CCVT Transient Surge Suppression

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INTRODUCTION

Puget Sound Energy (PSE) implements a variety of transmission auto schemes in order to isolate faults on the 115kV transmission system. There are two significant ramifications with this standard design:

1) a motor operated switch will automatically open or close to energize a section of transmission line and
2) a motor operated switch will be manually operated to drop line charge or re-energize a section of line for maintenance purposes.

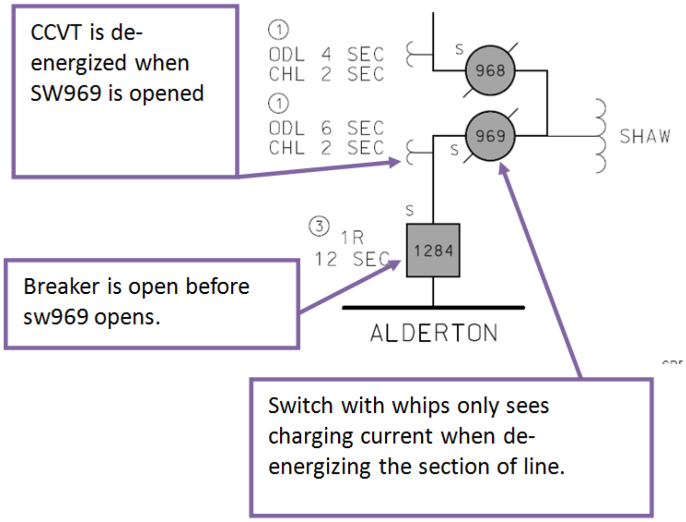
In both scenarios there are instances where a motor operated switch with either whips or arcing horns will be used to de-energize and energize a CCVT along with the section of transmission line being isolated. It is known that CCVTs will produce transients on the electric system. However, in 2015 and 2016 there were several substation projects which involved installing or making changes to a CCVT intended for line potential sensing. As the crews were working in the substations, arcing was observed on the control wires and the test switches of the CCVT as the 115kV switch would energize or de-energize the section of line with the CCVT. Several consequences were: visible arcing in the control house, restarts of the RTU, several communication modems were destroyed, and several RTU communication ports were no longer functional.
This was observed at several locations and was deemed a safety issue. Therefore the investigation was started to better understand the issue and to develop a suitable solution.

PSE TRANSMISSION AUTO SCHEME

Puget Sound Energy has adopted a 115kV transmission auto scheme that utilizes breakers and switches to isolate and sectionalize segments of the transmission system. In the image to the right, if the segment of line between breaker 1284 and SW969 were to be de-energized due to maintenance or construction, the process would be:

1) Open Breaker 1284 (this means Shaw substation is being fed radially from the north end).
2) Open SW969 to drop the line charge on the section of transmission line. This will also de-energize the CCVT.

One of the inherent consequences of this design is there will be 115kV switches used to drop or pickup line charge to isolate sections of the transmission line. This would include CCVTs installed on the system.



CCVT is de-energized when SW969 is opened

Breaker is open before sw969 opens.

Switch with whips only sees charging current when de-energizing the section of line.

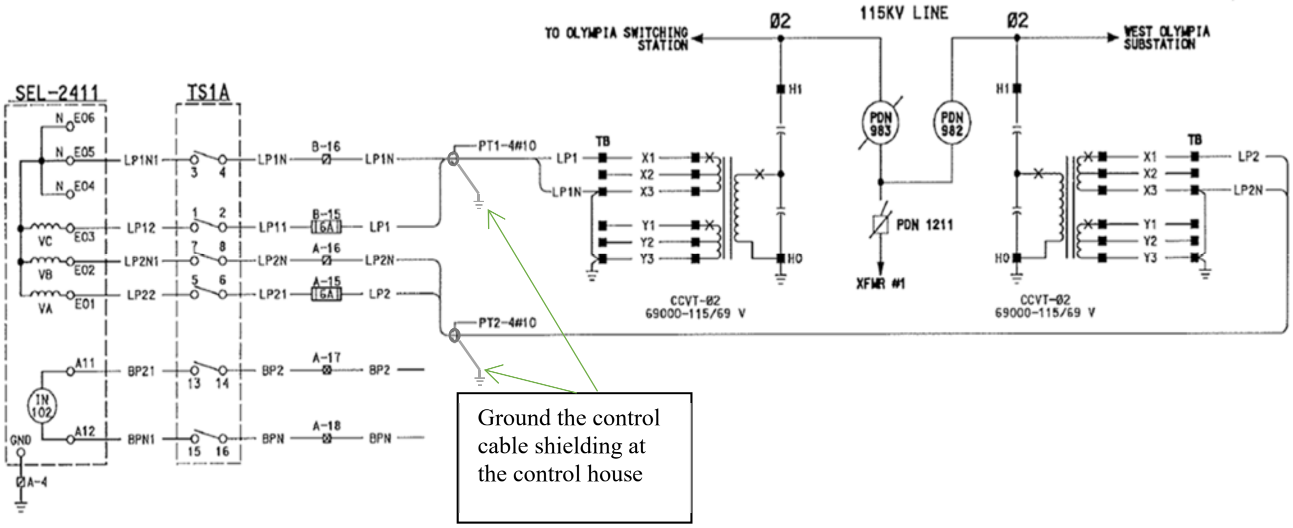
Example of the transmission line switching

