System Impact Study Report
Request # GI-2008-2

300 MW Wind Generation Interconnecting at Comanche Substation

PSCo Transmission Planning

June 3, 2011

A. Executive Summary

Public Service Company of Colorado (PSCo) Transmission Planning received a generation interconnection request to determine the potential system impacts associated with interconnecting a 300-MW wind generation facility at the Comanche Substation through a 46-mile transmission line. The 345-kV bus at Comanche was considered to be the Point of Interconnection. The Developer originally suggested a commercial operation date for their facility of October 1, 2010; however, a new commercial operation date would need to be established if this project proceeds forward. The study request indicates that the generation would be delivered to PSCo load.

This request was studied as both a Network Resource (NR)[1] and as an Energy Resource (ER)[2]. These investigations included steady-state power flow, short-circuit and transient stability analyses. The request was studied as a stand-alone project only, with no evaluations made of other potential new generation requests that may exist in the Large Generator Interconnection Request (LGIR) queue, other than the generation projects that were already approved and planned to be in service by the summer of 2010. The main purpose of this study was to evaluate the potential impact of GI-2008-2 on the PSCo transmission infrastructure as well as those of neighboring entities when injecting a total of 300 MW of new generation at Comanche, and delivering that additional generation to native PSCo loads. The costs to interconnect the project with the transmission system at Comanche 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.

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[1] **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. Network Resource Interconnection Service in and of itself does not convey transmission service.

[2] **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.

Stand Alone Results

The stand-alone analysis consisted of a comparative study of the system behavior with the addition of the Developer's 300-MW project to the PSCo system compared with that associated with the existing PSCo system. The power flow model used for this study is a 2010 budget model with heavy summer demand and a moderately stressed south-to-north flow from southern Colorado to the Denver Metro area.

Energy Resource (ER)

The results of this Feasibility Study indicate that firm transmission capacity for the 300 MW wind generation facility is not available due to existing overloads in the Black Hills/Colorado Electric Utility Company's,(BHC) Tri-State Generation and Transmission Association's and Colorado Springs Utilities' systems and firm transmission commitments are not possible without the construction of network reinforcements. Non-firm transmission capability may be available depending on marketing activities, dispatch patterns, generation 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 Developer 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.

As a network request, a contingency analysis was performed to determine the network upgrades that would be required to deliver the entire output of the GI-2008-2 wind facility as provided at the POI to PSCo native load customers. The estimated cost of the PSCo system upgrades to accommodate the project is approximately $3.298 million (2008 dollars) and includes:

$0.520 PSCo-Owned, Developer-Funded Interconnection Facilities
$2.778 PSCo-Owned, PSCo-Funded Network Upgrades for Interconnection
$0.000 PSCo Network Upgrades for Delivery[3].

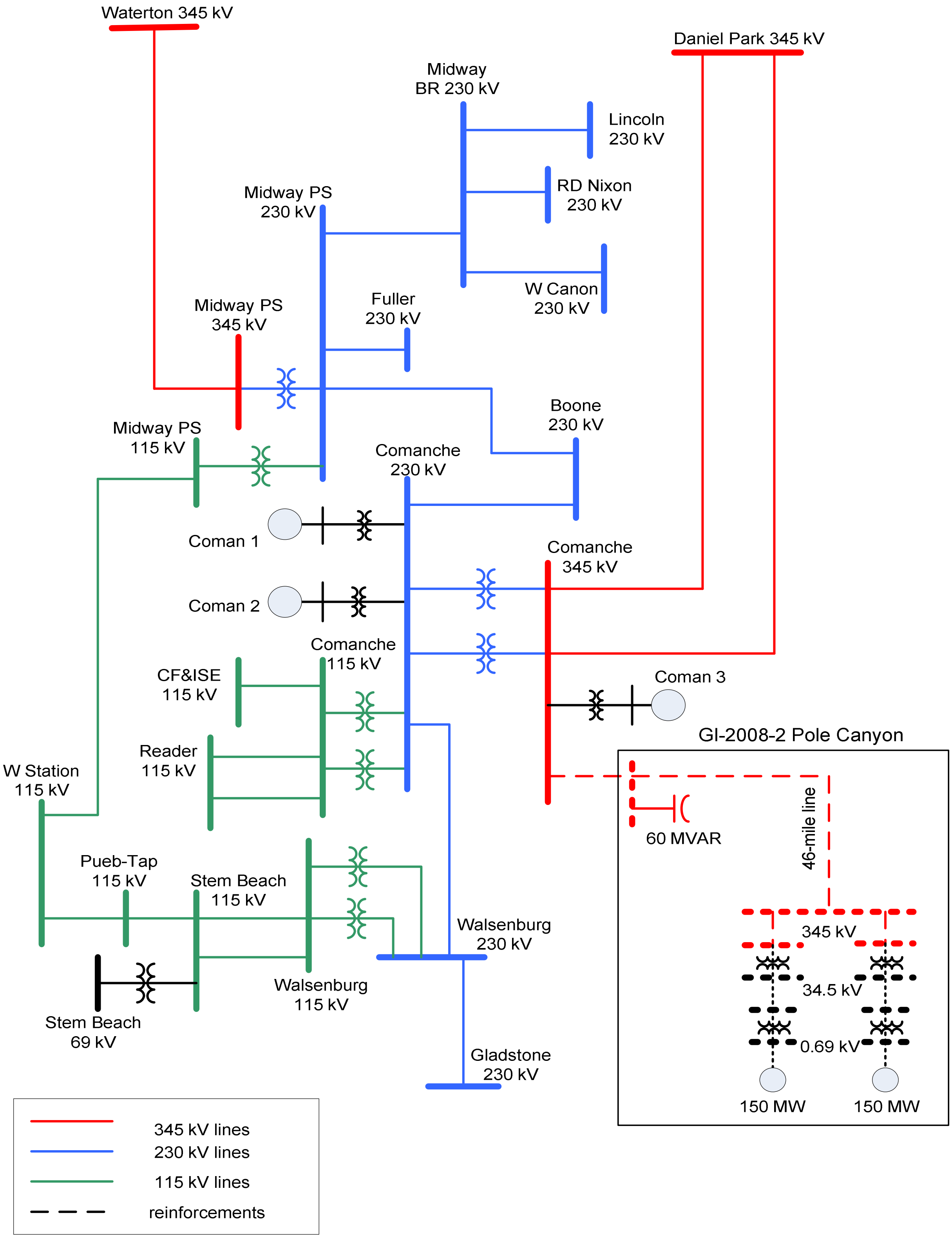
[3] This assumes that PSCo completes the network upgrade projects that have been identified in the study and are included in the PSCo Transmission Capital Budget.

