



Interconnection System Impact Study Report Request # GI-2006-4

200 MW Wind Expansion of Peetz Logan, near Peetz, Colorado
PSCo Transmission Planning
February 5, 2008

Executive Summary

Public Service Company of Colorado (PSCo) Transmission received a Large Generator Interconnection Request (LGIR) to determine the system impact of expanding an existing 400 MW Large Generator Facility (GI-2006-1 (g)) and a planned 200 MW Large Generator Facility (GI-2006-2), both interconnecting at the Pawnee 230kV bus via the existing 72-mile Customer's 230kV transmission line. This present transmission study designated GI-2006-4 would evaluate an additional 200 MW of new Customer wind turbine generation into the PSCo transmission system at the Pawnee Station 230 kV bus, which would bring the total Customer's Large Generator Facility to 800 MW at the Peetz Logan Wind Facility. The Customer proposed commercial operation date is October 1, 2008 with a back feed date of April 1, 2008. This request was studied as both an Energy Resource (ER) and a Network Resource (NR). The request was studied as a stand-alone project and considering other projects in the PSCo Generation Request queue¹, specifically GI-2006-1 and GI-2006-2. Transmission Planning studies indicate that the proposed 200 MW Customer's Large Generation Facility expansion does not meet the FERC Order 661-A guidelines for Low Voltage Ride Through (LVRT)² and therefore it is not feasible to expand the Customer's Large Generation Facility to a total of 800 MW.

Stand Alone Results

Energy Resource³:

The ER portion of this study determined that the Customer could provide 0 MW of firm energy without the construction of network reinforcements. This determination is based on existing limitations due to violation of the FERC Order 661-A guidelines for Low Voltage Ride Through Requirements.

¹ http://www.rmao.com/wtp/psco_studies.html

² <http://www.ferc.gov>

³ **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 nonfirm 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.



Network Resource⁴:

As a NR request, PSCo evaluated the network to determine the upgrades required to deliver the full 200 MW expansion of wind generation to PSCo native load customers. The power flow results indicate the system infrastructure needed to deliver the Customer's generation is:

- 345kV Pawnee – Smoky Hill Transmission Project

The total estimated cost of the recommended system upgrades to accommodate the project is approximately **\$120**⁵ million with a time frame of approximately 65 months.

The stability analyses indicate that the Customer's proposed 200 MW Large Generator Facility expansion does not meet the FERC Order 661-A guidelines for Low Voltage Ride Through requirements. The system alternatives, in addition to the 345kV Pawnee – Smoky Hill Transmission Project, were evaluated to comply with FERC Order 661-A include the following:

Alternative 1

Added SVC at Peetz Logan (-50 MVAR Inductive to +100 MVAR Capacitive)

Alternative 2

Added series compensation to long Peetz Logan – Pawnee 230kV transmission line – 50% compensation

Alternative 3

Added parallel Peetz Logan – Pawnee 230kV transmission line

Transmission Planning studies indicate that these alternatives do not mitigate the LVRT⁶ violations and therefore it is not feasible to expand the Customer's Large Generation Facility to a total of 800 MW. These violation issues are indicated in three manners, which include:

- LVRT2 violation
- ZVRT violation
- Convergence violation (Oscillatory - unstable)

The LVRT2 violation means that the Peetz Logan generation tripped off due to slow recovery times. For example, if all Peetz Logan generators were equipped with ZVRT capability, the wind farm would likely remain on line. ZVRT violations indicate a voltage

⁴ **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.

⁵ PSCo has filed on October 31, 2007 a CPCN for the Pawnee – Smoky Hill 345kV Transmission Project with a cost estimate of \$120 million and, if approved, the differential cost would be \$0 million.

⁶ Refer to Appendix G Interconnection Requirements for a Wind Generating Plant for LVRT requirements



collapse at the wind farm for a prolonged period of time such that all generation would be tripped. Lastly in some cases, the solution process failed to converge.

While the dynamics modeling only used LVRT2 parameters, the results of the analysis that show a voltage collapse after the fault was cleared indicates that re-running with ZVRT would not result in different answers.

Introduction

PSCo Transmission received a large generator interconnection request (GI-2006-4) to interconnect one hundred thirty-three 1.5 MW, GE model SLE doubly fed induction generator (DFIG) wind turbines, for a total of 200 MW generation, with a commercial operation date of October 1, 2008 and a back feed date of April 1, 2008. The proposed wind farm (Project) would be located near Peetz, Colorado and would interconnect into the PSCo transmission system via the existing Customer 72-mile radial 230 kV line terminating at the PSCo Pawnee Station. This transmission line is part of GI-2006-1 (g) interconnection and the proposed GI-2006-2 200 MW expansion project. The Customer has requested that this Project be evaluated as a Network Resource (NR) and an Energy Resource (ER) with the energy going to PSCo customers.

