



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

250 MW Wind Generation Expansion Interconnecting at Keenesburg

PSCo Transmission Planning

April 22, 2010

A. Executive Summary

The purpose of the System Impact Re-study is to determine the potential system impacts associated with expanding the Cedar Creek wind farm using different turbine manufacturers than the manufacturer assumed for the GI-2007-6 System Impact Study completed on June 12, 2009. The System Impact Study assumed that the Generation Provider would use Clipper Windpower C-93 2.5 MW wind turbines. This System Impact Re-study assumes that the Generation Provider would use a combination of General Electric (GE) 1.5 MW wind turbines and Nordex 2.5 MW wind turbines.

The Cedar Creek wind farm presently consists of the 300 MW Cedar Creek Wind Energy 1 (CCWE1) facility. The Generation Provider proposes to expand the Cedar Creek wind farm by 250 MW. The expansion, called the Cedar Creek Wind Energy 2 (CCWE2) facility, would consist of two groups of wind power units – a 50 MW group (GI-2007-5) consisting of 20 Clipper Windpower C-93 2.5 MW turbines and a 200 MW group (GI-2007-6) consisting of 80 Clipper Windpower C-93 2.5 MW turbines. After the GI-2007-6 System Impact Study was completed on June 12, 2009, the Generation Provider selected different turbine manufacturers for CCWE2. They notified the Transmission Provider that CCWE2 would consist of 68 GE 1.5 MW units and 60 Nordex 2.5 MW units. The change in the turbine manufacturers necessitated the re-study.

The Point of Interconnecton (POI) for CCWE1 is the Keenesburg 230 kV bus. CCWE1 connects to Keenesburg through the CCWE1-Keenesburg 78-mile radial line. CCWE2 would connect to the CCWE1-Keenesburg 230 kV line by way of a 20 mile 230 kV radial line that would tap the CCWE1-Keenesburg 230 kV line just outside the CCWE1 facility. The anticipated in-service date of CCWE2 is November 1, 2011 with a back-feed for site energization date of May 1, 2011.

The power flow analysis (assuming General Electric and Nordex turbines) indicate that CCWE2 could be considered a PSCo network resource together with CCWE1 (already deemed a PSCo network resource) if the following network upgrade is completed and operating limitation is observed:

- 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 power flow analysis also determined that the following facilities will be needed:

- Inductive reactors (approximately 45 MVAR¹) 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.
- Switchable capacitive reactors at up to three different locations between the POI, CCWE1 and CCWE2. In the re-study, the analysis indicated that a total of approximately 165 MVAR of switched capacitors will 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 165 MVAR of switched capacitors, 90 MVAR will need to be located at or near the Keenesburg POI at a capacitor switching station that will be laid out as a 230 kV three breaker ring bus.

More detailed studies should 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 the Cedar Creek wind farm and single-line-to-ground faults with delayed clearing at Keenesburg, Ft. St. Vrain and Green Valley. 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 delayed clearing analysis performed at Keenesburg, Green Valley and Ft. St. Vrain.

Figure 1 below is a conceptual one-line of Keenesburg, CCWE1 and the proposed CCWE2 facility. 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 inductive reactance consists of 35 MVAR of inductive reactance connected at the existing Cedar Creek facility (CCWE1) and 10 MVAR of inductive reactance connected at the expanded wind generation facility (CCWE2).