The study analysis concludes that the full 300-MW generation output of the GI-2008-2 project could be provided to PSCo after network upgrades to the affected parties' transmission systems have been completed. The Developer will have to coordinate with all parties to ensure that the upgrades are in place before GI-2008-2 is in operation.

The steady state analysis indicates that approximately 25 MVAR of reactors will likely be required for the Developer'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. The reactors would be needed whenever the Developer's facilities are off-line or generating at very low levels while the Developer is connected to the POI. In addition, about 60 MVAR of switched capacitors (or other reactive power source) will be needed to meet the voltage criteria at the POI near maximum generation from GI-2008-2. More detailed studies should be performed by the Developer to ensure that proposed wind generation facility will display acceptable performance during the commissioning testing.

A conceptual one-line of the interconnection of GI-2008-2 at the Comanche 345 kV bus is provided in Figure 1 below.

Figure 1. Diagram of the Interconnection of GI-2008-2 at Comanche 345 kV



B. Introduction

Public Service Company of Colorado received a large generator interconnection request (GI-2008-2) to interconnect a wind farm with a total generator nameplate capacity of 300.6 MW and a suggested commercial operation date of October 1, 2010. The proposed GI-2008-2 Project would be located approximately 10.5 miles northwest of Walsenburg, Colorado and connect to the transmission system at the Comanche Substation using a new 46-mile transmission line. Per the Developer's request, the 345-kV bus at Comanche was considered to be the Point of Interconnection. In the Study Agreement for the System Impact Study, the developer specified that their project would consist of 126 Mitsubishi MWT 95 2.4 MW wind turbines, with a total nameplate capability of 302.4 MW. Subsequent to that date, the Developer indicated that the facility would use 167 Vestas V90 1.8 MW wind turbines instead, which would reduce total installed capability to 300.6 MW. The Developer provided a detailed collector system model for the project based on the Vestas V90 units. This interconnection request has been evaluated as a stand alone project with no other higher queued projects modeled.

The Developer requested that this project be evaluated as a Network Resource (NR) and an Energy Resource (ER), with the energy delivered to PSCo native load customers.

C. Study Scope and Analysis

This system impact study evaluated the feasibility of delivering 300 MW of energy from GI-2008-2 through the Point of Interconnection at Comanche to PSCO native loads. This study consisted of steady state power flow analysis and transient stability analysis. The power flow analysis provided a preliminary identification of any thermal or voltage limit violations resulting from the interconnection, and for an NR request, a preliminary identification of network upgrades required to deliver the proposed generation to PSCo loads. In the transient stability analysis, simulations of system behavior during and immediately after severe system disturbances were performed to determine whether the additional generation would adversely impact system operation.

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 tries 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 between 0.92 per-unit and 1.07 per-unit at load buses for PRPA), 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) issues during or after standard fault clearing time for faults on the transmission system unless the wind farm becomes isolated.
- Damping and voltage recovery at various buses should be within applicable standards.

The potential affected parties for this proposed project are Tri-State Generation and Transmission Association (TSGT), Colorado Springs Utilities (CSU), and Black Hills/Colorado Electric Utility Company (BHC).

