

## Preliminary Results

# Interconnection System Impact Study Report Request # GI-2007-6

200 MW Wind Expansion of Cedar Creek, Near Grover, Colorado

PSCo Transmission Planning  
March 5, 2009

### A. Executive Summary

On December 12, 2007 Public Service Company of Colorado (PSCo) Transmission Planning received a generation interconnection request to determine the system impacts associated with a 200 MW expansion near the existing 300 MW Cedar Creek wind turbine generation facility and injecting the combined wind generation output into the PSCo transmission system at the Keenesburg 230 kV Switching Substation in Weld County, Colorado. The Customer proposed an in-service date of December 31, 2013 per the Interconnection System Impact Study Agreement (dated December 7, 2007). A generation interconnection request for a 50 MW expansion in the same area (GI-2007-5) was included as part of the study. The study request indicated that the generation would be scheduled to PSCo load. With the exception of including the 50 MW project proposed in GI-2007-5 to the study, this generation interconnection request was studied as a stand-alone project only.

This request was studied as both a Network Resource (NR)<sup>1</sup>, and as an Energy Resource (ER)<sup>2</sup>. These investigations included steady-state power flow, short-circuit and transient stability analyses. The request was studied as a stand-alone project only, with only the GI-2007-5 generation request added to the study (and no other projects that may exist in the Large Generator Interconnection Request queue), other than the generation projects that are already approved and planned to be in service by the summer of 2013. The main purpose of this study was to evaluate the potential impact on the PSCo transmission infrastructure as well as that of neighboring entities, when injecting a total of 550 MW of generation into the Keenesburg 230 kV bus, and

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<sup>1</sup> **Network Resource Interconnection Service** shall mean an Interconnection Service that allows the Interconnection Customer to integrate its Large Generating Facility with the Transmission Provider's Transmission System (1) in a manner comparable to that in which the Transmission Provider integrates its generating facilities to serve native load customers; or (2) in an RTO or ISO with market based congestion management, in the same manner as all other Network Resources. Network Resource Interconnection Service in and of itself does not convey transmission service.

<sup>2</sup> **Energy Resource Interconnection Service (ER Interconnection Service)** shall mean an Interconnection Service that allows the Interconnection Customer to connect its Generating Facility to the Transmission Provider's Transmission System to be eligible to deliver the Generating Facility's electric output using the existing firm or non-firm capacity of the Transmission Provider's Transmission System on an as available basis. Energy Resource Interconnection Service in and of itself does not convey transmission service

delivering the additional generation to native PSCo loads. The costs to interconnect the project with the transmission system at Keenesburg Substation have been evaluated by PSCo Engineering. This study considered facilities that are part of the PSCo transmission system as well as monitoring other nearby entities' regional transmission systems.

### Stand Alone Results

The stand-alone analysis consisted of a comparative study of the system behavior with the addition of the Customer's 200 MW expansion project to the PSCo system compared with that associated with the existing PSCo system. The delivery of power from the 200 MW expansion project to PSCo will be at the same POI as the existing wind facility. Therefore, the analysis focused on evaluating impacts from the Keenesburg POI. The generation from the existing facilities, the 50 MW GI-2007-5 expansion, and the 200 MW GI-2007-6 expansion (referred to collectively as Cedar Creek Wind Energy or CCWE) was modeled in the power flow cases in two ways - modeled at full output of approximately 550 MW, or modeled with the expansion off line (CCWE 350 MW output). The power flow model used in this study is a 2014 budget model with heavy summer load and moderately heavy stressed north-to-south (HSHN) flows.

### Energy Resource (ER)

Energy Resource Interconnection Service (ER) is an Interconnection Service that allows the Interconnection Customer to connect its Generating Facility to the Transmission Provider's Transmission System to be eligible to deliver the Generating Facility's electric output using the existing firm or non-firm capacity of the Transmission Provider's Transmission System on an as available basis. Energy Resource Interconnection Service in and of itself does not convey transmission service.

The study determined that the Interconnection Customer could interconnect as a Network Resource after the required Network Upgrades for Delivery are completed. Interconnection as an Energy Resource will require the same Network Upgrades to deliver the requested generation level on a firm basis. Some non-firm transmission capability may be available depending upon generation dispatch levels, demand levels, import path levels (TOT3, etc), and the operational status of transmission facilities.

### Network Resource (NR)

Network Resource Interconnection Service is an Interconnection Service that allows the Interconnection Customer to integrate its Large Generating Facility with the Transmission Provider's Transmission System in a manner comparable to that in which the Transmission Provider integrates its generating facilities to serve native load customers. A Network Resource is any designated generating resource owned, purchased, or leased by a Network Customer under the Network Integration Transmission Service Tariff. Network Resources do not include any resource, or any

portion thereof, that is committed for sale to third parties or otherwise cannot be called upon to meet the Network Customer's Network Load on a non-interruptible basis. Network Resource Interconnection Service in and of itself does not convey transmission service.

In addition to the delivery of 350 MW, 300 MW from the initial Cedar Creek facility and 50 MW from the proposed GI-2007-5 project, the full 200 MW generation output of the GI-2007-6 expansion project could be provided to PSCo after network upgrades to the PSCo transmission system have been completed. These network upgrades include looping the Ft.St.Vrain-Green Valley 230kV line (Circuit #5327) into the Keenesburg Substation and installing 230kV circuit breakers to terminate the new lines. The study determined that these network upgrades could be completed within eighteen months from the date of Authorization to Proceed.

### Transmission Proposal

The total estimated cost of the recommended system upgrades to interconnect the project is approximately **\$2,230,000** and includes:

- \$130,000 for PSCo-Owned, Customer-Funded Interconnection Facilities
- \$0 for PSCo-Owned, PSCo-Funded Network Upgrades for Interconnection
- \$2,100,000 for PSCo Network Upgrades for Delivery. This assumes that PSCo completes the network upgrade projects that have been identified and included in the PSCo Transmission Capital Budget.

