Interconnection System Impact Study Report
Request # GI-2007-5 Re-Study

50 MW Wind Generation Expansion Interconnecting at Keenesburg

PSCo Transmission Planning
October 26, 2010

A. Executive Summary

The purpose of the GI-2007-5 System Impact Re-study is to evaluate the Generation Provider's request to phase-in the first 50 MW of the 250 MW Cedar Creek Wind Energy Expansion (CCWE2) Project around January 2011. This represents the first phase of the 250 MW wind generation facility prior to the completion of the Ft. St. Vrain-Keenesburg–Green Valley 230 kV Project that requires looping the Ft. St. Vrain-Green Valley 230 kV line into the Keenesburg Substation. The GI-2007-5 System Impact Study that was completed on December 3, 2008 assumed the use of 20 Clipper 2.5 MW Liberty Series wind turbines. The Generation Provider has changed the wind turbines to GE 1.6 MW wind turbines and Nordex 2.5 MW units and the change in wind turbines coupled with different reactive power support requirements necessitated this re-study. The commercial operation date for the full CCWE2 Project is estimated as June 10, 2011.

The power flow analysis (based on the final configuration of General Electric and Nordex turbines) shows that for the 50 MW expansion, no network upgrades are required for delivery if the GE 1.6 MW and Nordex 2.5 MW wind turbines are installed and the planned DSTATCOMs, switched capacitors, and switched reactors are installed. The absence of the 120 MVAR of switched capacitors at the planned capacitor switching station (to be constructed by the Generation Provider) near the Keenesburg POI will have little impact on the PSCo system voltage level at the POI when the total generation from all connected wind turbines at the existing Cedar Creek Wind Energy (CCWE1) facility plus the 50 MW GI-2007-5 expansion increases from 300 MW to 350 MW. More detailed studies must be performed by the Generation Provider to ensure that proposed wind generation facility will display acceptable performance during the commissioning testing.

The transient stability analysis consisted of applying three-phase faults with normal clearing on the 230 kV transmission system at Keenesburg, RMEC, Green Valley, and at the Cedar Creek wind farm, with the STATCOM and the different wind turbines modeled. For the three-phase faults with normal clearing, the PSCO transmission system remained stable and all system oscillations damped out quickly with no criteria violations.

Faults on the CCWE1 and CCWE2 230-kV transmission system can result in the disconnection of all or a portion of the wind generation associated with the existing 300 MW CCWE1 facility and/or the proposed 50 MW CCWE2 facility depending on the fault location. Faults on the CCWE2 system (the 230 kV branch from the Cedar Creek 230 kV Tap to the CCWE2 site) should be cleared without tripping the CCWE1 generation facility. Conversely, faults on the CCWE1 system (the 230 kV branch from the Cedar Creek 230 kV Tap to the CCWE1 site) should be cleared without tripping the CCWE2 generation facility. These are planned tripping schemes and should not have an adverse impact on PSCo's transmission system.

However, this restudy determined that a three-phase 230 kV fault on the CCWE1 system near the Cedar Creek Tap will result in the planned disconnection of CCWE1 generators and the unexpected tripping of generators at the expansion facility. While the loss of the 230-kV Cedar Creek – Keenesburg line will result in the complete loss of power deliveries to Keenesburg, the design of the system between Cedar Creek Tap and the various 230/34.5 kV transformers is such that a fault in this area should not result in the unexpected loss of CCWE1 or CCWE2 generation and resultant need for replacement power. Other than the loss of more than planned generation by the generation providers of CCWE1 and CCWE2, there are no adverse impacts on the PSCo transmission system. These unexpected results are being studied by the Generation Provider.

B. Introduction

The purpose of this System Impact Re-Study is to evaluate the Generation Provider's request to phase in the first 50 MW of the 250 MW Cedar Creek Wind Energy Expansion (CCEW2) around January 2011. The study would determine the potential system impacts associated with the addition of the first 50 MW of the future 250 MW expansion of the existing 300 MW Cedar Creek Wind generation facility, based on the interconnection request GI-2007-5. The existing 300 MW CCWE1 facility interconnects to the bulk transmission system at the Keenesburg 230 kV bus (the Point of Interconnection or POI) through a 78-mile line. The CCWE2 expansion facility will be located about 20 miles north of New Raymer, in Weld County, Colo., and east of the existing 300 MW CCWE2 facility. The expanded facility connects to the existing facility through a 20-mile, 230 kV radial line.

