Interconnection System Impact Study Report
Requests # GI-2007-5 and GI-2007-6
Re-study 2

250 MW Wind Generation Expansion Interconnecting at Keenesburg

PSCo Transmission Planning

June 16, 2010

A. Executive Summary

The purpose of the GI-2007-5&6 System Impact Re-study 2 is to determine the potential system impacts associated with using GE's WindBOOST control software to increase the output of the GE 1.5sle turbines 100 kW to 1.6 MW. The GI-2007-5&6 System Impact Re-study completed on April 22, 2010 assumed that the expanded wind generation facility would consist of sixty-eight (68) GE 1.5 MW units and sixty (60) Nordex 2.5 MW units. The use of GE's WindBOOST control software for this expansion project allows the wind generation facility to use fewer GE wind turbine units (sixty-three GE 1.6 MW units instead of sixty-eight GE 1.5 MW units) and the use of this control software necessitated the second re-study.

The power flow analysis (based on the final configuration of General Electric and Nordex turbines) shows that the network upgrades required for delivery will not change if the GE WindBOOST control software is used. The following will be required:

- Loop the Ft. St. Vrain-Green Valley 230 kV line into the Keenesburg Substation
- Dispatch generation at Ft. St. Vrain within acceptable operating limits

The results of the power flow analysis indicate that using the GE WindBOOST control software does not appreciably change the results of the re-study completed on April 22, 2010. The following facilities, which represent one potential set of improvements, would allow the Generation Provider to meet relevant criteria:

- Switchable capacitors at three different locations between the POI, the Cedar Creek Wind Energy Project 1 (CCWE1), and the proposed wind generation expansion project. The analysis indicated that a total of approximately 155 MVAR of switched capacitors would be needed to meet the voltage criteria at the POI when the combined Cedar Creek wind farms are operating near the 550 MW maximum generation capability. Of the 155 MVAR of switched capacitors, two 45 MVAR switchable capacitors would need to be connected to the 230-kV system at a capacitor switching station located near the Keenesburg Substation.

- Reactors (approximately 45 MVAR[1]) for the Generation Provider's wind generating plant to maintain a power factor within the range of 0.95 leading to 0.95 lagging near minimum generation levels, measured at the POI. This would be needed whenever the Generation Provider's facilities are off-line or generating at very low levels while the facility is connected to the POI.

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 at Keenesburg and at the Cedar Creek wind farm and single-line-to-ground faults with delayed clearing at Keenesburg, Ft. St. Vrain, and Green Valley with the GE WindBOOST control software modeled. For the three-phase faults with normal clearing, the system remained stable and all system oscillations damped out quickly with no criteria violations. Similarly, the system remained stable for single-line-to ground faults with delayed clearing at Keenesburg, Green Valley and Ft. St. Vrain.

Figure 1 is a conceptual one-line diagram of Keenesburg, CCWE1, and the proposed wind generation expansion project. Figure 2 describes the future Keenesburg Substation after the Ft. St. Vrain-Green Valley 230 kV line is looped into Keenesburg.

[1] The 45 MVAR of reactors would consist of 35 MVAR of reactors connected at the existing Cedar Creek facility (CCWE1) and 10 MVAR of reactors connected at the wind generation expansion facility.