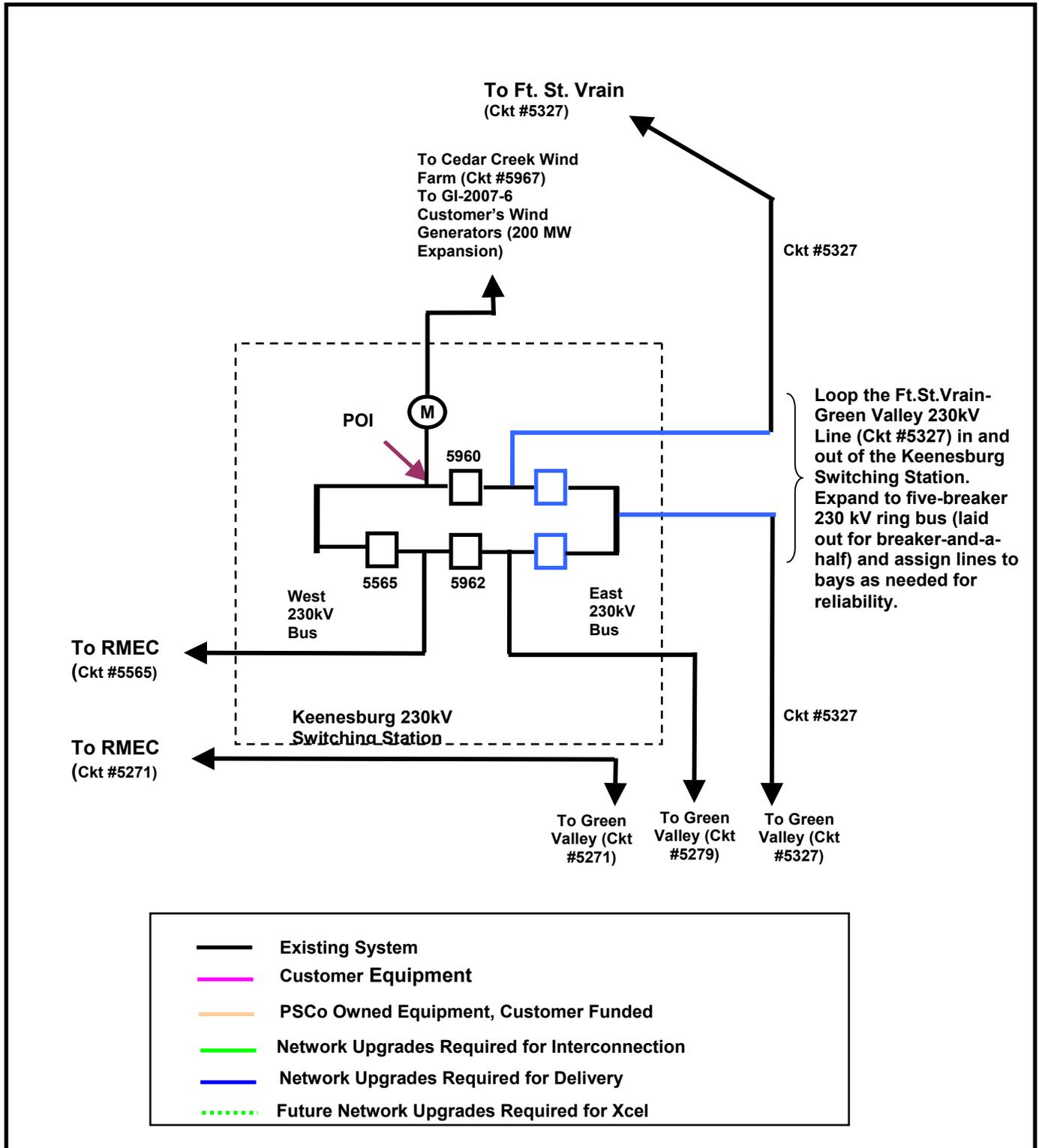
The system impact study indicates that approximately 100 MVAR of capacitors and 24 MVAR of dynamic reactive capability will likely be required for the Customer's wind generating plant to meet low-voltage ride-through (LVRT) capability during periods of high wind generation delivered to the POI. These levels of reactive power support will need to be evaluated by the Customer and appropriate facilities engineered by the Customer to enable LVRT criteria to be met and the full 550 MW of power to continue to be delivered to the POI after severe system disturbances on the PSCo system. A re-study of the dynamics analysis may be necessary to determine if the proposed dynamic support will enable all relevant criteria will be met. More detailed studies should be performed by the Customer to ensure that proposed wind generation facility will display acceptable performance during the commissioning testing.

The Interconnection Agreement (IA) requires that certain conditions be met, as follows:

1. The conditions of the Large Generator Interconnection Guidelines (LGIG) are met.
2. A single point of contact is given to Operations to manage the transmission system reliably for all wind projects delivering power at the Keenesburg POI.

3. PSCo will require testing of the full range of 0 MW to 550 MW of the combined original 300 MW wind project plus 50 MW expansion associated with GI-2007-5 and 200 MW associated with GI-2007-6. These tests will include, but not be limited to, power factor control, and voltage control as measured at the Keenesburg POI 230 kV bus for various generation output levels (0 to 550 MW) of the overall wind generation facility.
4. The Customer must show that the power factor at the POI is within the required +/-0.95 power factor range at all levels of generation and that the voltage levels and changes are within reliability criteria as measured at the POI for the full range of testing (including generator off-line conditions).

Figure 1 Conceptual One-Line for GI-2007-6 (Cedar Creek Wind Farm 200 MW Expansion)



## **B. Introduction**

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 requested in-service 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 17-mile 230-kV line to the wind farm end of the existing 72-mile 230 kV transmission line. This study was performed based upon both the existing 300 MW project and the 50 MW GI-2007-5 proposed expansion being in operation prior to this proposed 200 MW expansion. 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 Customer has requested that this project be evaluated as a Network Resource (NR) and an Energy Resource (ER), with the energy delivered to PSCo customers.

As part of the Interconnection System Impact Study Agreement that was signed December 7, 2007, the assumptions to be used for the study indicated a revised in-service date of December 31, 2013.

## **C. Study Scope and Analysis**

The Generator System Impact Study evaluated the transmission impacts associated with the proposed interconnection of an additional 200 MW of new wind generation at Cedar Creek with delivery of all power to the POI at Keenesburg. The study consisted of steady-state power flow, short circuit, and transient stability analyses.

The power flow analysis was structured to provide identification of any thermal or voltage limit violations resulting from the interconnection, and for an NR request, identification of network upgrades required to deliver the proposed generation to PSCo loads.