Figure 1. Conceptual One-Line Diagram of Cedar Creek

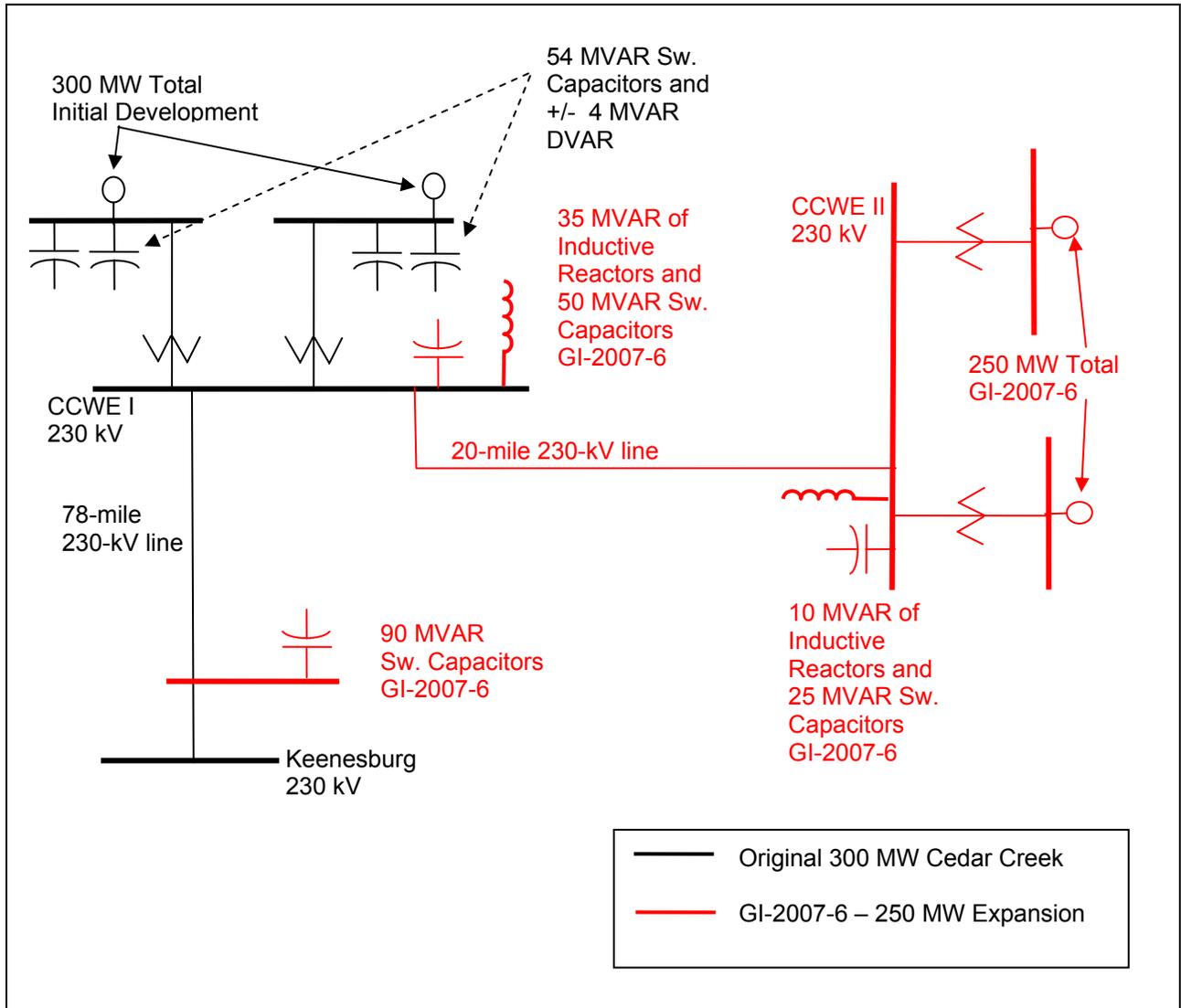
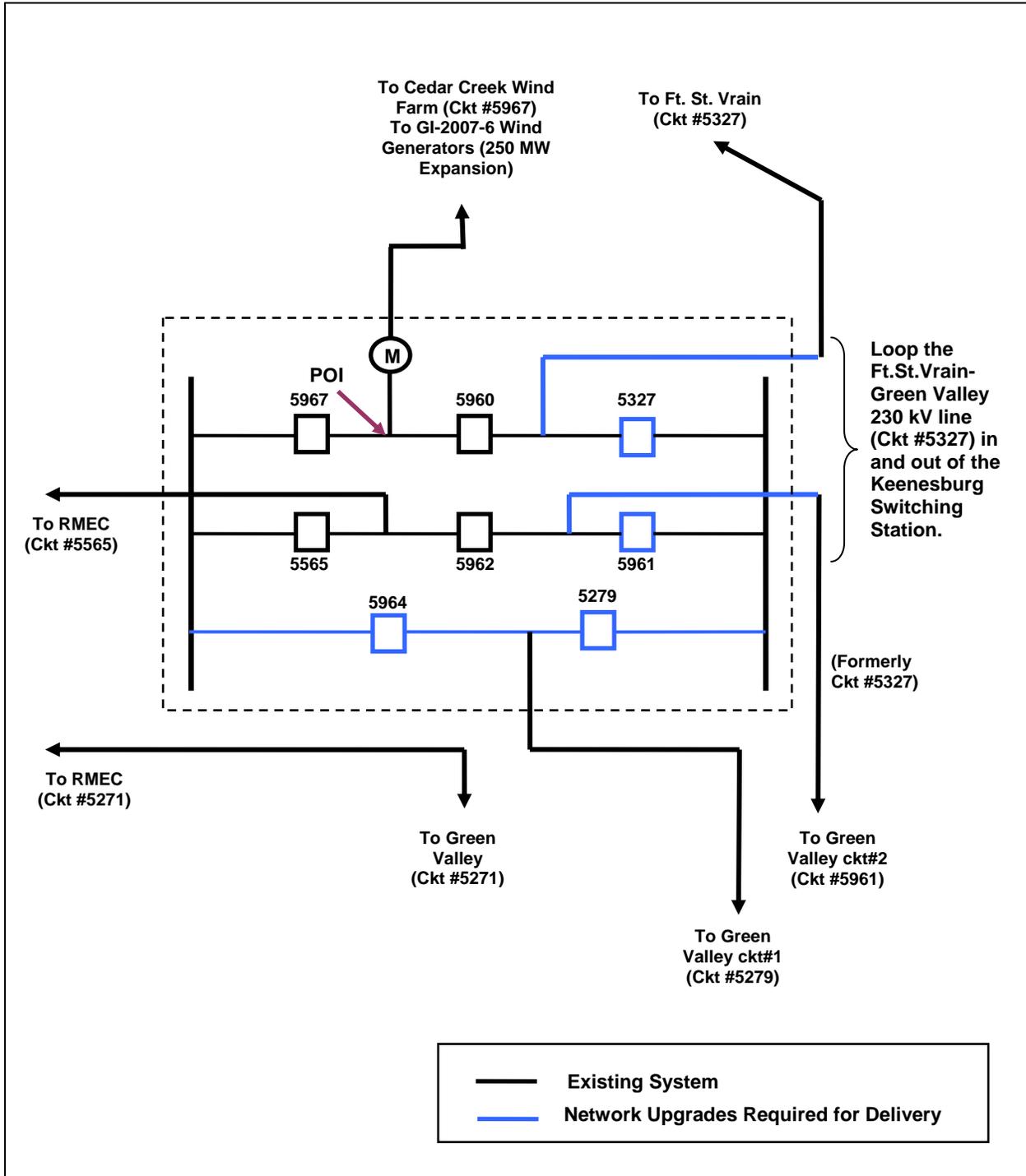