Figure 1. Conceptual One-Line Diagram of Cedar Creek

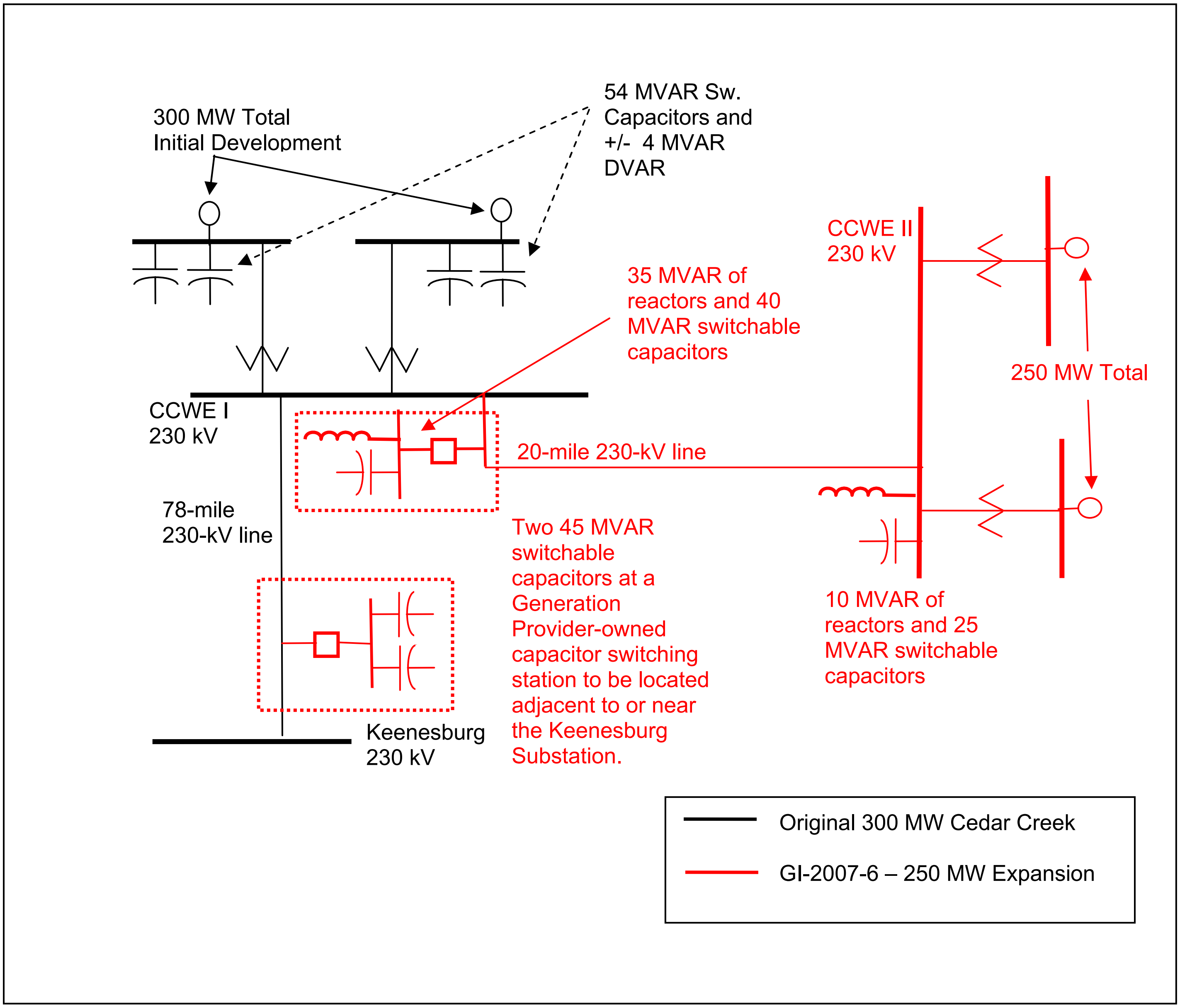
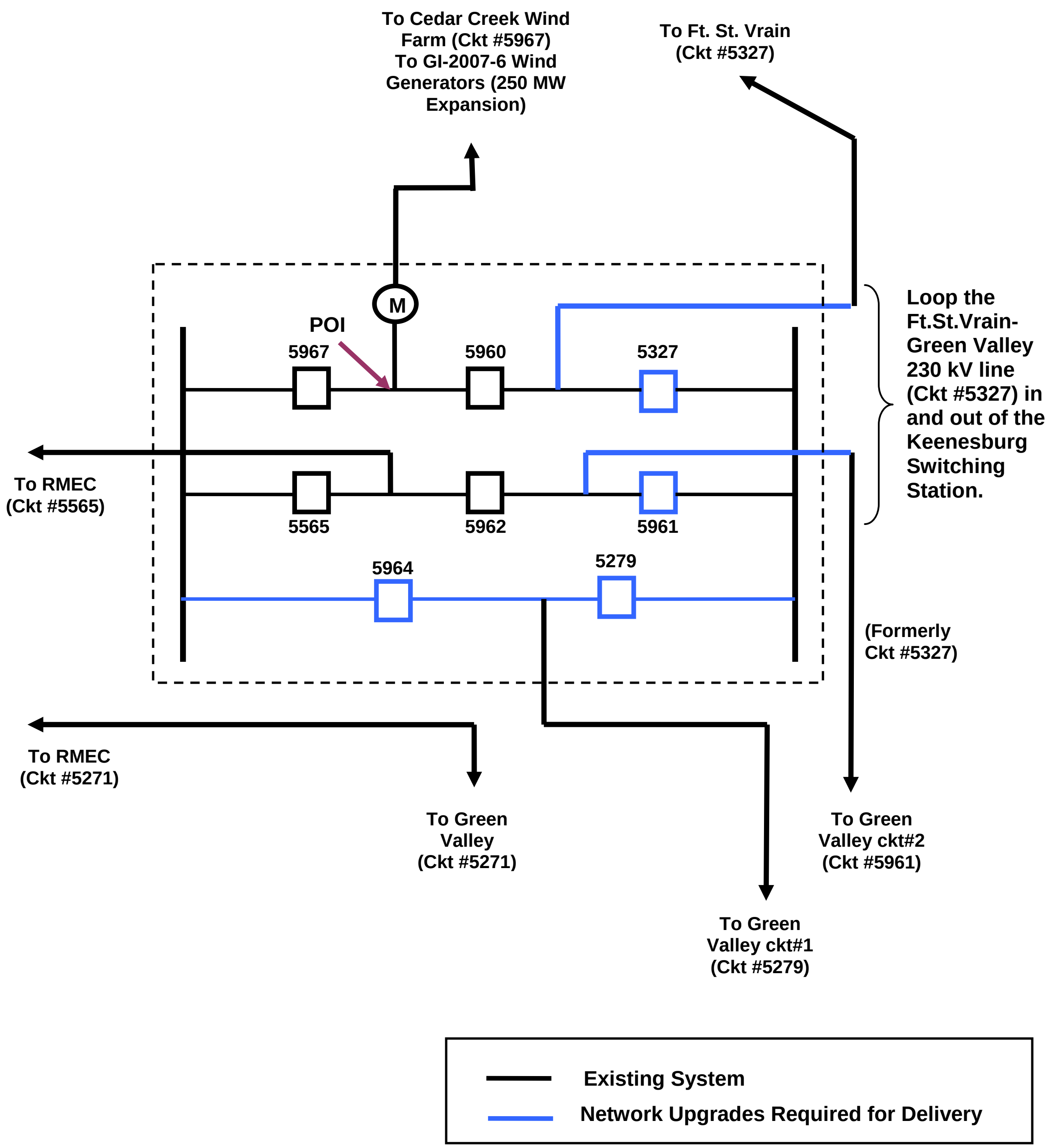