The short circuit analysis for this GI-2007-6 System Impact Study have not yet been completed. The purpose of the short circuit analysis is to determine the fault current levels at the Keenesburg 230kV bus after the proposed 200 MW wind generating facility is placed in-service and the network upgrades for delivery are completed. The studies are to provide an indication if the interrupting ratings of the breakers will be adequate after the addition of the proposed generating facilities and network upgrades. The short circuit study is expected to be complete within 30 days of the release of this preliminary results report.

The transient stability analysis provided simulations of the system behavior during and immediately after severe disturbances to determine whether the additional generation could adversely impact system operation.

PSCo adheres to NERC / WECC Reliability Criteria, as well as internal Company criteria for planning studies. The following criteria were used for the 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 under 1.0 per-unit of all elements' thermal (continuous current or MVA) ratings.
- Operationally, PSCo endeavors to maintain a transmission system voltage profile at 230 kV regulating buses in the Metro Denver-Boulder-Ft. Lupton region<sup>2</sup> between 1.02 p.u. and 1.03 p.u. A regulating bus is any transmission or generation bus with controllable VAR's. The Keenesburg 230 kV POI is considered a regulating bus.
- Following a single contingency element outage, transmission system steady state bus voltages must remain within 0.90 p.u. to 1.10 p.u. (and between 0.92 p.u. and 1.07 p.u. at load buses for PRPA, and power flows under 1.0 per-unit of the elements' continuous thermal ratings.
- Following fault clearing for single contingencies, transient stability studies must show that voltages on load buses do not dip more than 25% of the pre-fault voltage or dip more than 20% of the pre-fault voltage for more than 20 cycles.

#### **D. Power Flow Study Models**

With a December 2013 in-service date, the power flow studies were based on a PSCo-developed 2014 heavy summer base case that originated from the study model developed in early 2008 as part of PSCo's normal annual Five-Year Transmission Capital Budget project identification process. These budget case models are developed from Western Electricity Coordinating Council (WECC) approved models, modified as appropriate for PSCo planned and approved projects and associated topology. Load levels reflect 2014 heavy summer peak system conditions.

The first stage of development (300.5 MW) at Cedar Creek was completed at the end of 2007 and consists of 221 MW of Mitsubishi Model 1000A wind turbines and 79.5 MW of GE 1.5 MW wind turbines. The Mitsubishi turbines are 1.0 MW induction generators and each has 340 kVAR of switched capacitors near its terminals. The GE machines are 1.5 MW doubly-fed induction generators with LVRT II. The collector system for the

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<sup>2</sup> The Metro Denver-Boulder-Ft. Lupton region and its associated ideal, acceptable and emergency steady state voltage ranges are defined in the Rocky Mountain Voltage Coordination Guidelines revised July 2006. These guidelines were developed by the Voltage Coordination Guidelines Subcommittee (VCGS) of the Colorado Coordinated Planning Group (CCPG). CCPG is a reliability coordination group composed of Colorado and neighboring area utilities.

first stage operates at 34.5 kV and is arranged in two essentially equal sub-networks, with each connected to the first 230 kV substation bus with identical 100/133/167 MVA transformers. Additional reactive power support is provided by two 54 MVAR switched capacitor banks (one at each of the two 34.5 kV substation buses) and a total of 12 MVAR of DVAR<sup>3</sup> 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. Each of the 54 MVAR switched capacitor banks should be operated between 0 and 45 MVAR depending upon the total generation from the original 300 MW wind farm, with 45 MVAR online with high levels of generation. To establish the benchmark case for this study, the representation of the existing 300 MW wind farm reflected a somewhat simplified 34.5 kV collector system, with equivalencing of lateral feeders but maintaining the size of all relevant generators, switched capacitors and DVAR systems and the relative locations of the generators along the main 34.5 kV feeders. This initial stage of development is connected to the PSCO transmission system at the Keenesburg switching station in Weld County, Colorado via a single 72-mile 230-kV radial overhead transmission line.

The second stage of development for the Cedar Creek Wind Farm is planned in two separate phases. Phase 1, which was studied as GI-2007-5, consists of 50 MW of generation to be provided by 20 Clipper Windpower C-93 2.5 MW wind turbines. The collector system for this 50 MW expansion is connected to a single 35/45/55 MVA 230-34.5 kV transformer (9.0 % reactance on a 35 MVA base). Phase 2, which is considered in this GI-2007-6 report, consists of 200 MW of Clipper Windpower C-93 2.5 MW turbines.

Detailed collector system information including configuration, conductor size, and impedance data was provided by the Customer for both GI-2007-5 and GI-2007-6. This data was partially aggregated so as to provide an equivalent configuration with adequate detail to evaluate voltage levels near the proposed wind turbines during system disturbances.

Seventeen miles of 230 kV transmission connects the existing Cedar Creek 230 kV substation to the Stage 2 substation, where a 35/45/55 MVA transformer connects to the Phase 1 34.5 kV collector network. Two 65/85/110 MVA transformers, at this same substation location, will connect to the Phase 2 collector network. Figure 2 is a simplified diagram of the overall wind farm.