Study Scope and Analysis

The Interconnection System Impact Study evaluated the transmission requirements associated with the proposed interconnection to the PSCo Transmission System. It consisted of power flow and transient dynamic analyses. The power flow analysis provided a preliminary identification of any thermal or voltage limit violations resulting for the interconnection, and for a NR request, a preliminary identification of network upgrades required to deliver the proposed generation to PSCo loads. The transient dynamic analysis identified any oscillatory system behavior as a result of the NR request for the 200 MW Large Generator Facility expansion and any violations of FERC Order 661-A guidelines for LVRT requirements evaluated as an ER and NR request with the delivery of the proposed generation to PSCo loads.

PSCo adheres to NERC / WECC Reliability Criteria, as well as internal Company criteria for planning studies. During system intact conditions, criteria are to maintain transmission system bus voltages between 0.95 and 1.05 per-unit of system nominal / normal conditions, and steady state power flows within 1.0 per-unit of all elements' thermal (continuous current or MVA) ratings. Operationally, PSCo tries to maintain a transmission system voltage profile ranging from 1.02 per-unit or higher at generation buses, to 1.0 per-unit or higher at transmission load buses. Following a single contingency element outage, transmission system steady state bus voltages must remain within 0.90 per-unit to 1.10 per-unit, and power flows within 1.0 per-unit of the elements continuous thermal ratings.

Based on the results of other generator interconnection studies, impacts to TOT3 and the neighboring utilities are considered minimal. For this project, affected parties include Western Area Power Administration (WAPA), and Tri-State Generation and Transmission (TSGT). These parties will receive a copy of this system impact study report.



Power Flow Study Models

The power flow studies were based on a PSCo developed 2010 heavy summer base case that originated from the Western Electricity Coordinating Council (WECC) 2011 heavy summer base model. The 200 MW wind farm was modeled as one 200 MW conventional generator with a 0.95 per unit (p.u.) lagging power factor (overexcited) and a 0.95 p.u. leading power factor (under-excited) capability to simulate the VAR capabilities of the generators, which the Customer has stated to be the GE 1.5 MW model SLE Double Fed Induction Generator. The project generation was scheduled to the southern PSCo system by reducing generation in that area.

The power flow studies were also based on a PSCo developed 2013 heavy summer base.

Pertinent modeling adjustments:

- o Other generation at Pawnee was modeled at full output, which included GI-2006-1, GI-2006-2 or approximately 600 MW.
- o Study models included a planned upgrade of the existing Pawnee to Smoky Hill and Pawnee to Daniels Park 230 kV line to 637 MVA. These upgrades are projected to be complete in 2008.
- o Study models included the 345kV Pawnee – Smoky Hill Transmission Project filed as a CPCN on October 31, 2007.

The Point of Interconnection (POI) between the Customer and PSCo is assumed to be the point at which the Customer's 72-mile 230 kV transmission line connects to the Pawnee Substation bus. The 72-mile line was modeled per the Customer provided information:

- A single-circuit 72-mile, 230 kV line using a combination conventional 230 kV "H-frame" wood pole and single steel pole construction with a two conductor bundled 795 ACSR per phase, with a 800 MVA rating.
- One 230-34.5 kV, 132/176/220 MVA Customer GSU transformer, located at the Customer collector site.
- One 230-34.5 kV, 66/88/110 MVA Customer GSU transformer, located at the Customer collector site.
- One 230-34.5 kV, 75/100/125 MVA Customer GSU transformer, located at the Customer collector site.
- One 230-34.5 kV, 50/83.33 MVA Customer GSU transformer, located at the Customer collector site.
- One 230-34.5 kV, 75/100/125 MVA Customer GSU transformer, located at the Customer collector site.

To evaluate the capabilities and system requirements for firm transfer levels, the powerflow model was modified to moderate north to south power flow transfers. Efforts were made to include in the models all transmission projects expected to be in service



for the 2013 heavy summer season. The studies assumed 2013 peak summer demand conditions in the PSCo system and in other utility systems.