Figure 2. Breaker Arrangement at Keenesburg with the Cedar Creek Wind Farm 250 MW Expansion



B. Introduction

On April 22, 2010, the GI-2007-5&6 System Impact Re-study was completed. The re-study assumed that the expanded wind generation facility would consist of sixty-eight (68) GE 1.5 MW units and sixty (60) Nordex 2.5 MW units. Subsequently, the Generation Provider contacted the Transmission Provider to announce their intent to use GE's WindBOOST control software to increase the output of the GE 1.5sle turbines 100 kW to 1.6 MW. The use of GE's WindBOOST control software allows the wind generation facility to use fewer GE wind turbine units (sixty-three GE 1.6 MW units instead of sixty-eight GE 1.5 MW units) and the use of this control software necessitated the second re-study. The GI-2007-5&6 System Impact Re-study 2 was conducted to determine the potential system impacts associated with using GE's WindBOOST control software to increase the output of the GE 1.5sle turbines 100 kW to 1.6 MW.

C. Study Scope and Analysis

The System Impact Re-study 2 evaluates the impact of using GE's WindBOOST control software to increase the output of the GE 1.5sle turbines 100 kW to 1.6 MW. The use of GE's WindBOOST control software allows the proposed wind expansion project to use fewer GE wind turbine units that will make up part of the overall 550 MW of energy from Cedar Creek through the Keenesburg POI to PSCO native loads. This re-study consists of both steady state power flow analysis and transient stability analysis. The power flow analysis provides a preliminary identification of any thermal or voltage limit violations resulting from the interconnection and a preliminary identification of network upgrades required to deliver the proposed generation to PSCo loads. The transient stability analysis provides simulations of system behavior during and immediately after severe disturbances to determine whether the additional generation would adversely impacts system operation. Since Keenesburg is close to the Rocky Mountain Energy Center (RMEC) generating facility, it has been considered as a regulated bus for the purpose of this study.

PSCO adheres to NERC / WECC criteria as well as internal company criteria for planning studies. The following criteria were used for this study:

- For system intact conditions, transmission system bus voltages must be maintained between 0.95 and 1.05 per-unit of system nominal / normal conditions, and steady-state power flows must be maintained within 1.0 per-unit of all elements' thermal (continuous current or MVA) ratings.
- PSCO System Operations attempts to maintain a transmission system voltage profile ranging from 1.02 per unit or higher at regulating buses, and 1.0 per unit or higher at transmission load buses.
- Following a single contingency element outage, transmission system steady state bus voltages must remain within 0.90 per-unit to 1.10 per-unit, and power flows within 1.0 per-unit of the elements' continuous thermal ratings.

- For various contingencies occurring close to the Point of Interconnection in the PSCo system and on the wind farm, all generators in the system should be stable and remain in synchronism.
- None of the turbines on the wind farm should trip due to Low Voltage Ride Through (LVRT) for standard fault clearing time.
- Damping and voltage recovery at various buses should be within applicable standards.

D. <u>Power Flow Study Models</u>

Western Electricity Coordinating Council (WECC) coordinates the preparation of regional power flow cases for transmission planning purposes. PSCo Transmission Planning developed a base case for the 2010 heavy (on-peak demand) summer season as a part of their annual five-year project identification process, from WECC-approved models and modified for PSCo-approved projects and topology changes. In the 2010 case, the following generators in the PSCo Balancing Authority (Area 70) were re-dispatched to simulate high north-to-south stressed system conditions.

- The generation at RMEC and Spruce was increased to maximum capacity.
- The existing 300 MW generation at Cedar Creek was represented in detail and it was set to generate at maximum capacity. This facility consists of two hundred twenty-one (221) MW of Mitsubishi Model MWT-1000A wind turbines and 79.5 MW of GE 1.5 MW turbines. The Mitsubishi units are 1.0 MW induction generators and each has 340 kVAR of switched capacitors near its terminal. The GE machines are 1.5 MW doubly-fed induction generators with LVRT II. Additional reactive power is provided by two 54 MVAR capacitors banks (one on each of the two 34.5 kV substation buses) and a total of 12 MVAR of DVAR capability, with 4 MVAR on each of the 34.5 kV substation buses and the remainder split between the two overhead 34.5 kV feeders. This facility is connected to the PSCo system at Keenesburg in Weld County via a single 78-mile radial overhead line.
- The generation at Ft. St. Vrain was dispatched to 950 MW, close to its maximum capacity.
- These increases in generation were accommodated by decreasing the generation at the Comanche Units.
- The placeholder generation at Pawnee (Wind_pln) and San Luis Valley (SLV Solar) were removed.
- The Lamar DC tie was set to export 100 MW of generation

Implementation of these changes resulted in the benchmark case used for this study. Comanche Unit 1 was designated as the slack bus for the PSCo Balancing Authority (Area 70).