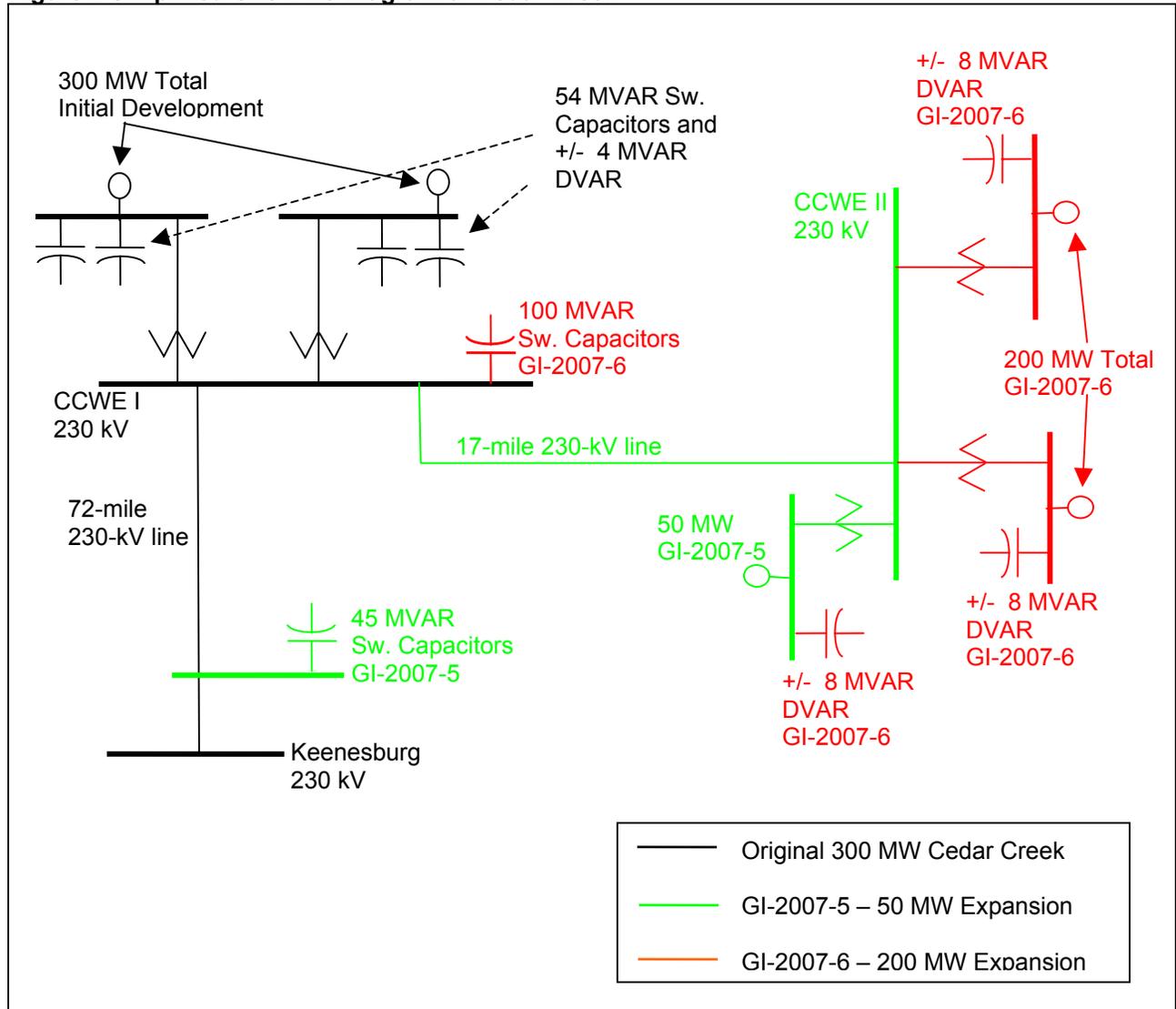
In order to meet the voltage criteria at the POI, the System Impact Study (SIS) report for GI-2007-5 indicated that 45 MVAR of switched capacitors would be needed near the POI at Keenesburg. These would provide the necessary reactive power needed to maintain the voltage at the POI within the voltage criteria for a controlled bus when CCWE was generating the full 350 MW, as documented in the GI-2007-5 SIS report. For this study, the starting benchmark case reflects the GI-2007-5 project and appropriate representation for the required reactive power support. This was done by

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<sup>3</sup> DVAR is an acronym for the “Dynamic VAR reactive compensation system”. A DVAR provides a source of dynamic VAR’s for a wide range of operational needs. A DVAR can be used to support a stable point of interconnection for a large-scale wind farm.

adding 45 MVAR of capacitors to the power flow model on the Keenesburg-Cedar Creek 230kV line, close to the Keenesburg Substation. The location for the source was taken to be 10% (about 7 miles) of the distance along the line from Keenesburg. The exact location is not critical, but the first four miles of the line conductor are strung on towers not owned Cedar Creek Wind Energy, so 10% is reasonable assumption. Note that this capacitor installation, as well as the 50 MW GI-2007-5 generating facilities, does not presently exist.

**Figure 2 Simplified One-Line Diagram of Cedar Creek**



Based upon documentation provided for the Clipper C-93 wind turbines, these units do not attempt to regulate voltage or frequency and thus should be modeled in the power flow analyses as simple generators with a fixed reactive power capability. For this study, a 0.995 power factor was assumed, such that generator reactive power output

was set to 0.357 MVAR for each 2.5 MW generator. While the manufacturer's documentation indicates that a separate reactive power management system is available, the Customer is not including this for either GI-2007-5 or GI-2007-6. As discussed later in the report, the studies show that additional dynamic reactive power support will be required to meet LVRT requirements during system disturbances.

The PSCo Balancing Authority (Area 70) wind generation facilities, other than GI-2007-5, GI-2007-6, and the existing 300 MW at Cedar Creek (collectively referred to herein as CCWE), were dispatched to approximately 12% of facility ratings, consistent with other similar planning studies. Generation at RMEC was modeled at 600 MW, the full capability of the facility. The Blue Spruce generating units were modeled at 270 MW (out of a maximum of 280 MW).

The two main power flow models were evaluated after adjustments were made to accommodate the increased generation from CCWE. The first power flow case was the benchmark model with the 300 MW output from the existing Cedar Creek facility plus the 50 MW expansion associated with GI-2007-5. In the second model the 200 MW expansion for GI-2007-6 was added. The GI-2007-6 output displaced other PSCo control area generation by 200 MW, in the southern part of the PSCo system. In particular, this was accomplished by decreasing the generation at Comanche 3 by 200 MW.

#### **E. Power Flow Study Process**

Automated contingency analysis was performed 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 control areas 70 (PSCo) and 73 (WAPA RM). Upon switching each element out, the program re-solves the power flow case with all voltage taps and switched shunt devices locked and control area interchange adjustments disabled.

#### **F. Power Flow Results**

The stand-alone results reflect that the 200 MW proposed expansion for GI-2007-6, the 50 MW expansion for GI-2007-5, and the 300 MW existing wind farm generation interconnecting at the Keenesburg 230 kV bus are modeled in the power flow case at full output, or approximately 550 MW, and the rest of the generation and loads in the power flow model reflect a heavy summer load 2014 case. The contingency studies were performed for both the "with GI-2007-6" generation expansion, and the "benchmark model" without the expansion but with the 300 MW existing facility and the 50 MW for GI-2007-5 represented. The results listing the overloaded elements (power flows in excess of their continuous rating) were compared. The summary presented in Table 1 shows those circuits that would be adversely affected by the 200 MW generation addition.