Power Flow Study Results and Conclusions

Energy Resource (ER) Study Results

The ER portion of this study determined that the Customer could provide 0 MW of firm energy without the construction of network reinforcements. This determination is based on existing⁷ limitations due to violation of the FERC Order 661-A guidelines for Low Voltage Ride Through Requirements. At a level of 600 MW⁸ at the Peetz Logan Large Generator Facility, the LVRT violations are indicated in two manners, which include:

- LVRT2 violation
- ZVRT violation

These results are summarized in table 1 below.

Table 1: Transient Stability Results – Case with GI-2006-2 (600 MW) and Network Upgrades for Delivery

	Fault Location	Action	Violation
1	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Fort Lupton 230 kV line	LVRT2
2	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee- Story 230 kV line	ZVRT

The loss of the 230kV Pawnee – Fort Lupton transmission line results in the LVRT2 violation. The LVRT2 violation means that the Peetz Logan generation tripped off due to slow recovery times. The loss of the 230kV Pawnee – Story transmission line results in the ZVRT violation. ZVRT violations indicate a voltage collapse at the wind farm for a prolonged period of time such that all generation would be tripped. Therefore, the Large Generator Facility Peetz Logan at 600 MW (pre-proposed 200 MW expansion GI-2006-4) does not meet the LVRT requirements and therefore the ER is 0 MW for the present request GI-2006-4.

Network Resource (NR) Study Results

The NR study determined the network upgrades that would be required to accept the full 200 MW from the proposed generating plant for the conditions studied. The power flow studies indicate that the 345kV Pawnee – Smoky Hill Transmission Project is required to deliver the 200 MW Peetz Logan Large Generator Facility

⁷ Existing limitations refer to GI-2006-2 LVRT violations

⁸ This level indicates an existing 400 MW wind facility (GI-2006-1 (g)) and a planned 200 MW expansion (GI-2006-2)



expansion. However, the stability analyses indicate that additional transmission⁹ is required to meet the FERC 661-A LVRT requirements.

Voltage Control at the Point of Interconnection

Studies show that the 200 MW expansion project under certain conditions cannot meet the interconnection guidelines as mandated by PSCo in their Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater than 20 MW (Guidelines). In addition, studies show that during high levels of wind generation (300 MW or greater) the 230 kV line from the Wind Farm to the POI is absorbing excessive reactive power from existing system connected to the Pawnee 230kV bus. This is an unacceptable operating condition. The Customer needs to demonstrate that the Guidelines are met. In addition, PSCo requires that the Customer provide a single point of contact¹⁰ to coordinate compliance with the power factor/voltage regulation at the POI. The Customer will need to control the VAR flow on their line according to the Interconnection Guidelines.

Stability Analyses Results and Conclusions

With 800 MW at Peetz Logan, the stability analysis consisted of 3-phase faults near the points of interconnection at the Pawnee 230kV bus. Normal fault clearing time was used in this study and consisted of 5-cycles for 230kV facilities. Stuck breaker cases were not considered in this study. The wind farm (800 MW) was modeled as 5 composite generators at the 575-volt level connected through composite GSUs to 34.5kV with minimal 34.5-kV feeders then connected to 34.5/230kV transformer, using transformer information provided by the Customer for impedance and off-nominal tap settings. This representation is provided in Appendix A. The representation of the 230kV system on the Peetz Logan wind farm used the impedance/line length information provided by the Customer.

Table 2 summarizes the results of the LVRT violations observed at 800 MW generation level in the Peetz Logan Wind Facility.

Table 2: Transient Stability Results – Case with GI-2006-4 and Network Upgrades for Delivery

	Fault Location	Action	Violation
1	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Brick Center 230 kV line	ZVRT
2	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Daniels Park 230 kV line	ZVRT
3	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Story 230 kV line	ZVRT
4	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee–Fort Lupton 230 kV line	ZVRT
5	3PH at Pawnee 230 kV bus; 5cycles	Trip Pawnee 230/22 kV line GСУ	ZVRT

⁹ This assumes that additional transmission may mitigate the LVRT violations, which needs to be evaluated fully.

¹⁰ The POI will provide a point of injection of wind generation from several different entities.

	Fault Location	Action	Violation
6	3PH at Peetz Logan 230 kV bus; 5 cycles	Trip Pawnee – Peetz Logan 230 kV line	none
7	3PH at feeder 34.5 kV bus; 5 cycles	Trip wind farm 230 kV feeder	none
8	3PH at Pawnee 230 kV bus; 5cycles	Trip Pawnee Generator	none

Table 2 depicts the ZVRT violations. Without any additional system reinforcements five (5) from the eight (8) faults studied in the Pawnee region resulted in violation of LVRT requirements. System alternatives were evaluated to mitigate the LVRT violations and comply with the FERC Order 661-A LVRT requirements. All system alternatives included the 345kV Pawnee – Smoky Hill Transmission Project.