The final proposed wind generation facility consists of sixty-three (63) GE 1.6 MW units with a terminal voltage of 0.69 kV and sixty (60) Nordex 2.5 MW units with a terminal voltage of 0.66 kV. The individual turbines are connected together on eleven 34.5 kV feeders. Four of these circuits have GE units and seven circuits have Nordex units. Two of the GE feeders will be connected to the each of the 34.5 kV substation buses A and B. Four Nordex feeders are connected to substation A and three Nordex feeders are connected to substation B. The two 34.5/230 kV transformers at the two substation buses raise the voltage to 230 kV for transmission purposes. The proposed expansion will be connected to the existing Cedar Creek facility by a 20-mile single circuit 230 kV radial line. Since this study involves transient stability analysis, the 250 MW Cedar Creek expansion facility has been represented in complete detail showing each individual generator. The additional generation from GI-2007-6 has been accommodated by decreasing the generation at Comanche unit 3.

The proposed GE units will have an enhanced reactive power capability with a power factor range of 0.90 lagging to 0.90 leading, based on the information provided by the Generation Provider. The Nordex units operate at varying power factors depending on the active power output of the turbines. When the units are at maximum capacity, they operate between 0.98 leading to 0.98 lagging power factor. For lower levels of generation the reactive support provided by these units increases. Only the cases with maximum generation and no generation at Cedar Creek were studied, since these should be the worst case scenarios with respect to the POI.

E. Power Flow Study Process

Automated contingency power flow studies were completed on all power flow models using the PSS®MUST program, switching out single elements one at a time for all of the elements (lines and transformers) in the PSCo Balancing Authority (Area 70) and the Western Area Power Administration Balancing Authority (Area 73). Upon switching each element out, the program re-solves the power flow model with all transformer taps and switched shunt devices locked, and control area interchange adjustments disabled.

F. Power Flow Results

Thermal Overloads

The results for the single line contingency analysis when a total of 550 MW are connected to the Keenesburg substation in the 2010 heavy summer case are shown in Table 1. The previous study recommended that the 230 kV line from Green Valley to St. Vrain be tapped at Keenesburg to decrease overloads in the PSCo Balancing Authority (Area 70). That recommendation was implemented in the base case for this study. Despite this modification, several lines in PSCo Transmission's area were found to be overloaded in this study. This can be observed in Table 1 below.

Xcel Energy

Table 1. Thermal Overloads with Additional 250 MW at Cedar Creek and Maximum Generation at Ft. St. Vrain

TDF cut-off = 1.5%

** From bus ** ** To bus ** CKT	Branch Rating (MVA)	Branch Flow Bench-mark (MVA)	Branch Flow With GI-2007-6 (MVA)	Contingency	FAC-009 Conductor Rating
70045 BANCROFT 115 70208 GRAY ST 115 1	120.0	130.3	133.5	70037 ARAPAHOB 115 70401 SOUTH 1 115 1	
70047 BARRLAKE 230 70048 GREENVAL 230 1	159.0	195.6	218.5	70192 FTLUPTON 230 70529 JLGREEN 230 1	506
70048 GREENVAL 230 70526 IMBODEN 230 1	435.0	110.2	123.5	70048 GREENVAL 230 70528 SPRUCE 230 1	764
70107 CHEROKEE 230 70324 LACOMBE 230 1	444.0	117.4	126.1	70266 LOOKOUT 230 70480 WESTPS 230 1	948
70107 CHEROKEE 230 70609 SILVSADL 230 1	365.0	93.6	103.1	70192 FTLUPTON 230 70529 JLGREEN 230 1	365
70191 FTLUPTON 115 70192 FTLUPTON 230 T3	280.0	104.4	107.1	70447 VALMONT 230 70592 SPNDLE 230 1	
70192 FTLUPTON 230 70410 ST.VRAIN 230 1	444.0	105.3	108.3	70192 FTLUPTON 230 70410 ST.VRAIN 230 2	506
70192 FTLUPTON 230 70410 ST.VRAIN 230 2	444.0	105.3	108.3	70192 FTLUPTON 230 70410 ST.VRAIN 230 1	506
70192 FTLUPTON 230 70529 JLGREEN 230 1	478.0	104.4	108.7	70192 FTLUPTON 230 70605 HENRYLAK 230 1	571
70193 FTN VALL 115 70449 DESRTCOV 115 1	105.0	87.9	101.8	70286 MIDWAYPS 230 73413 MIDWAYBR 230 1	
70193 FTN VALL 115 73412 MIDWAYBR 115 1	105.0	88.8	102.6	70286 MIDWAYPS 230 73413 MIDWAYBR 230 1	
70273 MALTA 115 70274 MALTA 230 T1	100.0	110.2	114.0	70155 DILLON 115 70156 DILLON 230 T2	
70396 SMOKYHIL 230 70528 SPRUCE 230 2	800.0	96.9	108.0	70528 SPRUCE 230 70532 POWHATON 230 1	850
70396 SMOKYHIL 230 70532 POWHATON 230 1	800.0	96.9	108.0	70396 SMOKYHIL 230 70528 SPRUCE 230 2	850
70447 VALMONT 230 70592 SPNDLE 230 1	478.0	104.0	107.9	70410 ST.VRAIN 230 70544 ISABELLE 230 1	558
70461 WASHINGT 230 70529 JLGREEN 230 1	413.0	119.0	124.1	70192 FTLUPTON 230 70605 HENRYLAK 230 1	579
70526 IMBODEN 230 70528 SPRUCE 230 1	435.0	108.5	121.8	70048 GREENVAL 230 70528 SPRUCE 230 1	744
70528 SPRUCE 230 70532 POWHATON 230 1	800.0	96.9	108.0	70396 SMOKYHIL 230 70528 SPRUCE 230 2	850
70590 RMEC 230 70820 KEENSBG 230 1	598.0	96.8	100.5	70048 GREENVAL 230 70590 RMEC 230 1	598