**Table 1 Branch Overloads Without Network Upgrades for Delivery**

** From bus	*** To bus	** CKT	Branch Rating	Loading as % of Branch Rating		Contingency
				Bench-mark Case	With GI-2007-6	
70048 GREENVAL	230 70820 KEENSBG	230 1	834.0	107.2	129.4	70048 GREENVAL 230 70590 RMEC 230 1
70048 GREENVAL	230 70590 RMEC	230 1	834.0	107.2	129.4	70048 GREENVAL 230 70820 KEENSBG 230 1
70609 SILVSADL	230 70610 REUNION	230 1	326.0	103.7	111.1	70192 FTLUPTON 230 70529 JLGREEN 230 1

The contingency analysis identified three circuits that would be overloaded and adversely impacted by the addition of GI-2007-6. These circuits would experience increases in contingency flows of 5.0 MW or more (2.5% of the GI-2007-6 200 MW expansion) due to the addition of the proposed 200 MW Cedar Creek Generation Facility.

Subsequent to completing the contingency analysis, it was determined that the 326 MVA rating of the Silver Saddle–Reunion 230-kV circuit (Circuit No. 5877) in the power flow case has been increased to 744 MVA (the thermal rating of the line), based on an evaluation of the substation termination equipment at Tri-State’s Silver Saddle and Reunion substations. Therefore, the reported contingency overloads of this element can be ignored, since it will not be overloaded under contingency conditions even with the additional generation.

The 230-kV transmission system between RMEC, Keenesburg and Green Valley does not have sufficient capability to accommodate the full output from both RMEC and the total generation from the existing Cedar Creek project plus the GI-2007-5 and GI-2007-6 expansions. Under contingency conditions, loading on either of the two 230-kV circuits to Green Valley with the outage of the other reaches 1,080 MVA, which is 129% of the circuit’s 834 MVA rating in the power flow case. In the GI-2007-5 system impact study report, these two circuits were overloaded under contingency conditions, requiring network upgrades for delivery. These network upgrades or network upgrades, (replacement of the aluminum bus at the Green Valley Substation) would increase the rating of each circuit to 965 MVA. As noted in that same report, constraints may exist at the RMEC Substation, owned by RMEC, that may limit the rating of the Green Valley–RMEC 230kV circuit to less than 965 MVA. These potential constraints are assumed to be resolved prior to this project. While the 965 MVA rating would be adequate for the GI-2007-5 project, it would only allow for the delivery of 78 MW, not the entire 200 MW GI-2007-6 expansion, in the 2014 time frame. Therefore, additional transmission system network upgrades would be necessary to deliver the Customer’s generation on a firm basis while maintaining system reliability and integrity.

A number of options were considered to increase the delivery capability from the Keenesburg POI, with most options based upon those considered in the GI-2007-6 feasibility study. These are described and the results presented in Appendix A.

Based upon the results of the analysis, looping the Ft. St. Vrain – Green Valley 230 kV circuit into the Keenesburg switching station will provide two additional outlet paths from the POI. With this reinforcement in place, the full 550 MW generating capacity of CCWE could be delivered to PSCO loads in 2014, as no other transmission facilities were observed to be adversely impacted in the steady state analysis.

#### Network Resource (NR):

The results of this study indicate that the 200 MW increase in wind generation at CCWE delivered to the Keenesburg POI could result in the overloading of facilities in the PSCO regional transmission system. Therefore, the 200 MW NR value requested will require interconnection and Transmission Network Upgrades. After these upgrades are complete, the 200 MW expansion could be considered a network resource with firm transmission capability for the entire output of the plant to be delivered to PSCO load.

#### Energy Resource (ER):

The study determined that the Interconnection Customer could interconnect as a Network Resource after the required Network Upgrades for Delivery are completed. Interconnection as an Energy Resource will require the same Network Upgrades to deliver the requested generation level on a firm basis. Some non-firm transmission capability may be available depending upon generation dispatch levels, demand levels, import path levels (TOT3, etc), and the operational status of transmission facilities.

#### Interconnection Requirements at the Point of Interconnection:

##### Principles:

- Interconnecting to the PSCO bulk transmission system requires the Customer to adhere to certain interconnection requirements. Many of these requirements are contained in the Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater than 20 MW (Guidelines).
- The Interconnection Guidelines make reference to interconnection requirements resulting from FERC Order 661A. FERC Order 661A describes the interconnection requirements for wind generation plants.
- PSCO System Operations conducts commissioning tests prior to the commercial in-service date for a Customer's facilities.

##### Guidelines:

The Customer must adhere to 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. The Transmission Provider's System Impact Study is needed to demonstrate that such a power factor requirement is necessary to ensure safety or reliability.

2. The voltage at a Point Of Interconnection shall be maintained in the ideal voltage range for the appropriate Colorado region and bus type (regulating<sup>4</sup> or non-regulating) as determined in the Rocky Mountain Area Voltage Coordination Guidelines<sup>5</sup>. The System Impact Study will investigate pertinent demand (on-peak or off-peak), season (summer or winter), 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 POI for a wind generating facility cannot be declared a regulating bus unless system studies demonstrate that the designation of the POI as a regulating bus is needed for system reliability or safety.
4. The impact of the wind generating facility on the reactive power schedules of nearby generating units may need to be mitigated by the Customer if system studies demonstrate that the proposed wind generating facility causes nearby generating units to generate or absorb reactive power for voltage control<sup>6</sup>. It is understood that sufficient reactive power reserve must be maintained on generating units to allow them to dynamically regulate voltage for extreme system conditions.
5. If a wind generating facility is interconnected to the bulk transmission system but is operating with its generation off-line and receiving power from the bulk transmission system for its station service requirements, that facility is acting as a load and will be required to maintain the power factor at the POI within 98% lagging or leading (when the station service load is greater than 85% of maximum) per the Xcel Energy document titled Interconnection Guidelines For Transmission Interconnected Customer Loads.
6. PSCo System Operations will require the Customer to perform operational tests prior to commercial operation that would verify that the equipment installed by the Customer meets operational requirements.

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<sup>4</sup> A regulating bus is defined in the Rocky Mountain Area Voltage Coordination Guidelines as any transmission or generation bus with controllable VAR's. This implies that the bus has a voltage schedule that is being regulated by a generating facility. Generating facilities include Static VAR Compensators (SVC's), synchronous generators, or synchronous condensers that can supply fast-acting reactive power (VAR) compensation to dynamically regulate voltage at a power system bus. Switchable capacitors, switchable reactors, load tap changing transformers, etc. are not defined as generating facilities as they do not provide controllable dynamic VARs'.