Figure 2. The Breaker Arrangement at Keenesburg with the Cedar Creek Wind Farm 250 MW Expansion



B. Introduction

On November 20, 2007 Public Service Company of Colorado (PSCo) Transmission Planning received two generation interconnection requests to determine the potential system impacts associated with interconnecting a total of 250 MW of additional wind generation at the Cedar Creek Wind Farm. The request GI-2007-5 was to add 50 MW while GI-2007-6 requested the addition of 200 MW of generation.

PSCo Transmission received a large generator interconnection request (GI-2007-6) to interconnect 80 Clipper C-93 2.5 MW wind turbines, with a total generation capability of 200 MW, with a commercial operation date of December 31, 2013. The proposed project would be located near the existing 300 MW Cedar Creek wind farm, near Grover, Colorado, and for study purposes represents a 200 MW expansion of the overall wind farm. A generator interconnection request for an initial 50 MW expansion near Cedar Creek (GI-2007-5) was also received and was studied prior to this request. The GI-2007-6 project would be connected at the same point as the GI-2007-5 project, at the end of a 230 kV line to the wind farm end of the existing 78-mile 230 kV transmission line. The existing 230 kV transmission line would deliver the total output from the existing 300 MW facility, the 50 MW GI-2007-5 expansion, and the proposed GI-2007-6 project to the Keenesburg switching station, the POI with PSCo.