Figure 1

CCVT CONTROL DESIGN

Several years ago, PSE implemented a design change to the CCVT secondary control circuit. In the schematics below, the neutrals for the New and Old control designs were both grounded at the CCVT. Also, the control cable shielding for both the New and Old designs were grounded at the control house. However, the new design does not include a separate surge protection device (SPD) which is indicated by SA1 (Surge Arrester 1) in the old schematic. The assumption and what was communicated by the manufacturer is there was sufficient surge suppression designed into the CCVT, therefore with the modern design additional surge protection is not necessary. Also, the new design includes an SEL-2411 which adds about 10kΩ of impedance to the circuit, whereas the old design had a Struthers Dunn relay which adds about 500Ω.

New 115kV Line Potential Sensing Schematic

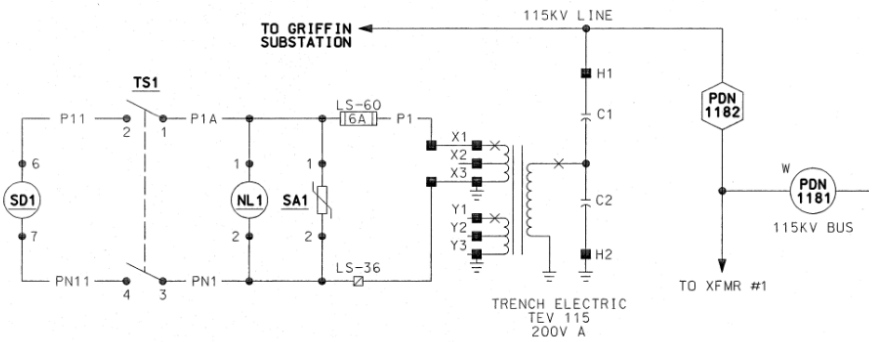


Ground the control cable shielding at the control house

The new control schematics for CCVTs

Figure 2

Old 115kV Line Potential Sensing Schematic



An example of an old style control schematic for CCVTs