D. <u>Wind Turbine Generator – Reactive Power Requirements</u>

Interconnecting a wind generation plant to the PSCo bulk transmission system requires the Interconnection Customer to adhere to the power factor (reactive power) range standard specified in FERC Order 661A. That order requires a wind generating plant to maintain a power factor within the range of 0.95 leading to 0.95 lagging, measured at the Point of Interconnection as defined in this LGIA, if the Transmission Provider's System Impact Study shows that such a requirement is necessary to ensure safety or reliability. The power factor range standard can be met by using, for example, power electronics designed to supply this level of reactive capability 606 (taking into account any limitations due to voltage level, real power output, etc.) or fixed and switched capacitors if agreed to by the Transmission Provider, or a combination of the two. The Interconnection Customer shall not disable power factor equipment while the wind plant is in operation. Wind plants shall also be able to provide sufficient dynamic voltage support in lieu of the power system stabilizer and automatic voltage regulation at the generator excitation system if the System Impact Study shows this to be required for system safety or reliability.

E. <u>Wind Turbine Generator – Power Factor Capability Requirements at the Point of Interconnection</u>

The Interconnection Customer should adhere to the following:

- The voltage at the Point Of Interconnection shall be maintained in the Regulating Bus Ideal Voltage Range for the appropriate Colorado region (i.e. voltage schedule) as specified in the Rocky Mountain Area Voltage

Coordination Guidelines[4]. Since these guidelines call for sufficient reactive power margins on the (synchronous) generating units to allow them to dynamically regulate voltage for extreme system conditions, any adverse impact of the interconnecting wind generating plant on the existing reactive power margins of nearby generating units identified in the System Impact Study may also have to be mitigated by the Interconnection Customer.

- The wind generating plant shall be designed to operate within the entire power factor range of 0.95 leading (absorbing vars) to 0.95 lagging (delivering vars), as measured at the Point Of Interconnection, to maintain the specified voltage schedule at the POI. The reactive power (Mvar) capability corresponding to the above power factor range shall be based on the aggregate rated power (MW) output of the wind generating plant at the POI.
- PSCo System Operations will require the Interconnection Customer to perform acceptance tests prior to commercial operation to verify that the equipment installed in the wind generating plant meets operational requirements. To facilitate this, the Interconnection Customer shall provide a single point of contact to coordinate compliance with the 0.95 lag/lead power factor range standard and the voltage regulation/control capability at the POI.
- It is the responsibility of the Interconnection Customer to design the wind generating plant to be compliant with the 0.95 lag/lead power factor range standard and have voltage regulation/control capability at the POI. The design must determine the appropriate locations, ratings and type of reactive power equipment – dynamic (DVAR/SVC) and/or static (switched capacitors/reactors, ,etc.) – that is needed for acceptable performance during the commissioning tests.
- 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 and 98% leading (when the station service load is greater than 85% of maximum) in accordance with Xcel Energy's Interconnection Guidelines For Transmission Interconnected Customer Loads.
- The System Impact Study[5] performed by PSCo as Transmission Provider demonstrates the transmission system reliability need for requiring power

[4] 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.

[5] PSCo performs the System Impact Study in conformance with NERC Transmission System Planning Performance Requirements (TPL Standards) and WECC System Performance Criteria. The System Impact Study will cover the pertinent demand (on-peak or off-peak), season (summer or winter), control area generation dispatch scenarios, and contingency outages based on the in-service date requested by the Interconnection Customer.

factor (reactive power) capability from an interconnecting wind generation plant, pursuant to FERC Order 661-A.

F. Wind Turbine Generator – Coordination and Testing

PSCo requires the Developer 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 Interconnection Agreement (IA) requires that certain conditions be met, as follows:

1. The conditions of the Large Generator Interconnection Guidelines[6] (LGIG) are met.

2. A single point of contact is given to Operations to manage the transmission system reliably for all wind projects using the transmission facilities associated with GI-2008-2 that deliver power to the Comanche POI, as indicated in the Interconnection Guidelines.

3. PSCo System Operations conducts commissioning tests prior to the commercial in-service date to verify the wind generation plant's power factor (reactive power) range at the POI and associated ability to maintain the specified voltage schedule at the POI. PSCo will require testing of the full range of 0 MW to 300 MW of the wind project. These tests will include, but not be limited to, power factor (pf) control, and voltage control as measured at the Comanche POI for various generation output levels (0 to 300 MW) of the overall wind generation facility.

4. The Developer 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).

G. Power Flow Study Models

Western Electricity Coordinating Council (WECC) coordinates the preparation of regional power flow cases for transmission planning purposes. PSCo transmission developed a base case for the 2010 heavy summer peak load 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 Area 70 (PSCo Transmission) were re-dispatched to simulate high south-to-north stressed system conditions.

[6] Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater than 20 MW, version 3.0, 12/31/06

- The generation at Fountain Valley was raised to maximum.
- The Lamar DC Tie imports were set to 200 MW.
- Generation at Comanche units 1, 2 and 3 was set near their respective maximum values.
- Generation at Manchief, St. Vrain, Spindle and RMEC was decreased to accommodate the increased generation schedules in southern Colorado.
- The placeholder generators at Pawnee (Wind_pln) and San Luis Valley (SLV Solar) were removed.
- Generation at RD Nixon, Front Range and Lincoln was set near maximum capacity.

Implementation of these changes resulted in the benchmark case that was used for this study. The Cherokee Unit 3 was designated as the slack bus for Area 70 (PSCo).

