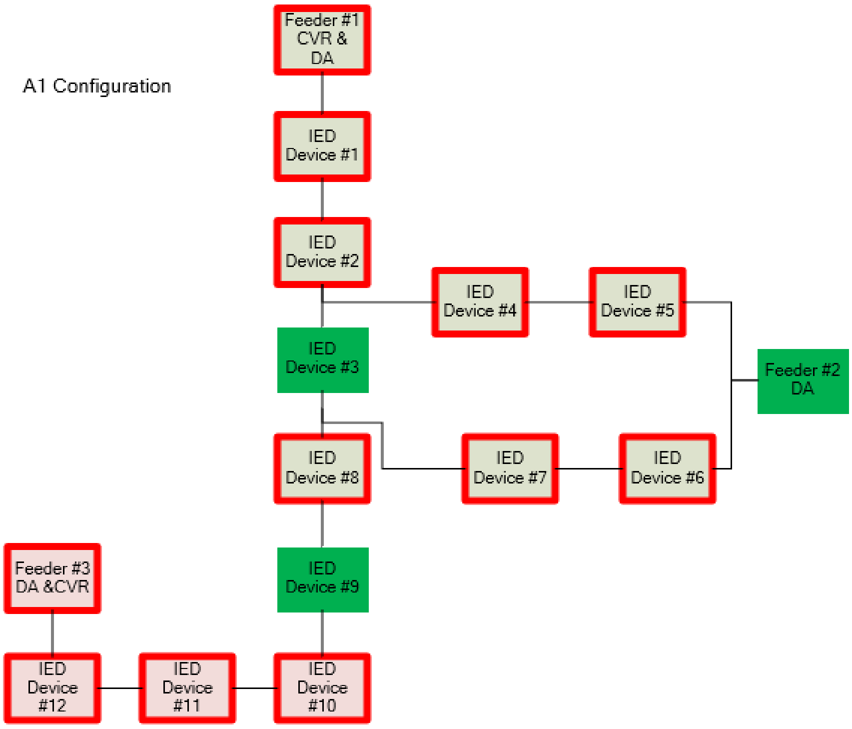

Figure 3 – A1 Configuration Case

The second configuration was defined as A2, is where Feeder #1 (DA&CVR), is used to restore Feeder #2 (DA) through IED Device #3. The single line of this configuration is below in Figure 4:

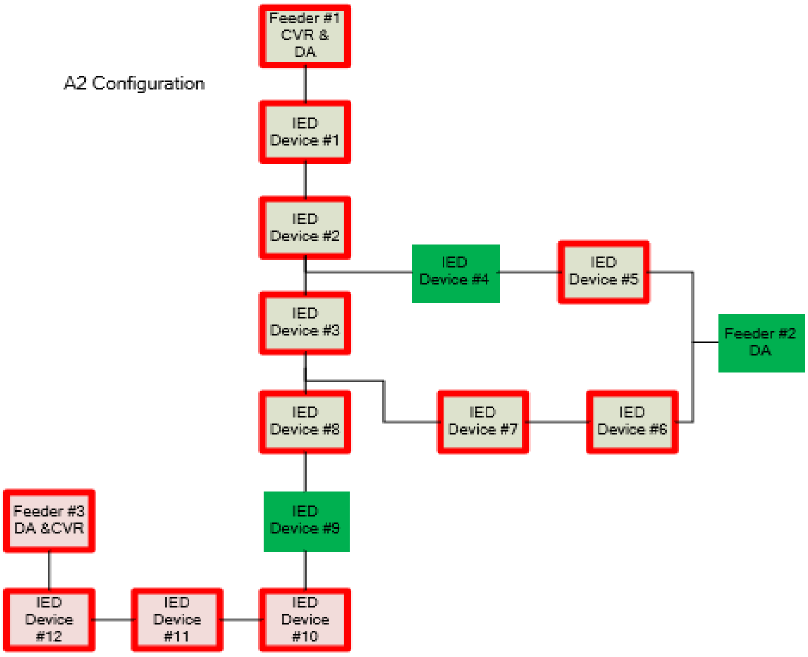

Figure 4 – A2 Configuration Case

The final configuration was defined as A3, is where Feeder #3 (DA&CVR) is used to restore Feeder #2 (DA) through IED Device #9. The single line of this configuration is below in Figure 5:

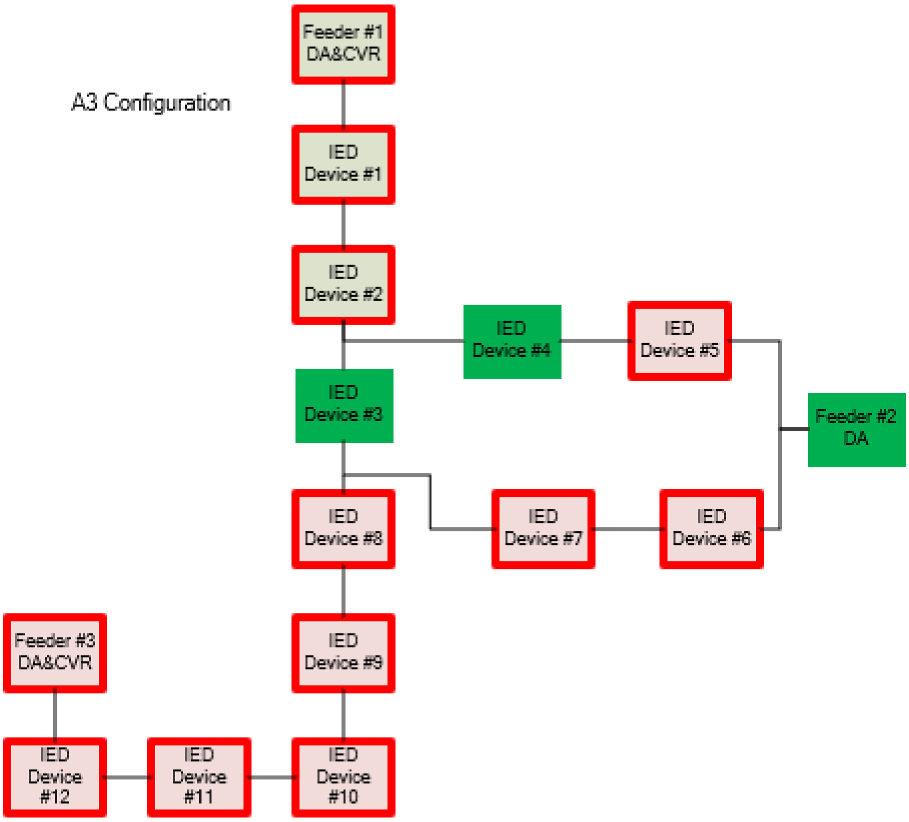

Figure 5 – A3 Configuration Case

Time Series Analysis Results

Time series analysis was performed on all three configurations with traditional regulation settings and CVR regulation settings to view operational performance between the two regulation settings. Because these scenarios are considered N-1 configurations, voltage ranges were dropped into Range B of ANSI C84.1. Voltages below 116V on a 120 base were considered violations. This value was selected to account for voltage drop in the service transformer, secondary voltage drop to the metering point of the customers, and a small buffer to account for model accuracy. Results discussed below are the lowest measured hourly voltage value on the CVR feeder used for restoration. Results are shown below for the A1 Configuration in Figure 6 and Table 3:

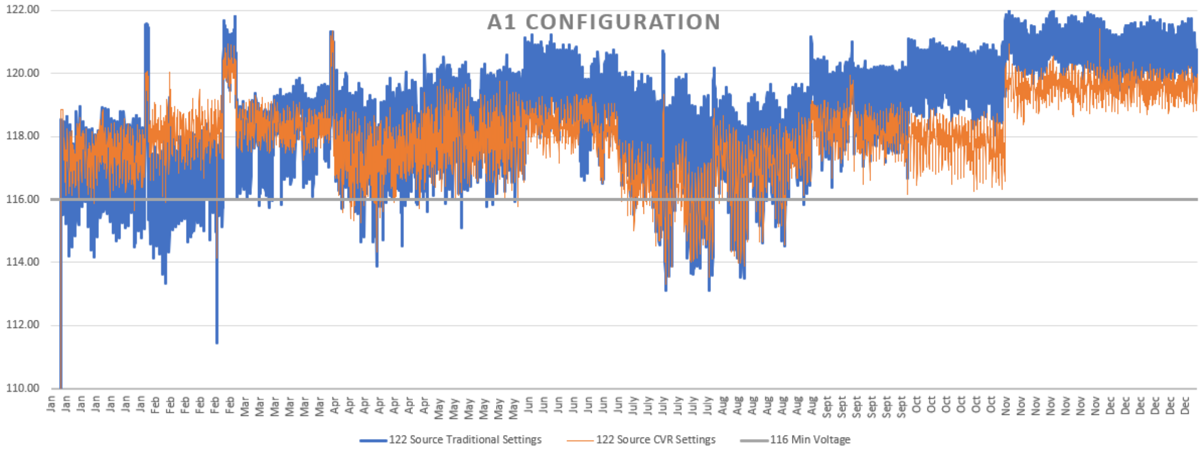

Figure 6 – A1 Configuration Results

Number of Hourly Violations			
Case	Traditional Violations	CVR Violations	CVR > Traditional within Violation
A1	590	396	129

Table 3 – Numbers of Hourly Violations A1

As the graph and the table show, the CVR settings are typically outperforming the traditional, although both have violations where voltages were below 116V. Although within the identified of violations of the CVR system, the CVR violations were less than the traditional violations roughly 33% of the time. Overall the CVR system would have violations of the voltage criteria for 4.5% of the year, if automation was to perform its restoration in this configuration.

Results from the A2 Configuration study are shown below in Figure 7 and Table 4:

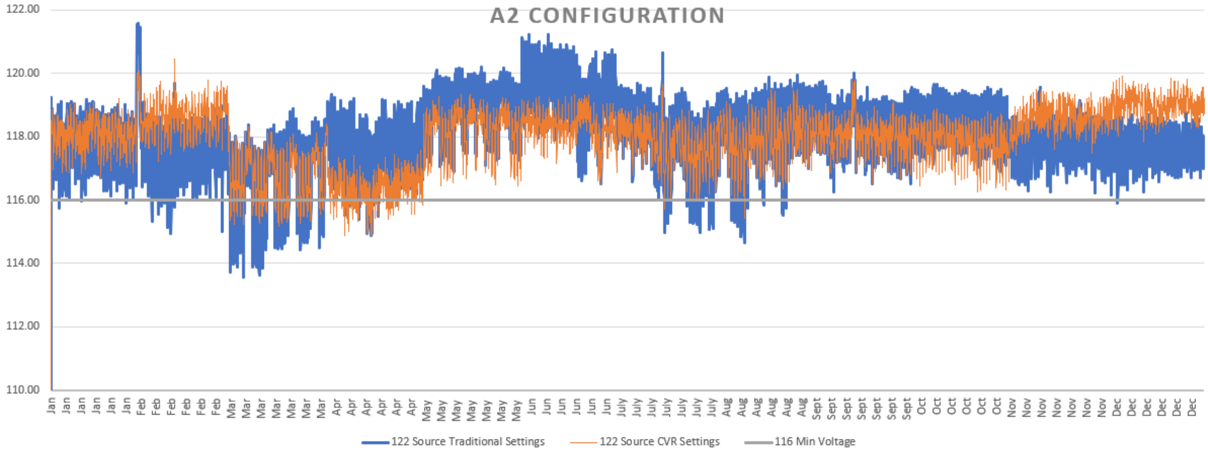

Figure 7 – A2 Configuration Results

Number of Hourly Violations			
Case	Traditional Violations	CVR Violations	CVR > Traditional within Violation
A2	457	328	152

Table 4 - Number of Hourly Violations A2

As the graph and the table show, the CVR settings are typically outperforming the traditional, although both have violations where voltage was below 116V. Although the A2 case has fewer violations than the A1 case. CVR also typically had less of a voltage violation than the traditional settings when a violation occurred. In this case 46% of identified CVR violations, CVR had a voltage that was closer to the minimum of 116V than the traditional settings.