Figure 3

LOCATION OF ARCING

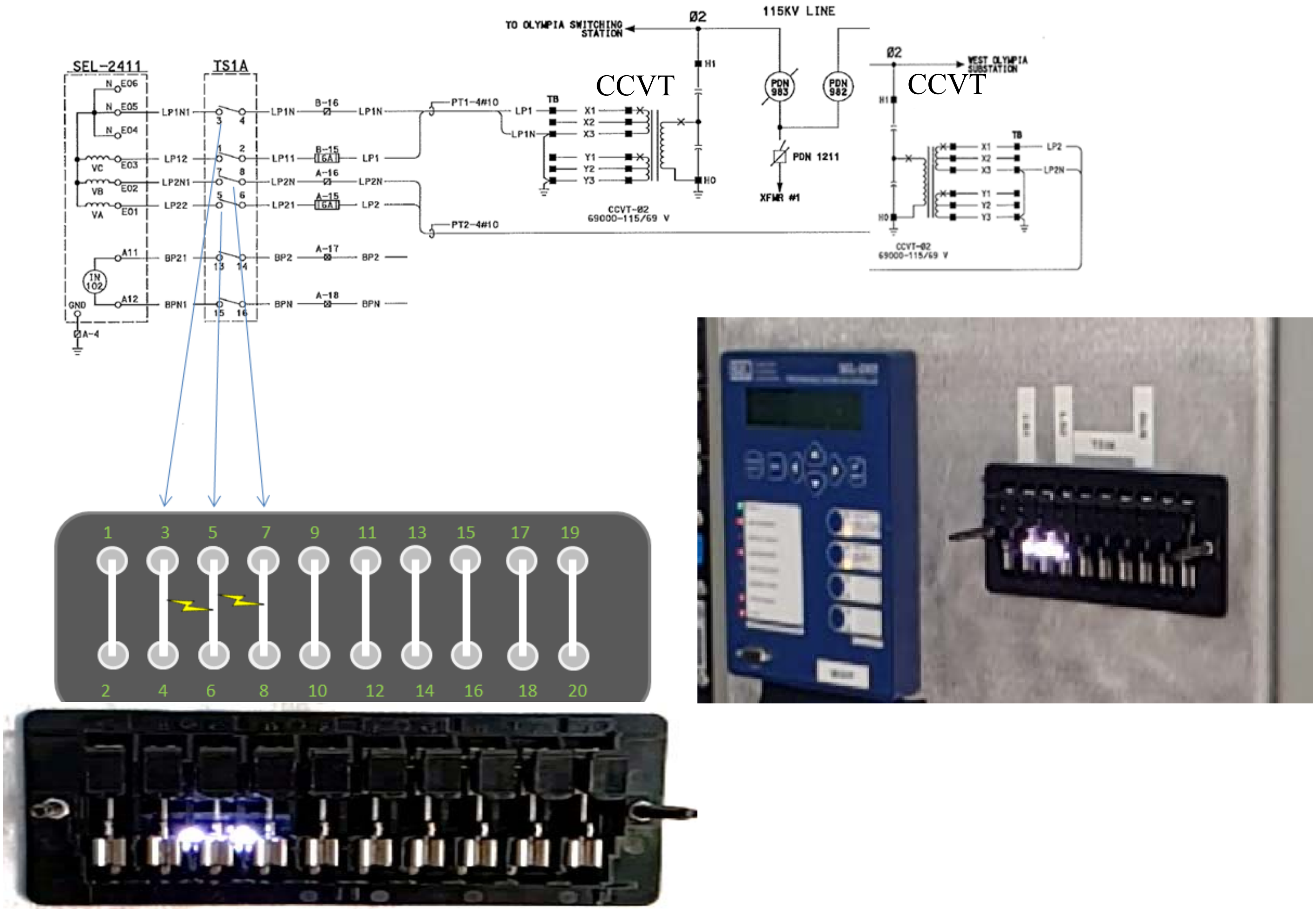
Arcing was seen only on the new 115kV line potential sensing design with the SEL-2411 as shown in the images below. The arcing due to the high magnitude transient produced was visually seen at:

- The test switches (this was the main location of the arcing)
- Back of the SEL-2411
- On some of the comm ports of the RTU

This immediately prompted a few questions:

- How is this significant transient being produced that would cause arcing on the test switches?
- What is the design difference between the New and Old control wiring configurations?

In the situation provided below there are two CCVTs for line sensing in the substation. In the situation where CCVT2 was being de-energized, the arcing occurred between the test switch positions of LP1N (neutral CCVT1) and LP22 (115V hot leg of CCVT2), also between LP22 and LP2N (neutral CCVT2). The test switches and the control wiring are rated for up to 600V.



The schematic and the images of the test switches show the electrical connection and the physical effects