The proposed wind generation facility consists of 167 Vestas V-90 1.8 MW wind turbines with a terminal voltage of 0.69 kV. Since this study also involves transient stability analysis, the generating facility has been represented in some detail. For this process, the data provided by the Developer has been used. The individual wind turbines will be connected to one of the twelve 34.5 kV circuits. For this study, Circuit No. 1 and Circuit No. 10 were represented in detail, modeling every wind turbine connected to those feeders with the appropriate 34.5 kV feeder impedances. For the remaining circuits, the turbines were represented by one generator of equivalent capacity for each circuit. The collector systems for those circuits have been simplified and the equivalent impedance has been calculated. Circuits No. 1 through No. 6 were connected to one 34.5-kV substation bus and Circuits No. 7 through No. 12 were connected to a second 34.5-kV substation bus. One step-up transformer was connected to each of the two 34.5 kV substation buses to raise the voltage to 345 kV. The wind generation facility was interconnected to the PSCo bulk transmission system at Comanche through a 46-mile 345kV radial line. A 795 kcmil ACSR (Drake) bundled conductor was used for this radial line, based upon the Developer's data.

H. <u>Power Flow Study Process</u>

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 control areas 70 (PSCo) and 73 (WAPA RM). 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.

I. Power Flow Results

Thermal Overloads

The results for the single line contingency analysis when 300 MW full output from GI-2008-2 is delivered to the Comanche substation in the 2010 heavy summer case are shown in Table 1. Connecting the new wind generation facility to the 345-kV bus at Comanche without any reinforcements causes several lines in PSCo's system, as well as some in the BHC system, to overload.

The Cherokee–Federal Heights2 115 kV circuit (Ckt # 9558) has a summer normal rating of 144 MVA and summer emergency rating of 159 MVA based on the "FAC-009"[7] list. The circuit is not considered overloaded. The normal and emergency rating of the Daniels Park–Prairie 230 kV branch (Ckt #5111), the Prairie-Greenwood 230 kV branch (Ckt #5111), and the Prairie2-Greenwood 230kV branch (Ckt #5707) have been raised to 478 MVA (see the Substation/Transmission Facility Equipment Rating FAC-009 list). The Daniels Park-Prairie2 230 kV branch (Ckt #5111) normal rating has been raised to 564 MVA and the emergency rating has been raised to 621 MVA.

Table 1. AC Contingency Analysis – Project Added With No Network Upgrades

** From bus ** ** To bus ** CKT	Ckt ID No.	Branch Rating in the Study Case	Loading as % of Branch Rating		Contingency	Revised Summer Normal Rating	Revised Summer Emergency Rating
			Bench-mark	Without Upgrade			
70108 CHEROKEE 115 70175 FEDERHT2 115 2	9558	149	102.1	106.7	70269 LOUISVIL 115 70444 VALMONT 115 1	144	159
70121 COMANCHE 115 70122 COMANCHE 230 A1		176	110.5	120.3	70121 COMANCHE 115 70122 COMANCHE 230 A2		
70121 COMANCHE 115 70122 COMANCHE 230 A2		184	106	115.4	70121 COMANCHE 115 70122 COMANCHE 230 A1		
70121 COMANCHE 115 70352 READER 115 2		239	93.2	102.9	70121 COMANCHE 115 70352 READER 115 1		
70122 COMANCHE 230 70459 WALSENBG 230 1		159	155.7	161.3	70336 PUEB-TAP 115 70456 W.STATON 115 1 (1)		239
70139 DANIELPK 230 70323 PRAIRIE2 230 1	5707	319	119.6	143.8	70139 DANIELPK 230 70331 PRAIRIE 230 1	564	621
70139 DANIELPK 230 70331 PRAIRIE 230 1	5111	319	127.5	151.6	70139 DANIELPK 230 70323 PRAIRIE2 230 1	478	478
70212 GREENWD 230 70323 PRAIRIE2 230 1	5707	319	119.6	143.8	70139 DANIELPK 230 70331 PRAIRIE 230 1	478	478
70212 GREENWD 230 70331 PRAIRIE 230 1	5111	319	87.8	112.4	70139 DANIELPK 230 70323 PRAIRIE2 230 1	478	478
70236 HYDEPARK 115 70339 PUEBPLNT 115 1		105	124.7	136.7	70122 COMANCHE 230 70459 WALSENBG 230 1		120
70236 HYDEPARK 115 70456 W.STATON 115 1		105	109.6	121.6	70122 COMANCHE 230 70459 WALSENBG 230 1		120
73391 CTTNWD N 115 73410 KETTLECK 115 1		132	106.7	113.9	73389 BRIARGAT 115 73393 CTTNWD S 115 1		
70336 PUEB-TAP 115 70456 W.STATON 115 1		95	233	239.4	70122 COMANCHE 230 70459 WALSENBG 230 1		
70463 WATERTON 115 70464 WATERTON 230 T1		100	121.3	128.5	70463 WATERTON 115 70464 WATERTON 230 T2		280
70463 WATERTON 115 70464 WATERTON 230 T2		100	122.4	129.6	70463 WATERTON 115 70464 WATERTON 230 T1		280

7 "FAC-009" = Substation/Transmission Facility Equipment Ratings FAC-009 Revision 2011-5 (May 13, 2011)

In comparing the results of the contingency analysis for the GI-2008-2 case against the benchmark case for the PSCo system, the loading on the 230/115-kV transformers at Comanche, the 115-kV line from Comanche to Reader, the 230-kV line from Walsenburg to Comanche and the 115/230-kV transformers at Waterton increases with the addition of generation from GI-2008-2. The 115/230-kV transformers at Comanche and Waterton have been replaced with transformers of higher ratings (280 MVA). The rating of the 230-kV line from Comanche to Walsenburg in the power flow case is an error; the correct rating is 239 MVA as per the FAC-009 report, with this limit due to the terminal equipment. The rating of this line can be increased by changing the terminal equipment at the two ends of this line.