From Table 1, it can be seen that the 230 kV lines from Barr Lake to Green Valley, Green Valley to Imboden, Cherokee to Lacombe, Ft. Lupton to St. Vrain, Ft. Lupton to JL Green, Washington to JL Green, and Imboden to Spruce are shown as overloaded under various contingencies. However, as per the Substation/Transmission Facility Equipment Rating FAC-009 list, the ratings of these lines have been revised and under the studied contingencies would no longer be overloaded. The transformers at Ft. Lupton and Malta may experience contingency overloads; however, the loading on these transformers is below 115% of their respective ratings, so the loading level can be accepted for short durations. The overloads observed for the 115 kV lines from Fountain Valley to Desert Cove and Midway are a result of the choice of generation sink and are not expected to occur under normal operating conditions.

The original System Impact Study assumed a total generation capability at Ft. St. Vrain of 732 MW. Since that time, an additional 300 MW of generating capacity has been installed at Ft. St. Vrain. When all the units at Ft. St. Vrain are operating at close to maximum capacity, the lines from Green Valley to Spruce and Cherokee to Silver Saddle could become overloaded under contingency conditions. However, since the Ft. St. Vrain units are peaking units and the probability of all the generation at St. Vrain being near maximum when the wind generation at Cedar Creek is concurrently at its maximum capability is very low, the likelihood of contingency overloads on the lines from Green Valley to Spruce and Cherokee to Silver Saddle is very low. When the wind generation is Cedar Creek is at 550 MW, the maximum generation at St. Vrain would need to be limited to approximately 650 MW, based on the 800 MVA ratings for the three 230 kV circuit segments between Smoky Hill and Spruce.

Voltage Criteria Violations

Interconnecting to the PSCo bulk transmission system involves the Generation Provider adhering to certain interconnection requirements. These requirements are contained in the Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater than 20 MW (Guidelines). The Guidelines make reference to interconnection requirements from FERC Order 661A. FERC Order 661A describes the interconnection requirements for wind generation plants. In addition, PSCo System Operations conducts commissioning tests prior to the commercial in-service date for a Generation Provider's facilities. Some of the requirements that the Generation Provider must complete include the following:

1. A wind generating plant shall maintain a power factor within the range of 0.95 leading to 0.95 lagging, measured at the POI, if the Transmission Provider's System Impact Study shows that such a requirement is necessary to ensure safety or reliability.
2. The System Impact Study will investigate pertinent demand, dispatch, and outage scenarios based on the defined study area that includes the proposed POI. The study will conform to the NERC Transmission System Planning Performance Requirements (TPL standards).
3. The results of the System Impact Study (mentioned in Item 1 and 2 above) do not absolve the Generation Provider from its responsibility to demonstrate to the satisfaction of PSCo System Operations prior to the commercial in-service date that it can safely operate within the required power factor and voltage ranges.
4. Reactive Power Control at the POI is the responsibility of the Generation Provider. Additional Generation Provider studies should be conducted by the Generation Provider to ensure that the facilities can meet the power factor control test and the voltage controller test when the facility is undergoing commissioning testing.
5. PSCo System Operations will require the Generation Provider to perform operational tests prior to commercial operation that would verify that the equipment installed by the Generation Provider meets operational requirements.
6. It is the responsibility of the Generation Provider to determine what type of equipment (DVAR, added switched capacitors, SVC, reactors, etc.), the ratings (MVAR, voltage--34.5 kV or 230 kV), and the locations of those facilities that may be needed for acceptable performance during the commissioning testing.
7. PSCo requires the Generation Provider to provide a single point of contact to coordinate compliance with the power factor and voltage regulation at the POI. The reactive flow at the end of 230 kV line near the POI will need to be controlled according to the Interconnection Guidelines.

The WECC/NERC reliability criteria indicate that for planning purposes, voltages at all buses in the system should remain between 0.95 per unit to 1.05 per unit under system intact conditions. The Rocky Mountain Voltage Coordination Guidelines that were developed by the Voltage Coordination Guideline Subcommittee of the Colorado Coordinated Planning Group, indicate that for Region 8 (Metro Denver-Boulder-Ft.Lupton), the ideal voltage range for a regulating[2] bus in Region 8 should be between 1.02 per unit and 1.03 per unit. The voltage at the 230 kV bus at Keenesburg in the benchmark case with 300 MW of generation at Cedar Creek is 1.028 per unit. The GE units and DVARs at the 34.5 kV substation buses control the voltage at the 230 kV bus at the existing Cedar Creek facility to 1.025 per unit.