The GI-2007-6 System Impact Study was completed on June 12, 2009; subsequently, PSCo received a request from the Generation Provider of GI-2007-5 and GI-2007-6 to modify the turbines to be used at the proposed facility. The revised project would consist of 68 GE 1.5 MW wind turbines and 60 Nordex 2.5 MW wind turbines, with a total generator nameplate capacity of additional 252 MW at Cedar Creek and an anticipated in-service date of November 1, 2011 with a back-feed for site energization date of May 1, 2011. The proposed project would be connected to the existing Cedar Creek facility, near Grover Colorado through a 20-mile 230 kV line. The existing 300 MW Cedar Creek facility is connected to Keenesburg with a 78 mile radial line. Therefore, the 230 kV bus at Keenesburg would be the Point of Interconnection (POI) for both the existing facility as well as the proposed expansion. For the purpose of this re-study and report, the individual requests of 50 MW for GI-2007-5 and 200 MW for GI-2007-6 have been combined and studied as a 250 MW project for GI-2007-6. This request is evaluated as a stand alone project with no other higher queued projects modeled.

C. Study Scope and Analysis

This system impact re-study evaluates the impacts of providing at total of 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 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.
- All the turbines on the wind farm should not 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. Power Flow Study Models

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 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 capacitor 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 proposed wind generation facility consists of 68 GE 1.5 MW units with a terminal voltage of 0.575 kV and 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. Five of these circuits have GE units and six circuits have Nordex units. All the GE feeders and one Nordex feeder will be connected to the 34.5 kV substation bus A and the other five Nordex feeders will be connected to the 34.5 kV substation bus 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 GE units will have enhanced reactive 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.



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 (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). This 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.

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	Bench-mark	With GI-2007-6	Contingency			FAC-009/cond 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 DESRTC OV	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 is 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%, 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 at maximum is very low, the likelihood of contingency overloads of 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 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 it is necessary to maintain voltages at all buses in the system between 0.95 per unit to 1.05 per unit under operating conditions. In the Rocky Mountain Voltage Coordination Guidelines that were developed by the Voltage Coordination Guideline Subcommittee of the Colorado Coordinated Planning Group, the ideal voltage for a regulating bus must be greater than 1.02 per unit. 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 as a regulating bus. 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.

With the addition of the 250 MW facility, the voltage at the POI drops to 1.018 per unit. The 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 195 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 50-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 1.027 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 1.036 per unit during periods of minimal wind generation. The transmission lines associated with the generation facilities supply 43.5 MVAR of reactive power to the PSCO system. The voltage at the existing Cedar Creek facility rises to 1.055 per unit, and the voltage at the proposed facility rises to 1.075 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 support requirements associated with the operation of the existing 300 MW facility. In addition, the actual location of the capacitor switching station (that will require a 230 kV three breaker ring bus configuration to terminate the lines and 90 MVAR of capacitive reactors) near the POI has not yet been determined or specified. The analysis has assumed that they would be about four miles from the POI (5% of the line length), primarily to recognize that they are the 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 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.

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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 individual generators. The turbines are connected through GSUs to 34.5 kV feeders. The 34.5 kV collector system at the Cedar Creek expansion consists of a total of 11 circuits that are connected to two 34.5 kV substation buses. The impedance information for these feeders was provided 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 msec. However, the other models in the WECC dynamic data file use a time step of 1/4th – 1/5th of a cycle. Therefore the dyre file was modified so that the Nordex model represented actual turbine behavior with a simulation time step of 1/4th of a cycle (\approx 5msecs).
- The over-frequency relay time delay was increased from 50 msec to 100 msec.
- 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 msec to 4 sec.

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 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. Generation remained online except when 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



Breaker Failure Studies at Keenesburg, Ft. St. Vrain and Green Valley

Transient stability analysis was also performed for breaker failure 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-phase 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 different contingencies studied for stuck breaker 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, stuck breaker analysis was performed at the 230 kV substation buses at Ft. St. Vrain and Green Valley. The results of this analysis 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

Contingency	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

Contingency	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

Contingency	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