Figure 4

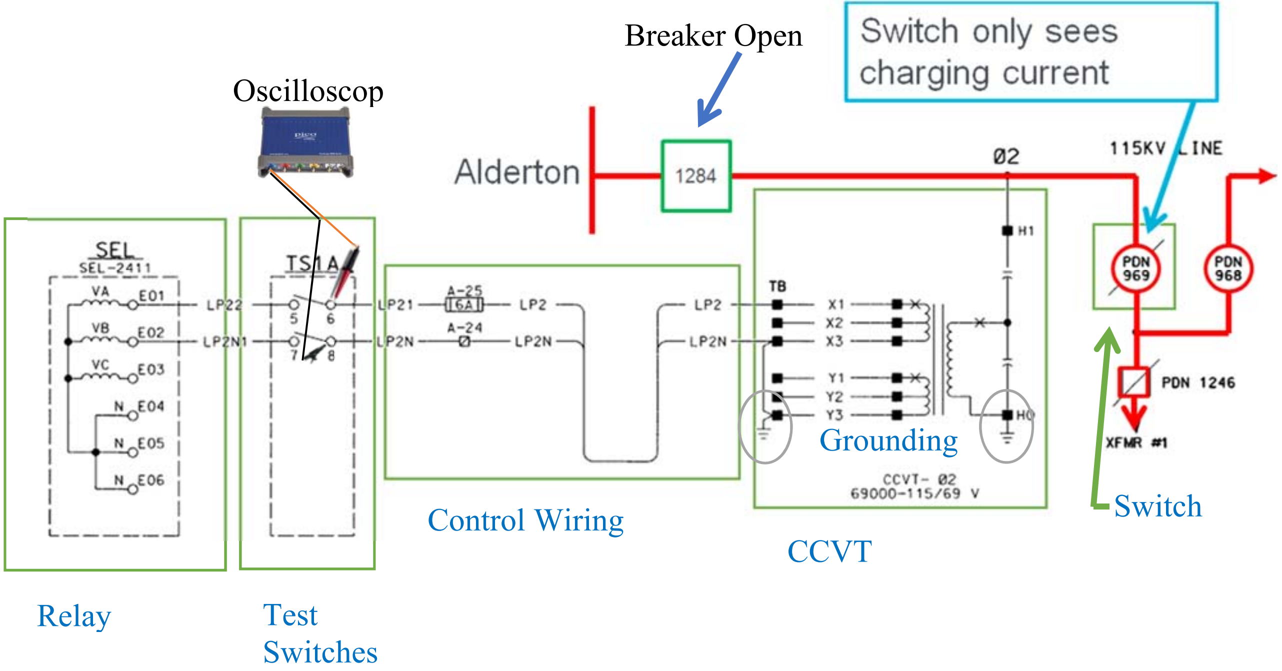
TESTING

There is a lot of supporting information to show CCVTs produce transients. Therefore, this fact changes the tack with regards to understanding the issue and determining a solution. The pursuit is not to eliminate transients produced, but to strive to manage, suppress or minimize the transients produced. Several specific items investigated under these categories were:

a. Transient Suppression
    i. Surge Protection Device (SPD)
    ii. CCVT Spark Gap
    iii. Potential sensing device design
b. Transient Management
    i. Grounding
c. Transient Minimization
    i. De-energization speed (fast vs slow operating device)

Test Setup:

Below is a diagram showing the different regions of the system that were investigated while there was an oscilloscope measuring the voltage between LP21 and LP2N (essentially the voltage output produced by the CCVT while it was being energized and de-energized). The majority of the test scenarios were administered under the guidance of a manufacture rep.



This shows the different elements of the system that were tested

Figure 5

Test Results:

The variety of scenarios and results that seemed to have no effect on the arcing and the transient magnitude measured:

Test#	**Conditions and changes made**	**Results**
1	Normal configuration of the new control scheme	Arcing on the test switches
2	Test switches open (SEL-2411 isolated from the control circuit)	Arcing on the test switches
3	Changing the CCVT output voltage from 115V to 69V	Arcing on the test switches
4	SPD tied to only the LP22 and LP2N	Arcing on the test switches
5	Ground the neutrals of the control scheme at the control house (rather than at the CCVT)	Arcing on the test switches

The variety of scenarios and results that decreased the transient magnitude but did NOT prevent the arcing across the test switches:

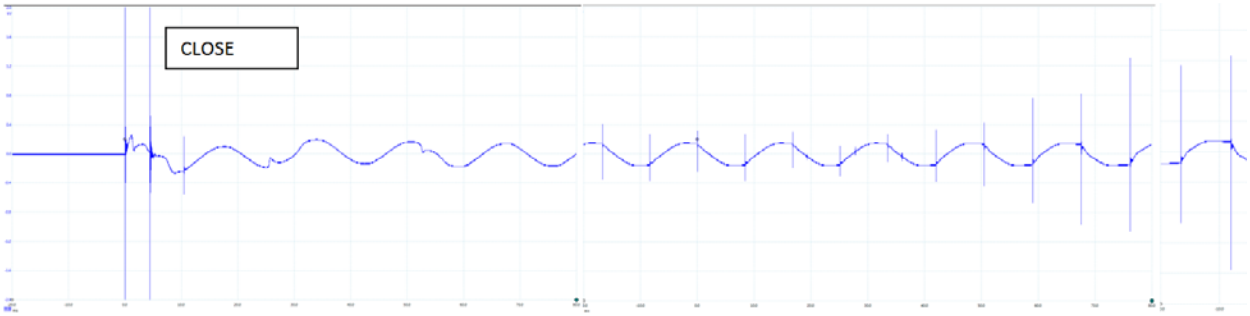
Test#	**Conditions and changes made**	**Results**
6	Control wire shielding grounded at the control house and the CCVT	Decreased transient magnitude but still had arcing on the test switches
7	Changing out the spark gap	Decreased transient magnitude but still had arcing on the test switches
8	Changing the burden in parallel to the circuitry (250Ω, 500Ω and 1000Ω)	Decreased transient magnitude but still had arcing on the test switches