The study demonstrates that the voltage at the POI drops to 1.018 per unit with the 250 MW expansion. Voltages at the 230 kV buses at the existing Cedar Creek facility and the proposed expansion fall below 1.0 per unit. The combined wind facilities draw 170.7 MVAR of reactive power from the PSCo system at the POI. Therefore, in order to keep the power factor at the POI between 0.95 leading to 0.95 lagging and the voltage level at Keenesburg near 1.028 pu, a 90-MVAR capacitor has been connected close to the POI, a 40-MVAR capacitor has been connected at the 230 kV bus on the existing facility and a 25-MVAR capacitor has been connected at the 230 kV bus of the proposed facility. The 34.5/230 kV transformers at the existing facility adjust to an off-nominal tap ratio of 1:1.00625. Similarly the tap ratios of the 34.5/230 kV transformers at the expanded facility adjust to 1:1.0125. With the indicated level of capacitors added, the voltage at the POI returns to 1.029 per unit during full wind generation. If no capacitors are considered near the POI and larger capacitors are connected at the two wind facilities, the total amount of the capacitors would be larger than what has been indicated here to keep the interconnection VAR neutral. More importantly, those larger capacitors would also cause the 230 kV voltages by the wind generation facilities to rise above 1.05 per unit under normal operating conditions.

The voltage at the 230 kV Keenesburg bus rises to 1.037 per unit during periods of minimal wind generation. The transmission lines associated with the generation facilities supply 49.7 MVAR of reactive power to the PSCO system. The voltage at the existing Cedar Creek facility rises to 1.052 per unit, and the voltage at the proposed facility rises to 1.067 per unit. Therefore, in order to keep the interconnection VAR neutral, a 35 MVAR inductive reactor needs to be connected at the existing Cedar Creek facility (CCWE1) and a 10 MVAR inductive reactor needs to be connected at the expanded wind generation facility (CCWE2).

No attempt has been made to evaluate the coordination issues between the capacitors or reactors that may need to be added due to GI-2007-6 with reactive power support requirements associated with the operation of the existing 300 MW facility. The 90 MVAR of capacitors (two 45 MVAR units) will be located at or near the Keenesburg

[2] Since Keenesburg is very close to the RMEC generating facility and would have direct impact on its reactive power reserve margin, it has been considered a regulating bus.

Substation and will be the financial and operational responsibility of the Generation Provider.

It is the responsibility of the Generation Provider to determine what type of equipment (DVAR, added switched capacitors, STATCOM, SVC, reactors, etc.), at what overall ratings (MVAR, voltage-34.5 kV, 345 kV), and at what locations (at the wind farm, near the POI) will be added to meet these reactive power control requirements. The voltage-tap settings on the main power transformers that connect the 34.5 kV system to the Generation Provider's transmission line will impact the operating voltages and related reactive power capabilities and requirements for Cedar Creek. This should also be considered by the Generation Provider in determining the final equipment design and control parameters.

G. Dynamic Stability Analysis and Results

Transient stability analysis determines the response of the transmission system to system disturbances such as the occurrences of faults, tripping of generator units, tripping of transmission lines or tripping of loads in the area around the POI. These studies evaluate generator frequency, generator rotor angles, bus voltages and power flows before, during and after a disturbance to determine if the system remains stable after the disturbance. In addition, FERC 661A requires the wind powered generators to remain on-line during voltage disturbances up to the time periods and voltage levels set for the Low Voltage Ride-Through (LVRT) capability standard. The system should also meet the following WECC post-fault voltage and frequency criteria (TPL – 001 thru 004):

- The final voltage at all buses in the system must be within 5% of the pre-fault voltage.
- The transient voltage dip should not exceed 25% at load buses or 30% at non-load buses and it should not exceed 20% for more than 20 cycles at load buses.
- The transient frequency at load buses should not drop below 59.6 Hz for more than 6 cycles.

Transient stability analysis was performed for different three-phase faults around Keenesburg, RMEC, St. Vrain, Green Valley and various buses on Cedar Creek. Table 2 lists the different contingencies studied for this analysis. Normal fault clearing time of 5 cycles for 230 kV facilities was used for this study. The proposed facility was modeled in detail with each GE and Nordex turbine represented as an individual generator. The turbines are connected through generator step-up transformers to 34.5 kV. The 34.5 kV collector system at the Cedar Creek expansion consists of a total of eleven circuits that are connected to two 34.5 kV substation buses. The impedance information for these feeders was supplied by the Generation Provider. This expansion will be connected to the existing Cedar Creek wind farm through a 20-mile transmission line. The previously described capacitors connected close to the POI, the existing Cedar Creek facility, and at the expansion facility to keep the power factor at the POI within criteria have been included in the model for the stability analysis. The generation at Ft. St. Vrain was set close to maximum capacity.