BHC provided PSCo with data pertaining to the ratings of the 115-kV circuits from Hyde Park to Pueblo Plant, Hyde Park to West Station, Pueblo Tap to West Station and Pueblo Tap to Stem Beach have been revised to 120 MVA. However, some of these lines would still be overloaded despite the revised ratings. The loading on these lines further increases due to the generation output from the 300-MW facility. Therefore, additional network reinforcements may be required to address the loading on the lines around the POI. BHC is working on several network upgrades for their system and these upgrades may address the overloads shown in Table 1. One possible reinforcement option that was considered for this study was the addition of a 115-kV line from Comanche to Stem Beach (Option 1). The results of the AC contingency analysis performed with this reinforcement are tabulated in Table 2. However, the reinforcements that will actually be built by BHC may or may not include this option. Furthermore, BHC will need to evaluate the impact of GI-2008-2 as it relates to the reinforcements that they are considering.

Table 2. AC Contingency Analysis with Network Upgrades

** From bus ** ** To bus ** CKT	Branch Rating	Loading as % of Branch Rating: With New Transformers	Loading as % of Branch Rating: Option 1	Contingency	FAC-009 Ratings
70002 BURNT MI 115 70456 W.STATON 115 1	100.0	104.0		70339 PUEBPLNT 115 70352 READER 115 1	
70004 FREEMARY 115 70352 READER 115 1	100.0	104.0		70339 PUEBPLNT 115 70352 READER 115 1	
70108 CHEROKEE 115 70175 FEDERHT2 115 2	149.0	107.3	118.4	70269 LOUISVIL 115 70444 VALMONT 115 1	159
70121 COMANCHE 115 70352 READER 115 2	239.0	111.9		70121 COMANCHE 115 70352 READER 115 1	
70122 COMANCHE 230 70459 WALSENBG 230 1	159.0	160.1	114.7	70336 PUEB-TAP 115 70456 W.STATON 115 1	239
70139 DANIELPK 230 70323 PRAIRIE2 230 1	319.0	139.7		70139 DANIELPK 230 70331 PRAIRIE 230 1	621
70139 DANIELPK 230 70331 PRAIRIE 230 1	319.0	147.5		70139 DANIELPK 230 70323 PRAIRIE2 230 1	478
70212 GREENWD 230 70323 PRAIRIE2 230 1	319.0	139.7	161.9	70139 DANIELPK 230 70331 PRAIRIE 230 1	478
70212 GREENWD 230 70331 PRAIRIE 230 1	319.0	108.2	125.3	70139 DANIELPK 230 70323 PRAIRIE2 230 1	478
70236 HYDEPARK 115 70339 PUEBPLNT 115 1	105.0	145.2		70122 COMANCHE 230 70459 WALSENBG 230 1	120
70236 HYDEPARK 115 70456 W.STATON 115 1	105.0	130.2		70122 COMANCHE 230 70459 WALSENBG 230 1	120
70336 PUEB-TAP 115 70456 W.STATON 115 1	95.0	239.6		70122 COMANCHE 230 70459 WALSENBG 230 1	
70339 PUEBPLNT 115 70352 READER 115 1	159.0	104.0		70122 COMANCHE 230 70459 WALSENBG 230 1	159
73391 CTTNWD N 115 73410 KETTLECK 115 1	132.0	113.0	113.0	73389 BRIARGAT 115 73393 CTTNWD S 115 1	
70060 BOONE 115 70061 BOONE 230 1	150.0			70061 BOONE 230 70254 LAMAR CO 230 1	
73477 FULLER 230 73481 FULLER 115 1	100.0	N/A	103.0	73412 MIDWAYBR 115 73416 RANCHO 115 1	

The 115-kV line from Cottonwood to Kettle Creek would still be overloaded even with the network reinforcements by BHC. One alternative to resolve this overload would be by opening the line from Palmer to Monument. However, this would need to be considered by all affected parties.