The variety of scenarios and results that significantly decreased the transient magnitude and had NO arcing on the test switches:

Test#	**Conditions and changes made**	**Results**
9	Energizing and de-energizing the CCVT via a breaker (i.e. a fast operating device)	Minimal voltage spike measured and no arcing
10	Swapped out the CCVT with a Wound PT	No Arcing
11	Testing a resistive pot device	No Arcing
12	Operating a line switch with whips (rather than a substation switch)	Minimal voltage spike measured and no arcing
13	Installed a SPD in parallel to the control circuitry and was specifically grounded to the earth ground (i.e. not to the neutral wire)	No Arcing

Example Voltage Plots Recorded with the Oscilloscope:

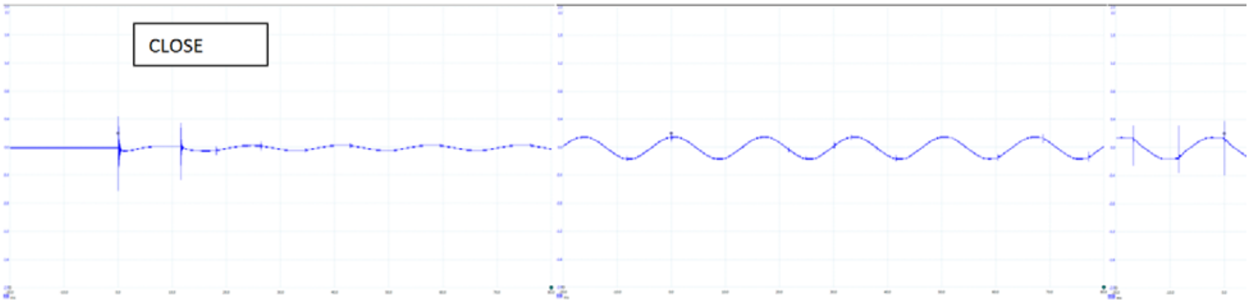
1) Normal conditions
    a. Voltage spike was reaching a peak of greater than 2000 V



The voltage seen on the control wires as a 115kV line switch is in the process of a closing operation

Figure 6

2) SPD Installed and grounded to the earth ground
    a. Voltage spike reaching up to about 400 V (which is acceptable with the short duration)



The voltage seen on the control wires after an SPD has been installed as a 115kV line switch is in the process of a closing operation

Figure 7

ELECTRO-MAGNETIC TRANSIENT PROGRAM MODEL (EMTP)

Within PSE, an Electro-Magnetic Transient Program model specialist modeled the arcing scenario to better understand the issue. There were several limitations with the EMTP model:

- The arcing model that was used came from IEEE papers which will be similar to our system but not exact
- This model does not capture a 115kV switch restrike scenario

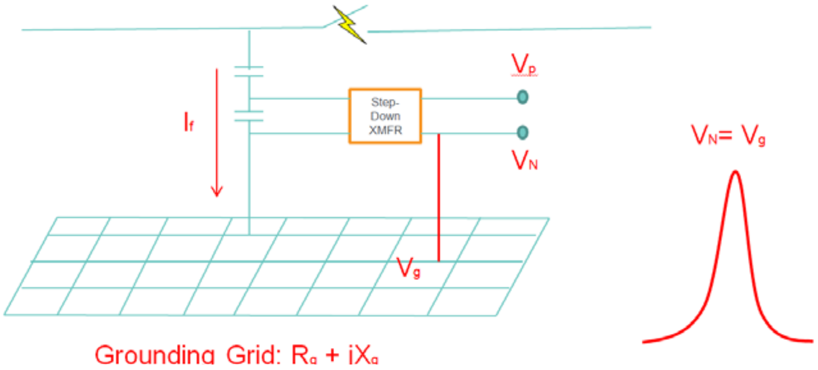


Diagram of the EMTP model
Figure 8

The EMTP modeling provided a clear relationship between the magnitude of the transient and ground configuration. Essentially, if the impedance from the CCVT circuitry to the ground grid is decreased then the magnitude of the transient will be decrease as well. However, is this enough to prevent the arcing? From the testing mentioned above it is clear that the changes made to the grounding grid per the recommendations were not able to prevent the arcing across the test switches.