On May 20, 2010, the Generation Provider entered into a long-term power purchase agreement (PPA) with PSCo. PSCo agreed to purchase 250 MW of electric power from CCWE2. This power supply acquisition was part of the 2009 All Source Solicitation for energy generators that is part of PSCo's 2007 Colorado Resource Plan. On June 16, 2010, the GI-2007-5&6 System Impact Restudy 2 was completed. The study confirmed that the delivery of the full 250 MW CCWE2 Project would require looping PSCo's St. Vrain-Green Valley 230 kV line into Keenesburg to prevent overloads on PSCo's system. The Generation Provider reviewed the study results and requested that another study, this study called "GI-2007-5 System Impact Restudy", be performed to determine if 50 MW of the 250 MW CCWE2 Project could be delivered at the Keenesburg POI

prior to PSCo's looping in St. Vrain-Green Valley 230 kV line into Keenesburg. This study consists of both steady state power flow analysis and dynamic analysis. The estimated in-service date for the 50 MW portion of the 250 MW CCWE2 project is January 2011.

C. Power Flow Study Models

Since the first 50 MW of the CCWE2 expansion project is looking to interconnect in January 2011, PSCo transmission developed a base case from the Western Electricity Coordinating Council (WECC) 2011 Heavy Winter (HW) operating case and modified it for PSCo-approved projects and topology changes. From this 2011 base case, the following changes were made in Area 70 (PSCo Transmission) to simulate high north-to-south stressed system conditions.

- The Area 70 slack bus was moved from Cherokee unit 3 to Comanche unit 1.
- The generation at RMEC units was increased to maximum capacity.
- The generation at Cherokee units was increased to near maximum capacity.
- The generation at Ft. St. Vrain units was increased to near maximum capacity.
- The simplified model of the existing 300 MW CCWE1 facility was replaced by a more detailed model and the generation was set to its full capacity.
- This increase in generation was accommodated by decreasing generation at Comanche and Spruce, and by taking the Ft. Lupton units off-line.
- To increase the flow across TOT 3, the area interchange from Area 73 (Western RM) to Area 70 was increased by 300 MW. This was done by increasing the Sidney DC Tie schedule by 300 MW importing and decreasing the Lamar DC Tie schedule by 300 MW, from 100 MW importing to 200 MW exporting.

The power flow case obtained after making these changes to the 2011 HW WECC case constitutes the benchmark case for this study.

The proposed 250 MW expansion facility (GI-2007-6) consists of a combination of GE 1.6 MW and Nordex 2.5 MW units. The generation facility for this 50 MW restudy was modeled by connecting select feeders of the 250 MW facility and disconnecting the remaining feeders. All the in-service generators were at maximum capacity and 50 MW of generation was achieved by taking units off-line. Three different configurations of the generation facility were studied, as described below:

1. 50 MW from only GE Units;
2. 50 MW from only Nordex Units; and
3. 25 MW each from GE and Nordex Units.

The additional generation at Cedar Creek was accommodated by decreasing the output of Comanche Unit 2.

All the feeders for the expanded facility were represented in full detail with every individual turbine modeled. Based on data from the customer, two 7.5 MVAR DSTATCOMs and two 22 MVAR switched reactors will be installed at the generation facility. Therefore, one STATCOM and one switched reactor were modeled at each of the two 34.5 kV substation buses for this study. The STATCOMs control the operation of the reactors.

The Generation Provider plans to install a 120 MVAR switched capacitor bank (to be constructed by the Generation Provider) near the Keenesburg POI. While the switched reactors and the STATCOMs are proposed to be energized around the same time as the wind turbines, the switched capacitors at the POI are expected to be in operation more than a month after the turbines are in operation. Therefore, two sets of analyses were performed – with and without the POI capacitor bank.

D. Steady State Power Flow Results

Thermal Overloads

Power flow contingency analysis was performed for the benchmark case and the power flow cases with three different wind turbine configurations for the 50 MW expansion (only GE, only Nordex and a combination of GE and Nordex units). The comparison of the results of the cases with the 50 MW expansion against the benchmark case indicates that no thermal overloads are caused by the addition of 50 MW at Cedar Creek, even without tapping the Green Valley to Ft. St. Vrain line at Keenesburg.