<sup>5</sup> The Voltage Coordination Guidelines Subcommittee (VCGS) of the Colorado Coordinated Planning Group developed the guidelines. The subcommittee consisted of representatives from major Colorado utilities including Colorado Springs Utilities, Platte River Power Authority, Tri-State Generation and Transmission, Public Service Company of Colorado, and Western Area Power Administration-Rocky Mountain Region. Other major utilities outside of Colorado were also involved in the development of these guidelines.

<sup>6</sup> The Rocky Mountain Area Voltage Coordination Guidelines (July 2006), page 8 of 34, Item 6, states that "Static VAR sources (switched shunt capacitors, reactors) should be operated to control the voltage profile before relying on LTC or generator VAR output, and should be used in such a manner to keep LTC transformers near their nominal tap range and to keep reactive margin on generating equipment. The rationale for this goal is that the generator is a dynamic reactive source that can provide high-speed reactive support to the transmission system after a disturbance that results in low voltages, or conversely are in a position to reduce voltages after a contingency that results in high voltages. Keeping transformers near their mid-tap range also allows for maximum response to either boost or reduce voltages following a disturbance".

7. It is the responsibility of the Customer 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.
8. PSCo requires the Customer 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 the line near the POI will need to be controlled according to the Interconnection Guidelines.

The System Impact Study examined the 200 MW expansion of GI-2007-6 along with the configuration of Cedar Creek wind development at the 350 MW level prior to the addition of GI-2007-6. The study determined that the delivery of the full 550 MW minus losses to the POI can be accomplished within the 0.95 leading and lagging criteria as currently configured. As can be seen from Table 2, the facility is within criteria. With the CCWE at 550 maximum output, 517.1 MW is injected into the POI from the CCWE-Keenesburg 230 kV transmission line. The Customer's facilities (line plus wind generation site) absorb 108.4 MVAR of reactive power, for a 0.979 leading power factor (CCWE-Keenesburg 230 kV line current leads the voltage at the POI). This level is within the 0.95 leading to 0.95 lagging power factor criteria.

These values reflect the addition of reactive support needed at CCWE to allow the 550 MW overall wind farm meet LVRT criteria under severe system disturbances. The specific reactive power additions are described in the dynamic stability analysis discussion.

**Table 2 Reactive Power Results at the Keenesburg POI With GI-2007-6**

	RMEC Generation Near Maximum	
	No CCWE Generation	550 MW Generation at CCWE
<b>Real Power Delivered to POI, MW</b>	0.0	517.1
<b>Reactive Power Delivered to POI, MVAR</b>	8.4	-108.4
<b>Power Factor of CCWE Deliveries</b>	0.0	-0.979
<b>Voltage at POI, pu</b>	1.041	1.035
<b>Voltage at CCWE   230 kV bus, pu</b>	1.041	1.038

In the total absence of wind generation at the existing and proposed wind facilities, less than 10 MVAR of reactive power would be delivered to PSCo at the POI. This reactive power is due to the distributed capacitance of the Customer transmission facilities. This condition reflects a scenario in which PSCo is delivering house power to the wind generation facilities. Voltages at the wind farm are within acceptable ranges, at or below 1.040. During these conditions, the power factor of the wind facility is approximately 0.0 lagging (assuming minimal house power). This power factor level is

outside the 0.98 lagging to 0.98 leading required power factor range for a load. To bring the power factor within range, an amount of reactive power of approximately 8 MVAR would need to be absorbed at the POI to account for line charging whenever the Customer's wind turbines are generating minimal or no power while still connected to the system at the POI.

The voltage levels on the Customer's 230 kV system and the PSCo system appear to be at acceptable levels. Since the stability analysis indicates a need for the Customer to further study the type of equipment, location, and size of reactive power support to meet the LVRT criteria, those specifications will likely impact the reactive power delivered to the POI under varying wind generation levels. This issue will need to be addressed if the project is to move forward.

### **G. Dynamic Stability Analysis and Results**

Transient stability studies determine the response of a transmission system to the occurrence of faults, tripping of generators, tripping of transmission lines, or tripping of loads. These studies evaluate generator frequency and internal generator rotor angles, bus voltages, and power flows before, during and after a disturbance to determine if the system remains stable after a disturbance. In addition, FERC Order 661A requires a wind generating plant to be able to remain on-line during voltage disturbances up to the time periods and associated voltage levels set for in the Low Voltage Ride-Through (LVRT) capability standard.

A discussion of the Cedar Creek wind farm representation in the dynamics analysis is presented in Appendix B, along with discussion about an issue concerning the dynamics model for the Clipper C-93 wind turbines. Once the issue was resolved, the stability analysis was started.

Several severe system disturbances, all but one in the form of three-phase faults close to the POI, were studied. The three-phase faults were assumed to be at the indicated end of a transmission element and would be removed by breaker operation within a normal clearing time of five cycles. The disturbances that were studied are summarized in Table 3. The stability analysis was performed for the benchmark case and the GI-2007-6 case for all contingencies applicable for these two cases.

For all system disturbances studied, the benchmark case was stable, with all generation that was not disconnected by breaker operation remaining online and all oscillations positively damped. However, with the addition of GI-2007, three-phase faults on the PSCo system result in prolonged low-voltage on the wind farm at a number of wind farm buses, resulting in the loss of some or all of the Mitsubishi wind turbines in the original Cedar Creek development. These wind turbines were tripped by their under-voltage protection. In reviewing these results, it became apparent that there was minimal reactive power support being provided by the Clipper wind turbines as modeled. Further, the nature of the results indicates that some combination of dynamic and static

reactive power would need to be added to raise voltage levels immediately after the fault was cleared.

Since the original Cedar Creek development used American Superconductor's DVAR system to provide dynamic reactive power to address LVRT issues, a number of combinations of DVAR sizes and switched capacitors options to provide reactive power were investigated with the sole purpose to determine if a viable solution could be reached that would allow all of the wind turbines to remain in operation during severe system disturbances. With the addition of an 8 MVAR DVAR system on each of the three 34.5 kV substation buses in the GI-2007-5 and GI-2007-6 projects coupled with the addition of 100 MVAR of switched capacitors added at the original Cedar Creek 230-kV bus, the results indicate that the LVRT criteria would be met and the PSCO system would operate in a stable manner for all contingencies.