Voltage Violations

The WECC/NERC criteria and the Rocky Mountain Voltage Coordination Guide indicate that it is necessary to maintain voltages at all buses in the system between 0.95 per unit to 1.05 per unit for steady state operation and the voltage at all regulating buses must be maintained above 1.02 per unit under normal operating conditions. Considering the 2010 heavy summer peak benchmark case, the voltages at the 230-kV bus and the 345-kV buses at Comanche will be 1.035 per unit and 1.032 per unit, respectively. With the connection of the proposed facility, the voltage would drop to 1.021 per unit at the POI and 1.028 per unit at the 230-kV bus. The voltage levels at buses on the wind farm would be greater than 1.0 per unit. Overall, these voltages are within criteria. However, the wind turbines do not provide any reactive support (pf = 1.0) and the facility would draw 61 MVAR of reactive power from the PSCo system during peak generation periods. The three generators at Comanche would be providing an additional 75 MVAR of reactive power to the system, thereby reducing the amount of dynamic support available to meet system emergencies. Therefore, switched capacitors or other reactive power source would be required to maintain dynamic reactive power capability at the three Comanche units and the power factor at the POI within 0.95 leading to 0.95 lagging. A 60 MVAR capacitor connected close to the POI by tapping the 345-kV line from GI-2008-2 to the POI would maintain the power factor and raise the voltage at the 345-kV bus and the 230-kV bus to 1.028 per unit and 1.032 per unit, respectively.

The voltages at the POI and the 230-kV Comanche bus rise to 1.033 per unit and 1.035 per unit, respectively during periods of minimal wind generation. The GI-2008-2 generation facility and its related transmission line supplies 27.7 MVAR of reactive power to the PSCO system. Therefore, in order to keep the power factor within the required range, a 25 MVAR reactor may need to be connected close to the POI. The voltages at the 345-kV and 230-kV buses with a 25 MVAR reactor are 1.030 per unit and 1.033 per unit, respectively.

The voltage at the Walsenburg 230-kV and 115-kV buses and the Stem Beach 115-kV bus will drop significantly for the loss of the 230-kV line from Comanche to Walsenburg, causing the voltage deviation to be greater than 5% of the initial voltage in the benchmark case as well as with the proposed generation. This violates WECC criteria. There is an operating procedure in place which opens the 230-kV line from Walsenburg to Gladstone for the loss of the Comanche-Walsenburg line. Using the operating procedure helps keep the voltage within criteria in the benchmark case. However, in the case with the proposed generation, a 30 MVAR capacitor, or other reactive power source, would need to be connected at the Stem Beach 115-kV bus in addition to the operating procedure to keep the voltage at Stem Beach and Walsenburg within criteria for the contingency discussed. The 115-kV line from Comanche to Stem Beach (Option 1) with the operating procedure would also resolve this issue.

It is the responsibility of the Developer 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. Off-nominal voltage-tap settings on the main power transformers that connect the 34.5-kV system to the Developer's transmission line can also impact the operating voltages and related reactive power capabilities and requirements for the GI-2008-2 facility. This should also be considered by the Developer in determining the final design equipment and parameters.

Energy Resource (ER):

The ER portion of this study indicates that the Developer could provide 0 MW without the construction of new transmission lines in the BHC area and some form of action by TSGT and CSU. Once the interconnection is made, at the 345 kV POI, non-firm transmission capability may be available depending upon marketing activities, dispatch patterns, generation levels, demand levels, import path flow levels and the operational status of the transmission facilities.

Network Resource (NR):

The results of this study indicate that the 300 MW output from the GI-2008-2 generation project delivered to the Comanche 345-kV POI could result in the overloading of facilities in the BHC's, TSGT's, and CSU's transmission systems. Therefore, the 300 MW NR value requested will likely require transmission network upgrades by one or more of the affected parties. The Developer will have to coordinate with them to ensure that the upgrades are in place before GI-2008-2 is in operation. After these upgrades are complete, the 300 MW generating facility could be considered a network resource with firm transmission capability so that the entire output of the plant could be delivered to PSCo load.

J. 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 would remain stable after the disturbance. In addition, FERC 661A requires the wind powered generators to remain online during system disturbances up to the time periods and voltage levels set for the Low Voltage Ride-Through (LVRT) capability standard.

Transient stability analyses were performed for different three-phase faults around Comanche, Boone, Midway and Walsenburg. Table 3 lists the different contingencies studied for this analysis. Normal fault clearing times of 5 cycles for 230-kV facilities and 4 cycles for 345-kV facilities were used for this study. The proposed facility was modeled at 0.69-kV, with the Vestas V90 turbines connected through GSUs to 34.5-kV. The 34.5-kV collector system at GI-2008-2 is proposed to consist of 12 circuits connected to two 34.5-kV substation buses. Two of these circuits were represented in detail, while the turbines for the other circuits were represented by a composite generator connected through feeders with equivalent impedance for each circuit. The wind farm was connected to the 345-kV bus at Comanche through a 46-mile transmission line. A 60 MVAR capacitor was connected close to the POI to maintain dynamic VAR capability at the Comanche generators.

There are four motor loads at Rosebud and York Canyon in Northeastern New Mexico close to Gladstone, which are represented as generators with negative generation in the power flow case. For a fault at Comanche 230-kV bus in the benchmark case, unstable operation was observed for Rosebud, which also distorted the voltage profile at Gladstone, Walsenburg and Comanche. This is because the power absorbed by the two motors at Rosebud is equal to their respective MVA base values. Decreasing the power absorbed by these motors resolves this issue.