Voltage Criteria Violations

The study determined that the addition of the 50 MW facility at Cedar Creek decreases the Keenesburg 230 kV bus voltage (POI) from 1.020 per unit to 1.017 per unit. The CCWE wind facility (at 350 MW) draws about 45 MVAR of reactive power from the PSCo system at the POI until the POI capacitor bank is installed. Once installed, the capacitor bank by the POI needs to be set to at least 30 MVAR in order to keep the connection VAR neutral at the POI and the voltage level at Keenesburg near 1.02 per unit. The STATCOMs provide some voltage and power factor control at the POI, and supply a total of 15 MVAR. No additional voltage criteria issues were observed in the PSCo system as a result of the 50 MW expansion of Cedar Creek for any single line contingency in the Area 70 or the Area 73. Switching off the generation units at RMEC does not impact the voltage and reactive power requirements at the POI under contingency conditions.

The study area can experience periods of minimal wind speeds that reduces the available generation output. During periods of minimal wind generation at the existing Cedar Creek facility (CCWE1) and the expanded Cedar Creek facility (CCWE2), the voltage at the 230 kV Keenesburg bus increases from 1.020 per unit to 1.027 per unit.

The transmission lines associated with the generation facilities supply 33.5 MVAR of reactive power to the PSCO system. The STATCOMs automatically switch in the reactors at the Cedar Creek expansion facility and this keeps the interconnection at the POI "VAR neutral" and the voltages at all buses at the expanded generation facility and the existing CCWE1 system below 1.05 per unit.

E. Dynamic Stability Analysis and Results

Transient stability analysis was performed for various three-phase faults at the Keenesburg 230 kV bus, the RMEC 230 kV bus, the Green Valley 230 kV and buses at CCWE1 and CCWE2 (the expanded facility). Dynamic simulations of these faults were performed for each of the three power flow cases with the different configurations of wind turbines. In all the cases studied, the generation at each individual turbine was set at its maximum capacity, with desired generation levels established by the number of turbines connected online. No partial output of individual turbines was studied. Sensitivity analysis was also performed with and without the switched capacitor at the POI. Normal fault clearing time of 5 cycles for 230 kV facilities was used for this study. Table 1 tabulates the results of this analysis for the various contingencies studied.

The following was observed:

- The PSCo system remains stable and no voltage or frequency violations are observed on PSCo's system for all fault simulations studied.

- A fault at the CCWE1 230 kV substation bus and subsequent outage of part or the complete CCWE1 facility causes turbines on the CCWE2 facility (the 50 MW expanded facility) to trip under low frequency (in the case of GE units) or low voltage (in the case of Nordex units) (see Contingency 8 and Contingency 8a)

- A fault on the 230 kV bus at CCWE 2 facility (the 50 MW expanded facility) and the subsequent outage of one 230/34.5 kV transformer at CCWE2 causes the generators connected to the other transformer at CCWE2 to trip due to low voltage or low frequency. (See Contingency 11).

- The status of the proposed switched capacitor banks near the POI does not impact the study results.

- A fault at CCWE1 and a subsequent outage of part or the entire 300 MW facility when CCWE2 consists of only GE units causes the frequency at the turbines of the expanded facility to drop to about 52 Hz that leads to these units tripping about 0.25 seconds after the fault is cleared.

- A fault at CCWE1 and a subsequent outage of part or the entire 300 MW facility when CCWE2 consists of only Nordex units causes the terminal voltage of the wind turbines at CCWE2 to drop to below 0.05 per unit during the fault. This causes the Nordex units to trip instantaneously. This occurs only when the STATCOMs are in-service. Without the STATCOMs, the terminal voltage drops

to 0.06 per unit and recovers quickly, thus preventing any Nordex units from tripping due to LVRT.

- A combination of GE and Nordex units (for contingencies 8, 8a and 11) results in Nordex turbines tripping due to low voltage during the fault and the GE turbines tripping due to low frequency after the fault is cleared.