With the initial machine model data for the Nordex units, when a three-phase fault at the Keenesburg bus was studied, the simulation model indicated that the Nordex units would be tripped by their high frequency relays shortly after the fault was cleared. Some of the GE units on the existing and expanded Cedar Creek facility also tripped as a result of high frequency. When the high frequency relays for the Nordex units were disabled to trace the issue, some of the Mitsubishi units were found to be tripped by their under-voltage relays. These observations were conveyed to the Generation Provider and subsequently to Nordex. After reviewing the results and local system configuration, Nordex modified the machine model data file. These modifications changed the following model characteristics:

- The original Nordex model used a time step of 10 msecs. However, the other models in the WECC dynamic data file use a time step of $1/4^{th}$ – $1/5^{th}$ of a cycle. Therefore the dyre file was modified so that the Nordex model represented actual turbine behavior with a simulation time step of $1/4^{th}$ of a cycle (≈ 5msecs).
- The over-frequency relay time delay was increased from 50 msecs to 100 msecs.
- The active power output of the Nordex units during the fault was limited. This decreased the frequency rise during the fault.
- The time period for which the Nordex units provide reactive support was increased from 500 msecs to 4 secs.

The changes to the machine model data file are not just refinements to the PSS®E model of the wind turbine. They also represent changes to the control system parameters of the physical units that are proposed to be installed at Cedar Creek. The Generation Provider must ensure that all these changes are implemented in the Nordex turbines to be installed at their facility.

The stability analysis was performed using the updated Nordex machine model data and the results are summarized in Table 2. The results of the analysis indicate that the system remains stable during and after each contingency studied and all system oscillations damp out quickly. The final voltage was within 5% of its pre-fault values at all buses in the PSCo Balancing Authority (Area 70) and the Western Area Power Administration Balancing Authority (Area 73) for all contingencies studied. The frequency and voltage deviation at all buses were within specified WECC criteria. All the wind turbines at the existing CCWE1 and the proposed expansion remained online, except when any would be electrically disconnected from the system.

Table 2. Results of Stability Analysis with Normal Clearing Time

Num	Fault Location	Action	With 300 MW at Cedar Creek	With 550 MW at Cedar Creek
1	Keenesburg 230-kV	Trip 230-kV line from Keenesburg to Cedar Creek	Stable, no viol	Stable, no viol
2	Keenesburg 230-kV	Trip 230-kV line from Keenesburg to RMEC	Stable, no viol	Stable, no viol
3	RMEC 230-kV	Trip 230-kV line from Keenesburg to RMEC	Stable, no viol	Stable, no viol
4	Keenesburg 230-kV	Trip 230-kV line from Keenesburg to Green Valley ckt 1	Stable, no viol	Stable, no viol
5	Green Valley 230-kV	Trip 230-kV line from Keenesburg to Green Valley ckt 1	Stable, no viol	Stable, no viol
6	Keenesburg 230-kV	Trip 230-kV line from Keenesburg to St. Vrain	Stable, no viol	Stable, no viol
7	St. Vrain 230-kV	Trip 230-kV line from Keenesburg to St. Vrain	Stable, no viol	Stable, no viol
8	RMEC 230-kV	Trip 230-kV line from RMEC to Green Valley	Stable, no viol	Stable, no viol
9	Green Valley 230-kV	Trip 230-kV line from RMEC to Green Valley	Stable, no viol	Stable, no viol
10	Cedar Creek 1 230-kV	Trip 34.5/230-kV Xmer from CCWE 1 to CCWE1 bus A	Stable, no viol	Stable, no viol
11	-	Drop RMEC Unit 3	Stable, no viol	Stable, no viol
12	Cedar Creek 1 230-kV	Trip 230-kV line from CCWE 1 to CCWE 2	Stable, no viol	Stable, no viol
13	Cedar Creek 2 230-kV	Trip 34.5/230-kV Xmer from CCWE 2 to CCWE2 bus A	Stable, no viol	Stable, no viol

Delayed Clearing Studies at Keenesburg, Ft. St. Vrain and Green Valley

Transient stability analysis was performed for breaker failure events at the Keenesburg, Ft. St. Vrain, and Green Valley substations, where the initial breaker operations fail to clear the fault and back up breaker operation is required. If there is a single-line-to-ground fault on a line close to the Keenesburg 230 kV bus and one of the breakers at the Keenesburg end of the line fails to operate, the back up breakers should open after a delay of 13 cycles. This opens two network elements at the Keenesburg switching station. The effect of such an event on the transmission system was studied for a number of different contingencies. The contingencies studied for delayed clearing simulation around Keenesburg are summarized in Table 3. The results indicate that the system remains stable and there are no voltage or frequency criteria violations. Similarly, delayed clearing analysis was performed at the 230 kV substation buses at Ft. St. Vrain and Green Valley. The results of these analyses are shown in Tables 4 and 5, respectively. As seen from these tables, the system remains stable and does not violate any criteria.

Table 3. Delayed Clearing Contingencies at Keenesburg

Contin-gency	Fault Location	Cycles	Cleared circuit 1 (Connected at Keenesburg but open at remote end)	Stuck Breaker	Cleared circuit 2 (Due to breaker failure)	Cycles	300 MW at Cedar Creek	550 MW at Cedar Creek
1	Keenesburg 230 kV	5	Keenesburg - Cedar Creek 230 kV	5960	Keenesburg - Ft. St. Vrain 230 kV	18	stable, no viol	stable, no viol
2	Keenesburg 230 kV	5	Keenesburg - Ft. St. Vrain 230 kV	5960	Keenesburg - Cedar Creek 230 kV	18	stable, no viol	stable, no viol
3	Keenesburg 230 kV	5	Keenesburg - RMEC 230 kV	5962	Keenesburg - Green Valley 230 kV ckt 1	18	stable, no viol	stable, no viol
4	Keenesburg 230 kV	5	Keenesburg - Green Valley 230 kV ckt 1	5962	Keenesburg - RMEC 230 kV	18	stable, no viol	stable, no viol
5	Keenesburg 230 kV	5	Keenesburg - Green Valley 230 kV ckt 2	5964	-	18	stable, no viol	stable, no viol