Results from the A3 Study configuration are below in Figure 8 and Table 5:

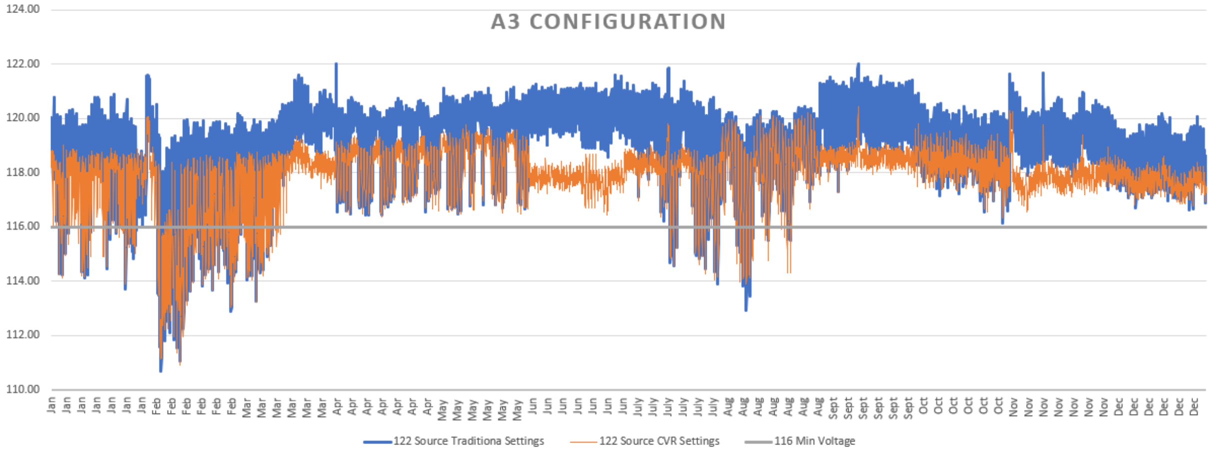

Figure 8 – A3 Configuration Results

Number of Hourly Violations			
Case	Traditional Violations	CVR Violations	CVR > Traditional within Violation
A3	414	640	148

Table 5- Number of Hourly Violations A3

For this case, the traditional settings outperformed the CVR system. It appears that the higher system loading impacts caused many of these voltage violations as most were in January, February, early March, July, and August. All those time periods are considered peaking times for the PSE system.

Time Series Analysis Conclusion

The times series analysis successfully showed the distribution system impact around integrating the DA FLISR and CVR system successfully. In the case of using Feeder 1 to restore Feeder 2, the CVR settings performed better than the traditional settings in both configurations studied. The recommendation would be for the A2 restoration path to be the preferred path. This can be done with a simple software configuration within the centralized DA FLISR software.

For the A3 case where the traditional settings outperform the CVR settings, we can use the time series analysis data to determine configuration changes necessary to limit the amount of load DA should restore. In the case of February, if we limit the restoration to a total of 2.9MVA at the normal open point, CVR settings will have no voltage violations. Further investigation across the year would need to be explored, and then the potential impacts to reliability would also need to be vetted before implementing.

Other solutions to make the integration between the two systems perform optimally would be to investigate developing different CVR R&X settings for the LTC. Today, settings are developed upon the 50% load factor of the feeder at peak season. Time series analysis could be used to determine which section of the line provides that 50% load factor over the year. This might make for a more efficient setting that represents the regulation point accurately.

Settings also could be created utilizing the abnormal configuration of the DA restoration case, although this could negatively impact the energy savings of the CVR system in the normal system configuration. Another solution would be to move towards a more active solution. Feeder 2 has a set of line regulators on it that could have SCADA control added to them and logic could be implemented to change settings to boost regulation on that feeder after a restoration event. SCADA control also could be added to the LTC controller on the CVR transformer to switch settings.

Another low-cost solution would be to utilize the bi-directional passive setting of the regulator and develop settings for restoration for that. Optimal placement of the regulator for restoration could also be explored.

This is one example of where a time series analysis can be a tool for future planning needs as the distribution system has additional modernization systems deployed. As we move forward to integrate more systems on the distribution system these types of studies will become a toolset that distribution planning engineers will need to deploy, whether it is for CVR and DA integration, for distributed energy resource impacts, and/or non-wired alternative studies.

BIBLIOGRAPHY

[1] United States Department of Energy Smart Grid System Report "2018 Report to Congress" (page 4)