**Table 3 Stability Results**

	Faulted End	Circuit Faulted	Results	
			Benchmark Case	GI-2007-6 <sup>(1)</sup>
1	Keenesburg	Keenesburg - CCWE 230 kV	Stable, generation disconnected	Stable, generation disconnected
2	Keenesburg	Keenesburg - Green Valley 230 kV	Stable	Stable
3	Keenesburg	Keenesburg - RMEC 230 kV	Stable	Stable
4	CCWE 230 kV	One CCWE 167 MVA 230/34.5 kV transformer	Stable, generation disconnected	Stable, generation disconnected
5	RMEC	RMEC – Keenesburg 230 kV	Stable	Stable
6	RMEC	RMEC – Green Valley 230 kV	Stable	Stable
7	Green Valley	Green Valley – RMEC 230 kV	Stable	Stable
8	Green Valley	Green Valley – Keenesburg 230 kV circuit 1	Stable	Stable
9		Loss of RMEC 3 generating unit	Stable, generation disconnected	Stable, generation disconnected
10	Keenesburg	Keenesburg – Ft. St. Vrain 230-kV (GI-2007-6 case)	--	Stable
11	Ft. St. Vrain	Ft. St. Vrain – Keenesburg 230 kV (GI-2007-6 case)	--	Stable
12	Green Valley	Green Valley – Ft. St. Vrain (benchmark case)	Stable	--
13	Ft. St. Vrain	Ft. St. Vrain – Green Valley 230 kV (benchmark case)	Stable	--
14	Cedar Creek II 230 kV	One Cedar Creek II 230/34.5 kV transformer for GI-2007-6	--	Stable, generation disconnected

Note:

1. GI-2007-6 with three 8-MVAR DVAR systems and 100 MVAR capacitors added.

With those additions for GI-2007-6, the results of the simulations indicate that the system would be stable before, during and after the contingencies. All system oscillations were positively damped. All generation remained online after the fault was cleared except for those units isolated by the fault.

While the described configuration represents one possible solution, it is the Customer's responsibility to engineer, specify, and locate any facilities necessary for the project to meet LVRT criteria for the proposed GI-2007-6 facility as well as the existing wind farm and the GI-2007-5 expansion.

#### **H. Costs Estimates and Assumptions**

The estimated total cost for the required upgrades is approximately **\$2,230,000**.

The estimated costs shown are (+/-30%) estimates in 2009 dollars and are based upon typical construction costs for previously performed similar construction. These estimated costs include all applicable labor and overheads associated with the engineering, design, and construction of these new PSCo facilities. This estimate did not include the cost for any other Customer owned equipment and associated design and engineering.

This estimate does not include any network network upgrades that may be required to meet the interconnection guidelines as required by PSCo in the Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater than 20 MW (Guidelines). Other projects are included in the PSCo Capital Budget process and are assumed to be in-service by the commercial in-service date of the 200 MW expansion.

Since this project intends to use the interconnection for the existing 300 MW Cedar Creek Wind Facilities GI-2006-1(i) and the 50 MW GI-2007-5 expansion at the Keenesburg Substation, there will be only minimal costs of approximately \$130,000 associated with the interconnection required for this 200 MW expansion project GI-2007-7.

The following tables lists the improvements required to accommodate the interconnection and the delivery of the Project. The cost responsibilities associated with these facilities shall be handled as per current FERC guidelines. System improvements are subject to change upon more detailed analysis.

**Table 4 PSCo Owned; Customer Funded Interconnection Facilities**

Element	Description	Cost Est. (Millions)
<b>Keenesburg 230 kV Substation</b>	Interconnect Customer to tap at PSCo's Keenesburg 230 kV Substation. The new equipment includes: <ul style="list-style-type: none"> <li>• These facilities already exist, so it is assumed that no additional work will be required.</li> </ul>	<b>\$0.000</b>
	Customer LF/AGC and Generator Witness Testing. (Customer generation telemetry equipment, and witnessing the Customer generator commissioning testing).	<b>\$0.130</b>
	<b>Total Cost Estimate for PSCo-Owned, Customer-Funded Interconnection Facilities</b>	<b>\$0.130</b>
<b>Time Frame</b>	<b>Site, engineer, procure and construct</b>	<b>Two months</b>

**Table 5 PSCo Owned; PSCo Funded Interconnection Facilities**

Element	Description	Cost Estimate (Millions)
<b>Keenesburg 230 kV Substation</b>	Interconnect Customer to tap at PSCo's New Keenesburg 230 kV Substation. The new equipment includes: <ul style="list-style-type: none"> <li>• These facilities already exist, so it is assumed that no additional work will be required.</li> </ul>	<b>\$0.000</b>
	<b>Total Cost Estimate for PSCo-Owned, PSCo-Funded Interconnection Facilities</b>	<b>\$0.000</b>
<b>Time Frame</b>	<b>Site, engineer, procure and construct</b>	<b>N/A</b>

**Table 6 PSCo Network Upgrades for Delivery**

Element	Description	Cost Est. (Millions)
<b>Keenesburg 230kV Substation</b>	Substation work to loop in Fort St. Vrain – Green Valley 230kV transmission line <ul style="list-style-type: none"> <li>○ Two 230kV breakers</li> <li>○ Six 230kV switches</li> <li>○ Structures and associated equipment</li> </ul>	<b>\$1.535</b>
<b>FSV – Green Valley 230kV Line</b>	Transmission Line work to loop into Keenesburg 230kV substation <ul style="list-style-type: none"> <li>○ 4 new deadend structures</li> <li>○ 1 new tangent structure</li> <li>○ Associated insulators and hardware</li> </ul>	<b>\$0.565</b>
	<b>Total Cost Estimate for PSCo Network Upgrades for Delivery</b>	<b>\$2.100</b>
<b>Time Frame</b>	<b>Network Upgrades for Delivery – to be constructed via the PSCo Capital Budget Construction Process.</b>	<b>18 months</b>
	<b>Total Cost of Project</b>	<b>\$2.230</b>

### Assumptions for Alternatives

- The cost estimates provided are “scoping estimates” with an accuracy of +/- 30%.
- Estimates are based on 2009 dollars (no escalation applied).
- There is no contingency or AFUDC included in the estimates.
- Labor is estimated for straight time only – no overtime included.
- Lead times for materials were considered for the schedule.
- The Wind Generation Facility is not in PSCo’s retail service territory. Therefore, no costs for retail load metering are included in these estimates.
- PSCo (or it’s Contractor) crews will perform all construction and wiring associated with PSCo owned and maintained facilities.
- The estimated time for PSCo to site, engineer, procure and construction the scope of work identified in Table 6 is **18 months** after Authorization to Proceed has been obtained. This is completely independent of other queued projects and their respective in-service dates.