The Vestas V90 model VCUS version 6.0.2 was used to represent the wind turbine generators for the GI-2008-2 Project. When a three-phase fault was applied at any of the Comanche buses, the dynamic solution did not converge for the duration of the fault and spikes were observed in the plots of various generator parameters. However, no issues were seen after the fault was cleared. This was conveyed to Vestas and they suggested modifications to the turbine model data, changing the current injection threshold during a fault from 0.5 per unit to 0.1 per unit for the VWLVRT user-model. This resolved the issue.

Table 3. Results of Transient Stability Analysis

Num	Fault Location	Action	Benchmark Case	With 300 MW at Pole Canyon
1	Comanche 230.00	Trip Comanche - Boone 230-kV	stable, no viol	stable, no viol
2	Boone 230.00	Trip Comanche - Boone 230-kV	stable, no viol	stable, no viol
3	Comanche 230.00	Trip Comanche - Midway 230-kV	stable, no viol	stable, no viol
4	Midway 230.00	Trip Comanche - Midway 230-kV	stable, no viol	stable, no viol
5	Comanche 345.00	Trip Comanche - Daniel Park 345-kV	stable, no viol	stable, no viol
6	Daniel Park 345.00	Trip Comanche - Daniel Park 345-kV	stable, no viol	stable, no viol
7	Comanche 230.00	Trip Comanche 230/345-kV transformer ckt 1	stable, no viol	stable, no viol
8	Comanche 345.00	Trip Comanche 230/345-kV transformer ckt 1	stable, no viol	stable, no viol
9	Comanche 230.00	Trip Comanche - Walsenburg 230-kV ckt 1	stable, max voltage dip>25% Vpre-fault, ΔV>5%	stable, max voltage dip>25% Vpre-fault, ΔV>5%
10	Walsenburg 230.00	Trip Comanche - Walsenburg 230-kV ckt 1	stable, max voltage dip>25% Vpre-fault, ΔV>5%	stable, max voltage dip>25% Vpre-fault, ΔV>5%
11	Comanche 230.00	Trip Comanche 115/230-kV transformer ckt A1	stable, no viol	stable, no viol
12	Comanche 115.00	Trip Comanche - Reader 115-kV ckt 1	stable, no viol	stable, no viol
13	Comanche 345.00	Trip Comanche 24/345-kV transformer ckt 1 Drop Comanche Unit 3	stable, no viol	stable, no viol
14	-	Trip Comanche 22/345-kV transformer ckt 1 Drop Comanche Unit 3	stable, no viol	stable, no viol
15	Comanche 230.00	Trip Comanche 24/230-kV transformer ckt U1 Drop Comanche Unit 1	stable, no viol	stable, no viol
16	Comanche 345.00	Trip Comanche - GI-2008-2 345-kV	-	stable, no viol
17	GI-2008-2 345.00	Trip Comanche - GI-2008-2 345-kV	-	stable, no viol
18	GI-2008-2 North Sub 34.50	Trip GI-2008-2 34.5/345-kV transformer ckt 1	-	stable, no viol

The results of the study indicate that the system remains stable during and after each contingency studied and that all system oscillations damp out quickly. However, for loss of the 230-kV line from Comanche to Walsenburg (Contingencies 9 and 10) the final voltage at Walsenburg and Stem Beach buses is significantly lower than the pre-fault voltage. The final voltage deviation is greater than 5%. Also the voltage dip after initial recovery is greater than 25% of the pre-fault voltage. These are WECC voltage criteria violations. They are observed in the benchmark case as well as with GI-2008-2. These issues can be resolved by adding the 30-MVAR capacitor at Stem Beach and applying the operating procedure which opens the 230-kV line from Walsenburg to Gladstone for the loss of the Comanche-Walsenburg line. The faults that would be cleared by disconnecting all or a portion of GI-2008-2 generation were also found to be stable.

Delayed Clearing Studies at Comanche

Transient stability analysis was also performed for system disturbances with delayed clearing at the Comanche 230-kV and 345-kV buses. When there is a single-phase fault on a line close to the Comanche 230-kV or 345-kV buses and the breaker at the Comanche end of the line fails to operate, the back up breaker opens after 14-16 cycles. This opens two network elements from Comanche. The effect of such a contingency on the transmission system was studied. The different contingencies studied for stuck breaker simulations around Comanche are summarized in Table 4.

The results of the study indicate that the system remains stable during and after each contingency studied and all system oscillations damp out quickly. However, for loss of the 230-kV line from Comanche to Walsenburg (delayed clearing contingencies 4 and 8) the final voltage at Walsenburg and Stem Beach buses is significantly lower than the pre-fault voltage and the final voltage deviation is greater than 5%. While this would violate WECC criteria, TSGT has an operating procedure in place which opens the 230-kV line from Walsenburg to Gladstone for the loss of the Comanche-Walsenburg 230-kV line. This keeps the voltage at Walsenburg and Stem Beach within criteria.