Table 1. Results of Stability Analysis with Normal Clearing Time

Num	Fault Location	Action	With 300 MW at CCWE	CCWE 2 50 MW GE with STATCOM	CCWE 2 50 MW GE with STATCOM & POI cap	CCWE 2 50 MW Nordex with STATCOM	CCWE 2 50 MW Nordex with STATCOM & POI cap	CCWE 2 50 MW GE+Nordex with STATCOM	CCWE 2 50 MW GE+Nordex with STATCOM & POI cap
1	Keenesburg 230-kV	Trip 230-kV line from Keenesburg to Cedar Creek	Stable, no viol *	Stable, no viol *	Stable, no viol *	Stable, no viol *	Stable, no viol *	Stable, no viol *	Stable, no viol *
2	Keenesburg 230-kV	Trip 230-kV line from Keenesburg to RMEC	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol
3	RMEC 230-kV	Trip 230-kV line from Keenesburg to RMEC	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol
4	Keenesburg 230-kV	Trip 230-kV line from Keenesburg to Green Valley	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol
5	Green Valley 230-kV	Trip 230-kV line from Keenesburg to Green Valley	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol
6	RMEC 230-kV	Trip 230-kV line from RMEC to Green Valley	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol
7	Green Valley 230-kV	Trip 230-kV line from RMEC to Green Valley	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol
8	Cedar Creek 1 230-kV	Trip 34.5/230-kV Xfmer from CCWE1 to CCWE1 bus A	Stable, no viol *	GE units at CC2 trip on under frequency after the fault is cleared.		Nordex units at CC2 trip due to low voltage before the fault is cleared.		Nordex units trip on low voltage before fault clearing and GE units trip on low frequency after the fault is cleared	
		Trip 34.5/230-kV Xfmer from CCWE1 to CCWE1 bus B							
8a	Cedar Creek 1 230-kV	Trip 34.5/230-kV Xfmer from CCWE1 to CCWE1 bus A	Stable, no viol *	GE units at CC2 trip on under frequency after the fault is cleared.		Nordex units at CC2 trip due to low voltage before the fault is cleared.		Nordex units trip on low voltage before fault clearing and GE units trip on low frequency after the fault is cleared	
9	-	Drop RMEC Unit 3	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol	Stable, no viol
10	Cedar Creek 1 230-kV	Trip 230-kV line from CCWE1 to CCWE 2	N/A	Stable, no viol *	Stable, no viol *	Stable, no viol *	Stable, no viol *	Stable, no viol *	Stable, no viol *
11	Cedar Creek 2 230-kV	Trip 34.5/230-kV Xfmer from CCWE 2 to CCWE2 bus B	N/A	GE units at CC2 trip on under frequency after the fault is cleared.		Nordex units at CC2 trip due to low voltage before the fault is cleared.		Nordex units trip on low voltage before fault clearing and GE units trip on low frequency after the fault is cleared	

* Generation disconnected

Detailed Dynamic Analysis for Faults on the Existing Cedar Creek Facility

The study determined that a fault on the existing Cedar Creek facility leads to LVRT and under frequency tripping of the units on the expanded facility. Therefore, further analysis was performed for these faults (contingencies 8 and 8a) for various configurations of CCWE1 and the expanded facility. The various configurations studied and the results of the stability analysis for each case are tabulated in Table 2. The contingencies studied in detail are as follows:

1. **Contingency 8:** A three phase fault on the 230 kV bus at the existing Cedar Creek facility. The segment between Cedar Creek 1 and the point at which Cedar Creek 2 connects to Cedar Creek 1 is outaged to clear the fault.
2. **Contingency 8a:** A three phase fault on the 230 kV bus at the existing Cedar Creek facility. One of the 230/34.5 kV transformers at Cedar Creek 1 is outaged to clear the fault.

As described earlier, when the generation at the expanded facility at Cedar Creek is 50 MW, the units at the expanded facility trip for a fault by the existing facility. The only exception is when the expanded facility consists of 50 MW of Nordex units only with no STATCOM installed.

Stability analysis was also performed for contingencies 8 and 8a with the generation at the expanded facility at the full 250 MW (combined GI-2007-5 and GI-2007-6), with and without the STATCOMs (Table 2 configurations 6 and 7). In these cases it was seen that the units on the expanded facility do not trip for the loss of generation at the existing facility. Similarly, no units trip for these faults when the generation at the expanded facility is around 125 MW. However, when the generation at the expanded facility is decreased to 100 MW, the units trip. This indicates that at low levels of generation at CCWE 2, there is a probability of losing generation when there is a fault by the existing facility. Varying generation levels at CCWE1 does not impact these results.