## Appendix A

### Reinforcement Options

With the full output from GI-2007-6 coupled with the other generation in the area, each of the two circuits between RMEC and Green Valley will be loaded to about 129% of their rating with the loss of the other circuit. To accommodate the additional generation proposed for GI-2007-6, some form of system augmentation is necessary.

Five possible network upgrades of the PSCo transmission system have been considered to accommodate the additional generation at Cedar Creek. These consisted of:

- 1) Looping the existing Ft. St.Vrain-Green Valley 230-kV circuit into Keenesburg,
- 2) Constructing a 230-kV circuit from Keenesburg to Cherokee, bypassing Fort Lupton.
- 3) Constructing a 230-kV circuit from Keenesburg to Fort Lupton,
- 4) Construct 230-kV circuits from Keenesburg to Fort Lupton and from Fort Lupton to Cherokee, and
- 5) Constructing a 230-kV circuit from Keenesburg to Green Valley.

To evaluate each of these reinforcement options, a power flow model was created that reflected the option to be studied. Contingency analysis was performed for each option and the branch loadings then summarized to establish the effectiveness in eliminating adverse impacts on the area transmission system due to this project. These results are presented in Table 7.

Since the Silver Saddle to Reunion circuit has been up-rated to 744 MVA, the most cost effective reinforcement is the first option, looping the existing Ft. St. Vrain to Green Valley 230 kV circuit into the substation at Keenesburg.

**Table 7 Overloaded Circuits Adversely Impacted with the Addition of GI-2007-6  
For the Most Significant Contingencies for Proposed Network Upgrades for Delivery**

			Reinforcement Options						
			0	1	2	3	4	5	
Overloaded Branches	Rating	w/o CC2 Ph2	w CC2 Ph2	Ft.St.Vrain Keenesburg GreenValley	Keenesburg- Cherokee	Keenesburg- Ft.Lupton	Keenesburg- Ft.Lupton- Cherokee	Keenesburg- GreenValley	Contingency
	MVA	%	%	%	%	%	%	%	
GreenValley- Keenesburg 230	834.0	107.2	129.4	< 100.0	< 100.0	< 100.0	< 100.0	< 100.0	GreenValley- RMEC 230
GreenValley- RMEC 230	834.0	107.2	129.4	< 100.0	< 100.0	< 100.0	< 100.0	< 100.0	GreenValley- Keenesburg 230
SilverSaddle- Reunion 230	326.0	103.7	111.1	106.1	< 100.0	104.0	< 100.0	111.2	Ft.Lupton- JLGreen 230

## Appendix B

### Stability Analysis Setup

The representation of the Cedar Creek wind farm in the power flow models used in the steady state analysis was also used for the stability analysis,

Two types of wind machine are in use on initial development of the Cedar Creek, 221 Mitsubishi induction machines (each 1 MW) and 53 GE machines (each 1.5 MW). The GE machines are doubly-fed induction generators. The wind park network model was simplified by organizing the machines into groups and modeling each group by a single electrically equivalent machine. The PSS/E dynamics data for these machines have been setup for earlier studies on this network, and have been reused for the present studies. Additionally, the DVAR systems and capacitor banks were part of the initial Cedar Creek development have been included in the model for this analysis.

The 50 MW GI-2007-5 expansion for Cedar Creek consists of 20 Clipper Windpower 2.5 MW C-93 wind turbines, and the GI-2007-6 expansion consists of an additional 80 2.5 MW Clipper machines. The Clipper machine is a fully converted generator, and the PSS/E dynamic models of the generator, inverter and associated protection were provided to PSCO as Fortran source code and supporting documentation<sup>7</sup>. Since the Customer indicated that Clipper's CVAR system was not in their plans, the initial stability analysis setup for GI-2007-6 did not include any separate dynamic reactive power equipment for the proposed expansion.

The 45 MVAR capacitor bank near the Keenesburg POI that was indicated in the GI-2007-5 system impact study as necessary for reactive power support at the POI was also included in the setup for the stability analysis for GI-2007-6. The looping of the Ft. St. Vrain – Green Valley 230 kV circuit into Keenesburg was included in the GI-2007-6 model.

During the course of using these models on the Cedar Creek network, it was established that there was an error in the modeling of the current limiting action of the converter, which comes into operation when there is significant voltage depression at the inverter terminals. The effect of this modeling error is to inject excessive current into the network during periods of severe system disturbance at the wind park, resulting in network solutions failing to converge. Once the severe disturbance is removed, the current injection returns to normal levels as provided for in the model's code. Fortunately, since the model's source code was available, it was possible to identify and correct this error, and then continue the studies. While it is believed that this

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<sup>7</sup> "Modeling the Clipper Windpower C-93 Wind Turbine for Load Flow, Short Circuit and Stability Studies using PSS/E Version 30", July 20, 2005.

modification of the model is reasonable, this issue needs to be resolved by the manufacturer.

## **Appendix C**

### **Schedule**

The following Gantt chart represents a generic project schedule and includes the estimated time frame for siting, permitting, easement, and right-of-way acquisition, design and construction for the PSCo network upgrades.

ID	Task Name	Duration	M-1	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19
1	<b>GI 2007-6 200 MW expansion of the Cedar Creek Wind Farm</b>	<b>380 days</b>																				
2	Permitting	2 mons																				
3	<b>Substation</b>	<b>340 days</b>																				
4	Engineering	4 mons																				
5	Procurement	8 mons																				
6	Construction	5 mons																				
7	<b>Transmission Line</b>	<b>260 days</b>																				
8	Engineering	2 mons																				
9	Procurement	8 mons																				
10	Construction	3 mons																				
11	Project Complete	0 days																				

Project: GI 2007-6 Schedule Date: Tue 3/3/09	Task		Milestone		External Tasks	
	Split		Summary		External Milestone	
	Progress		Project Summary		Deadline	