The final conclusions from the EMTP study were as follows:

1) The CCVT control cable should be a shielded cable with one continuous run from the CCVT to the control house (i.e. no make-up boxes or splices in the control cable when pulling the cable through conduit)
2) The control cable shields should be grounded at both the CCVT and the control house (this was also recommended by the manufacturer and another utility using CCVTs)
3) Run one or two 4/0 solid copper grounding conductors in parallel and in close proximity to the control cables in order to decrease the effect of magnetic coupling
4) Use PVC conduit in order to decrease the capacitive coupling affects between the overhead high voltage conductors and the control wire
5) If needed, look at using triaxial cable which minimizes the effects of magnetic coupling

CAUSE OF THE VOLTAGE TRANSIENT

It is clear the grounding of the CCVT control cable has an effect on the transient magnitude but changes to the grounds were not able to eliminate the arcing issue in this situation. The conclusion for the primary variables causing the voltage transients is the combination of a 115kV switch used to energize and de-energize a section of line with a CCVT. In the event of a switch opening and closing there is going to be reignition and restrike from the switch which would rapidly charge and discharge the CCVT.

The EMTP model and the oscilloscope recordings during testing show that in the event of the CCVT being energized or de-energized there are short duration high frequency transients produced (close to the 600 hertz). As can be seen from the equation below, as the frequency seen by the CCVT increases this will cause the capacitive impedance of the CCVT to decrease, which is going to have a direct effect to the voltage ratio between the primary and secondary of the CCVT. As a result, a higher voltage will be seen on the secondary side of the CCVT.

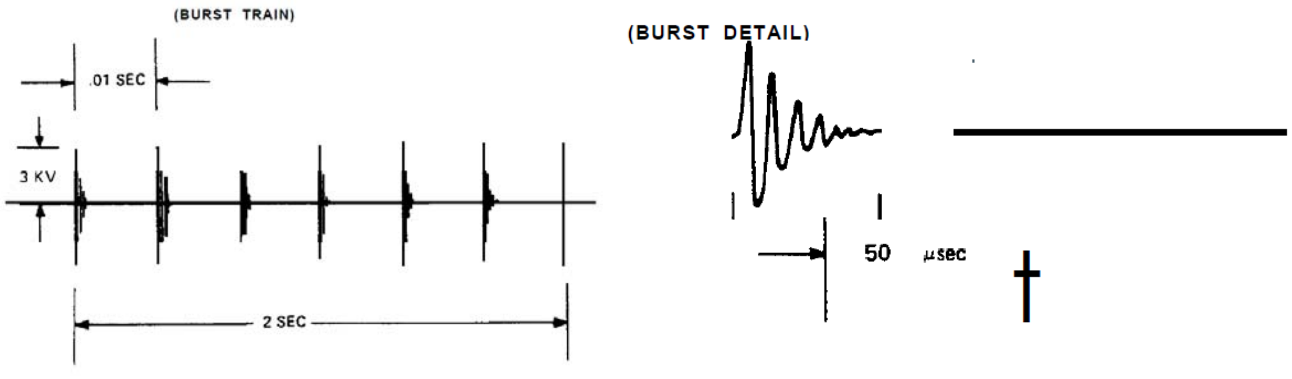
$$Xc = \frac{1}{2 * pi * f * C}$$

Xc = Capacitive reactance in ohms
f = frequency in hertz
C = capacitance in farads
pi = 3.1416…

In the white paper "Substation Transients and Solid State Controls" by GE[1], they state:

> *"The transients originate in the re-striking or prestriking of the switch during either opening or closing operations. This is a very powerful transient source which may be coupled to a low voltage control circuit over a wide area, and thus appear on widely separated parts of that circuit. Usually it appears most strongly on secondary cables from high voltage instrument transformers and dc control wiring connected to high voltage equipment associated with the switched bus."*