Table 4. Delayed Clearing Contingencies at Ft. St. Vrain

Contin-gency	Fault Location	Cycles	Cleared Circuit 1 (Connected at Ft. St. Vrain but open at remote end)	Stuck Breaker	Cleared Circuit 2 (Due to breaker failure)	Cycles	300 MW at Cedar Creek	550 MW at Cedar Creek
1	Ft. St. Vrain 230 kV	5	Ft. St Vrain - Weld PS 230 kV	5319	-	18	stable, no viol	stable, no viol
2	Ft. St. Vrain 230 kV	5	Ft. St. Vrain - Windsor - Ault 230 kV	5308	-	18	stable, no viol	stable, no viol
3	Ft. St. Vrain 230 kV	5	Ft. St. Vrain Unit 1 Transformer	5301	-	18	stable, no viol	stable, no viol
4	Ft. St. Vrain 230 kV	5	Ft. St. Vrain - Longs Peak 230 kV	5306	Ft. St. Vrain - Isabelle 230 kV	18	stable, no viol	stable, no viol
5	Ft. St. Vrain 230 kV	5	Ft. St. Vrain - Isabelle 230 kV	5306	Ft. St. Vrain - Longs Peak 230 kV	18	stable, no viol	stable, no viol
6	Ft. St. Vrain 230 kV	5	-	5310	Ft. St. Vrain - Spindle 230 kV	18	stable, no viol	stable, no viol
7	Ft. St. Vrain 230 kV	5	Ft. St. Vrain - Spindle 230 kV	5310	-	18	stable, no viol	stable, no viol
8	Ft. St. Vrain 230 kV	5	Ft. St. Vrain Unit 2 Transformer	5312	Ft. St. Vrain - Ft. Lupton 230 kV ckt 2	18	stable, no viol	stable, no viol
9	Ft. St. Vrain 230 kV	5	Ft. St. Vrain - Ft. Lupton 230 kV ckt 2	5312	Ft. St. Vrain Unit 2 Transformer	18	stable, no viol	stable, no viol
10	Ft. St. Vrain 230 kV	5	Ft. St. Vrain - Ft. Lupton 230 kV ckt 1	5322	-	18	stable, no viol	stable, no viol
11	Ft. St. Vrain 230 kV	5	Ft. St. Vrain Unit 3 Transformer	5322	Ft. St. Vrain - Keenesburg 230-kV ckt 1	18	stable, no viol	stable, no viol
12	Ft. St. Vrain 230 kV	5	Ft. St. Vrain - Keenesburg 230 kV ckt 1	5322	Ft. St. Vrain Unit 3 Transformer	18	stable, no viol	stable, no viol
13	Ft. St. Vrain 230 kV	5	Ft. St. Vrain Unit 4 Transformer	5324	-	18	stable, no viol	stable, no viol
14	Ft. St. Vrain 230 kV	5	Ft. St. Vrain Unit 6 Transformer	5328	-	18	stable, no viol	stable, no viol
15	Ft. St. Vrain 230 kV	5	Ft. St. Vrain Unit 5 Transformer	5302	-	18	stable, no viol	stable, no viol

Table 5. Delayed Clearing Contingencies at Green Valley

Contin-gency	Fault Location	Cycles	Cleared Circuit 1 (Connected at Green Valley but open at remote end)	Stuck Breaker	Cleared Circuit 2 (Due to breaker failure)	Cycles	300 MW at Cedar Creek	550 MW at Cedar Creek
1	Green Valley 230 kV	5	Green Valley - Barr Lake 230 kV	5272	Green Valley - Ft. Lupton 230 kV	18	stable, no viol	stable, no viol
2	Green Valley 230 kV	5	Green Valley - Ft. Lupton 230 kV	5272	Green Valley - Barr Lake 230 kV	18	stable, no viol	stable, no viol
3	Green Valley 230 kV	5	Green Valley - RMEC 230 kV	5274	Green Valley - Sky Ranch 230 kV	18	stable, no viol	stable, no viol
4	Green Valley 230 kV	5	Green Valley - Sky Ranch 230 kV	5274	Green Valley - RMEC 230 kV	18	stable, no viol	stable, no viol
5	Green Valley 230 kV	5	Green Valley - Keenesburg 230 kV ckt 1	5276	Green Valley - Imboden - Spruce 230 kV	18	stable, no viol	stable, no viol
6	Green Valley 230 kV	5	Green Valley - Imboden - Spruce 230 kV	5276	Green Valley - Keenesburg 230 kV ckt 1	18	stable, no viol	stable, no viol
7	Green Valley 230 kV	5	Green Valley - Keenesburg 230 kV ckt 2	2578	Green Valley - Spruce 230 kV	18	stable, no viol	stable, no viol
8	Green Valley 230 kV	5	Green Valley - Spruce 230 kV	5278	Green Valley - Keenesburg 230 kV ckt 2	18	stable, no viol	stable, no viol