Figure 1. Diagram Showing the Fault Locations for Contingencies 8 and 8a

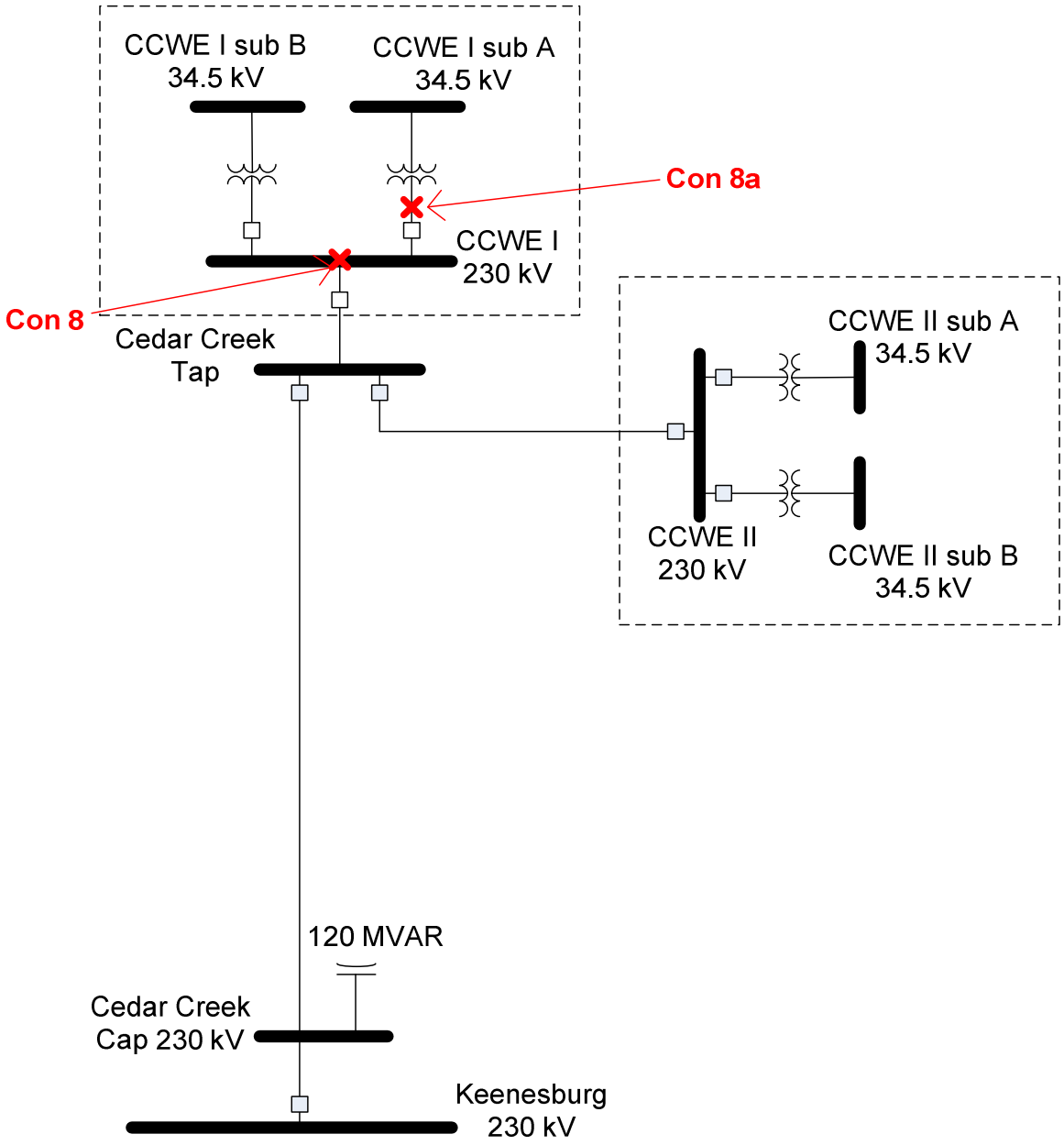

Table 2. Stability Analysis for Contingencies 8 and 8a for Various Generation Configurations at Cedar Creek