An image in GE's document to illustration the possible profile of a transient produced by switch restrike is provided below:



Illustrations provided in the white paper "Substation Transient and Solid State Controls" by GE

Figure 9

The waveforms captured by the oscilloscope during testing have very similar characteristics of the restrike scenario as described by GE

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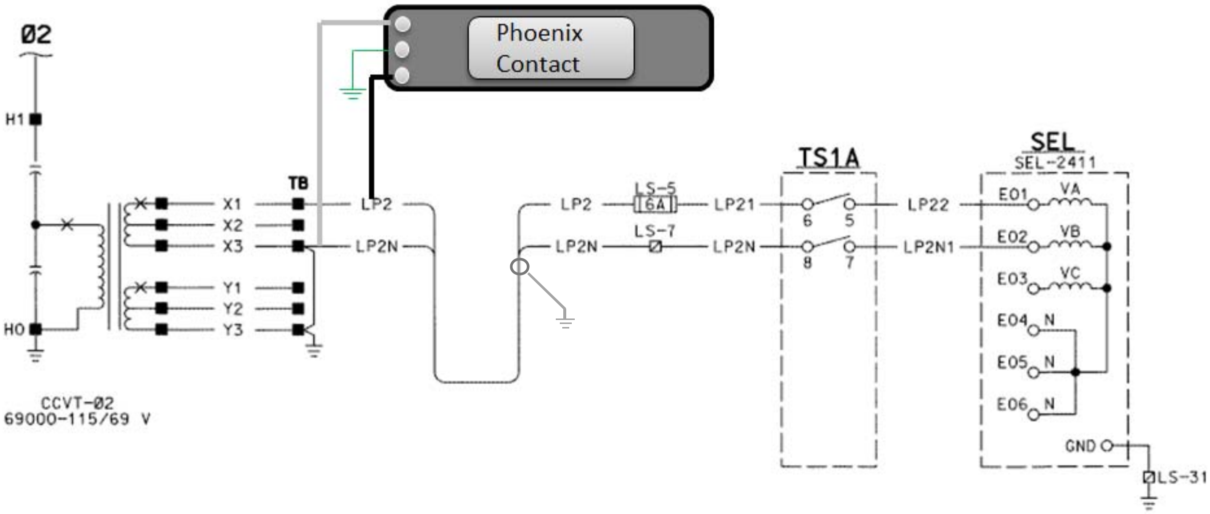
CONCLUSION

The discovery that the primary issue is the utilization of 115kV switches to energize and de-energize CCVTs for isolating sections of the transmission line and the understanding that the grounding influences the magnitude of the voltage transient has resulted in a two phase solution.

Phase 1: Mitigating the Existing Issue on the System

Installing surge protection devices on the control cables proved to prevent the arcing on the test switches. It does not totally eliminate the transient, but it does suppress the transient to an acceptable level and prevents the arcing on the test switches. These SPDs will be installed in parallel to the control wiring at all locations where the CCVT has potential for being energized or de-energized via a 115kV line switch.



An illustration of a surge protection device installed in parallel to the control circuit

Figure 10

Phase 2: Standardize the Future Design for 115kV Potential Sensing

Presently, Puget Sound Energy is in process of finalizing the standard design for 115kV potential sensing. However, several options being explored are:

A) Replace the CCVT with a Wound PT
B) Replace the CCVT with a Resistive Potential Device
C) Modify the CCVT control wiring to include the following:
    a. Surge Protection Device
    b. Continuous cable runs from the CCVT to the control house with shielded cable
    c. Ground the cable shielding at the control house and the CCVT
    d. Add 4/0 solid copper ground in parallel with the control wiring
D) Modify the control cable conduit similar to a neighboring utility

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REFERENCES

1. W. C. Kotheimer, "Substation Transients and Solid State Controls," 51st Annual Northwest Electric Light and Power Conference, Yakima, Washington, April 23, 1974.

BIOGRAPHY

Kevin Gowan is a substation field engineer for Puget Sound Energy located in the beautiful Northwest. He has enjoyed the past 5 years at PSE. In addition to his present role, Kevin has also worked as an Electric Distribution System Planner, been majorly involved with storm restoration, was selected to work on a process improvement team, managed special projects, and implemented a custom Storm Damage Assessment App. Kevin has a Bachelor's of Science in Mechanical Engineering from Washington State University and has received certifications in Electrical Engineering and is in process of getting his masters.