Sensitivity Analyses

Several alternatives were considered to mitigate the ZVRT violations observed in Table 2. These alternatives consisted of modeling 1) SVC, 2) Series compensation and 3) Parallel Pawnee – Peetz Logan 230kV transmission line. Transmission studies show that none of these alternatives mitigated all LVRT violations.

(1) SVC near Pawnee station

The study results indicate that there is no benefit (system change) provided by the installation of the SVC. These results are depicted in Table 3.

Table 3: Transient Stability Results – Case with GI-2006-4 and Network Upgrades for Delivery with SVC near Pawnee

	Fault Location	Action	Violation
1	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Brick Center 230 kV line	ZVRT
2	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Daniels Park 230 kV line	ZVRT
3	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Story 230 kV line	ZVRT
4	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee–Fort Lupton 230 kV line	ZVRT
5	3PH at Pawnee 230 kV bus; 5cycles	Trip Pawnee 230/22 kV line GSU	ZVRT
6	3PH at Peetz Logan 230 kV bus; 5 cycles	Trip Pawnee – Peetz Logan 230 kV line	none
7	3PH at feeder 34.5 kV bus; 5 cycles	Trip wind farm 230 kV feeder	none
8	3PH at Pawnee 230 kV bus; 5cycles	Trip Pawnee Generator	none

(2) Pawnee – Peetz Logan series compensation

The study results indicate that there is significant improvement provided by the series compensation of the Customer’s 230kV transmission line. However, the loss of the Pawnee – Story 230kV line causes the simulation to crash. These results are depicted in Table 4.



Table 4: Transient Stability Results – Case with GI-2006-4 and Network Upgrades for Delivery with Customer’s 230kV line series compensated

	Fault Location	Action	Violation
1	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Brick Center 230 kV line	none
2	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Daniels Park 230 kV line	none
3	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Story 230 kV line	Non-convergent
4	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee–Fort Lupton 230 kV line	none
5	3PH at Pawnee 230 kV bus; 5cycles	Trip Pawnee 230/22 kV line GSU	none
6	3PH at Peetz Logan 230 kV bus; 5 cycles	Trip Pawnee – Peetz Logan 230 kV line	none
7	3PH at feeder 34.5 kV bus; 5 cycles	Trip wind farm 230 kV feeder	none
8	3PH at Pawnee 230 kV bus; 5cycles	Trip Pawnee Generator	none

(3) 2nd Pawnee – Peetz Logan 230kV line

This alternative consisted in modeling a 2nd 230kV Pawnee – Peetz Logan transmission line parallel to the existing Customer’s line. The results provided slight improvement from the series compensation alternative: the loss of the Pawnee – Story 230kV line causes the simulation to oscillate. These results are depicted in Table 5.

Table 5: Transient Stability Results – Case with GI-2006-4 and Network Upgrades for Delivery with 2nd 230kV Customer’s line

	Fault Location	Action	Violation
1	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Brick Center 230 kV line	none
2	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Daniels Park 230 kV line	none
3	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee-Story 230 kV line	System Unstable
4	3PH at Pawnee 230 kV bus; 5 cycles	Trip Pawnee–Fort Lupton 230 kV line	none
5	3PH at Pawnee 230 kV bus; 5cycles	Trip Pawnee 230/22 kV line GSU	none
6	3PH at Peetz Logan 230 kV bus; 5 cycles	Trip Pawnee – Peetz Logan 230 kV line	none
7	3PH at feeder 34.5 kV bus; 5 cycles	Trip wind farm 230 kV feeder	none
8	3PH at Pawnee 230 kV bus; 5cycles	Trip Pawnee Generator	none



The stability analyses conclude that it is not feasible to inject an additional 200 MW (GI-2006-4) from the existing 400 MW Peetz Logan Wind Farm to the Pawnee 230kV bus due to the FERC Order 661-A LVRT requirements violations without any additional system upgrades under the conditions studied. Several alternatives were considered but did not mitigate all LVRT2, ZVRT and oscillatory system violations.



Appendix A
Peetz Logan 230kV Switching Station



Figure A-1. Peetz Logan Wind Project Conceptual One-line