Config No.	CCWE1 generation	CCWE2 generation	CCWE2 turbines	CCWE2 STATCOM status	POI capacitor	Analysis Results	Undesired trip (Y/N)
1	300 MW	50 MW	GE	STATCOM ON	0 MVAR	For both contingencies 8 and 8a, CCWE 2 trips after the fault is cleared. Under frequency relay trip	Y
2	300 MW	50 MW	GE	STATCOM OFF	0 MVAR	For both contingencies 8 and 8a, CCWE 2 trips after the fault is cleared. Under frequency relay trip	Y
3	300 MW	50 MW	Nordex	STATCOM ON	0 MVAR	For both contingencies 8 and 8a, CCWE 2 trips during the fault due to low voltage	Y
4	300 MW	50 MW	Nordex	STATCOM OFF	0 MVAR	For both contingencies 8 and 8a, CCWE 2 does not trip	N
5	300 MW	50 MW	GE+Nordex	STATCOM OFF	0 MVAR	For both contingencies 8 and 8a, CCWE 2 trips after the fault is cleared. GE units trip on low frequency at 0.308 sec and Nordex Units trip due to low voltage at 0.233 secs. The fault is applied at 0.2 sec	Y
6	300 MW	250 MW	GE+Nordex	STATCOM ON	120 MVAR	Contingencies 8 and 8a do not cause CCWE 2 to trip	N
7	300 MW	250 MW	GE+Nordex	No STATCOM, with capacitor banks at CC1 and CC2	90 MVAR	Contingencies 8 and 8a do not cause CCWE 2 to trip	N
8	300 MW	50 MW	GE	No STATCOM, with capacitor banks at CC1 and CC2	0 MVAR	For both contingencies 8 and 8a, CCWE 2 trips after the fault is cleared. Under frequency relay trip	Y
9	200 MW	50 MW	GE	STATCOM ON	0 MVAR	For both contingencies 8 and 8a, CCWE 2 trips after the fault is cleared. Under frequency relay trip	Y
10	300 MW	50 MW	GE+ collector system for full 250 MW	STATCOM ON	0 MVAR	For both contingencies 8 and 8a, CCWE 2 trips after the fault is cleared. Under frequency relay trip	Y
11	300 MW	50 MW	GE	STATCOM ON	30 MVAR	For both contingencies 8 and 8a, CCWE 2 trips after the fault is cleared. Under frequency relay trip	Y
12	300 MW	50 MW	Nordex	STATCOM ON	30 MVAR	For both contingencies 8 and 8a, CCWE 2 trips during the fault due to low voltage	Y
13	300 MW	50 MW	GE+Nordex	STATCOM ON	30 MVAR	For both contingencies 8 and 8a, CCWE 2 trips after the fault is cleared. GE units trip on low frequency at 0.308 sec and Nordex Units trip due to low voltage at 0.233 secs. The fault is applied at 0.2 sec	Y
14	300 MW	150 MW	Nordex	STATCOM ON	60 MVAR	Contingencies 8 and 8a do not cause CCWE 2 to trip	N
15	300 MW	125 MW	GE+Nordex	STATCOM ON	60 MVAR	Contingencies 8 and 8a do not cause CCWE 2 to trip	N
16	300 MW	100 MW	GE+Nordex	STATCOM ON	30 MVAR	For both contingencies 8 and 8a, CCWE 2 trips after the fault is cleared. GE units trip on low frequency at 0.308 sec and Nordex Units trip due to low voltage at 0.233 secs. The fault is applied at 0.2 sec	Y

With the expansion facility developed to a total capacity of 250 MW (combined GI-2007-5 and GI-2007-6), the critical faults by the CCWE1 230 kV bus do not result in the tripping of individual generators on the expansion facility. If the generation at the expansion facility is reduced to the 100 - 125 MW level, then the individual generator tripping is observed again.

The issues that have been observed are related to low voltages on the expansion facility during faults that are magnified for low levels of generation. One method to raise the voltage could be additional dynamic reactive power support. Another method to mitigate the depressed voltage on the expansion facility's collector system during a fault could be the use of a 230/34.5 kV transformer with a higher effective impedance. In a dynamic simulation run, the use of a higher effective impedance transformer allowed 50 MW of either GE or Nordex units to remain on line during and after the critical faults at CCWE1.

F. Conclusions

The Cedar Creek wind generation facility can be expanded by 50 MW without PSCo transmission system reinforcements. No adverse impacts on PSCo's transmission system were observed in the steady state analysis with respect to thermal loading or voltage criteria. The stability analysis showed system performance after three-phase system disturbances on the PSCO transmission system were cleared was stable with positively damped oscillations and within applicable criteria.

Faults on the Customer's 230-kV transmission system result in the disconnecting of all or a portion of the generation associated with the existing CCWE1 facility or the expansion facility depending upon fault location, which is planned, and do not have an adverse impact on PSCo's transmission system. However, a three-phase 230 kV fault by CCWE1 will result in the expected disconnection of CCWE1 generators and the unexpected tripping of generators at the expansion facility. Other than the loss of more than expected generation from the overall Cedar Creek facility by PSCo, there are no other adverse impacts on the PSCo transmission system.