Table 4. Delayed Clearing Contingencies Near Comanche

Contin-gency	Fault Location	Cycles	Cleared Circuit 1 (Connected at Comanche But Open at Remote End)	Stuck Breaker	Cleared Circuit 2 (Due to Breaker Failure)	Cycles	Benchmark Case	With GI-2008-2
1	Comanche 345 kV	4	Comanche 230/345 kV Transformer 2	7012	Comanche - Daniel Park 345 kV ckt 1	14	stable, no viol	stable, no viol
2	Comanche 345 kV	4	Comanche-3 24/345 kV Transformer	7014	Comanche - Daniel Park 345 kV ckt 2	14	stable, no viol	stable, no viol
3	Comanche 345 kV	4	Comanche-Daniel Park 345 kV ckt 1	7012	Comanche 230/345 kV Transformer 2	14	stable, no viol	stable, no viol
4	Comanche 230 kV	5	Comanche - Boone 230 kV ckt 1	5412	Comanche - Walsenburg 230 kV	16	stable, ΔV>5% Vpre-fault	stable, ΔV>5% Vpre-fault
5	Comanche 230 kV	5	Comanche - CFI&F 230 kV ckt 1	5410	Comanche - MidwayPS 230 kV ckt 1	16	stable, no viol	stable, no viol
6	Comanche 230 kV	5	N/A	5414	Comanche - MidwayPS 230 kV ckt 2	16	stable, no viol	stable, no viol
7	Comanche 230 kV	5	Comanche - MidwayPS 230 kV ckt 1	5410	Comanche - CFI&F 230 kV ckt 1	16	stable, no viol	stable, no viol
8	Comanche 230 kV	5	Comanche - Walsenburg 230 kV	5412	Comanche - Boone 230 kV ckt 1	16	stable, ΔV>5% Vpre-fault	stable, ΔV>5% Vpre-fault
9	Comanche 345 kV	4	Comanche- Daniel Park 345 kV ckt 2	7014	Comanche-3 24/345 kV Transformer	14	stable, no viol	stable, no viol
10	Comanche 230 kV	5	Comanche-2 24/230 kV Transformer	5402	Comanche 230/345 kV Transformer 2	16	stable, no viol	stable, no viol
11	Comanche 230 kV	5	Comanche 230/345 kV Transformer 2	5402	Comanche-2 24/230 kV Transformer	16	stable, no viol	stable, no viol

K. Cost Estimates and Assumptions

The estimated total cost for the required upgrades is approximately **$ 3.298 million.**

The estimated costs shown are (+/-30%) estimates in 2008 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 developer-owned equipment and associated design and engineering.

This estimate does not include any network reinforcements 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 300 MW project.

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 5 PSCo Owned; Developer Funded Interconnection Facilities

Element	Description	Cost Est. Millions
PSCo's Comanche 345 kV Substation	Interconnect Customer at PSCo's Comanche 345 kV Substation. The new equipment includes revenue metering and associated equipment.	$0.165
	Transmission Tie Line into Substation.	0.200
	Customer LF/AGC and Generator Witness Testing	0.145
	Siting and Land Rights for required easements, report, permits and licenses.	0.010
Total	**Total Cost Estimate for PSCo-owned, Customer-funded Interconnection Facilities**	$0.520
Time Frame	Substation and Transmission	18 Months

Table 6 PSCo Owned; PSCo Funded Interconnection Facilities

Element	Description	Cost Estimate (Millions)
PSCo's Comanche 345 kV Substation	Interconnect Customer at PSCo's Comanche 345 kV Substation. New 345 kV line termination requiring the following equipment: ○ Two 345 kV circuit breakers ○ Six 345 kV gang switches ○ Electrical bus work ○ Required steel and foundations ○ Minor site work (station wiring, grounding)	$2.778
	Total Cost Estimate for PSCo-Owned, PSCo-Funded Interconnection Facilities	$2.778
Time Frame	Site, engineer, procure and construct	18 Months

Table 7 PSCo Network Upgrades for Delivery

Element	Description	Cost Est. (Millions)
PSCo's Transmission Network	PSCo Network Upgrades for Delivery include the following: ○ Upgrade the two Comanche 230-115 kV transformers to 280 MVA ○ Add a Comanche-Reader 115 kV Line #2 ○ Uprate the Daniels Park-Prairie 230 kV Line ○ Uprate the Prairie-Greenwood 230 kV Line ○ Replace the MidwayPS-Daniels Park 230 kV Line with the MidwayPS-Waterton 345 kV Line. ○ Install a 560 MVA 345-230 kV transformer at the MidwayPS Substation ○ Install a 560 MVA 345-230 kV transformer at the Waterton Substation	PSCo-funded costs
	Total Cost Estimate for PSCo Network Upgrades for Delivery	N/A
Time Frame	Network Upgrades for Delivery – to be constructed via the PSCo Capital Budget Construction Process.	
	Total Cost of Project	**$3.298**

Assumptions

- The cost estimates provided are "Scoping Estimates" with an accuracy of +/- 30%.
- Estimates have not been escalated. Estimates are based on 2008 dollars.
- There is no contingency added to the estimates.
- AFUDC is not included.

- Labor is estimated for straight time only – no overtime is included.
- PSCo (or its Contractor) crews will perform all construction and wiring associated with PSCo-owned and maintained facilities.
- The cost estimates for the PSCo Network Upgrades for Delivery are not included as should be part of PSCo's Capital Budget Construction process.
- No additional land will be required at the Comanche Substation.
- A 230 kV interconnection was deemed not feasible; therefore, those estimates were not developed.