Interconnection System Impact Study Report
Request # GI-2006-2 Restudy
Dynamics study to verify compliance with FERC Order 661-A

200 MW Wind Expansion of Peetz-Logan, near Peetz, Colorado

Public Service Company of Colorado Transmission Planning
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Executive Summary

PSCo transmission finalized the System Impact Study (SIS) for request GI-2006-4 for a total of 800 MW at Peetz- Logan on February 5th, 2008. In the process of conducting that SIS for GI-2006-4 (200 MW) at Peetz Logan for a total of 800 MW it was determined that the original GI-2006-2 SIS dated April 2007 would need to be reevaluated. Transmission Planning studies for GI-2006-4 indicated 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)[1] and therefore it is not feasible to expand the Customer's Large Generation Facility to a total of 800 MW. In addition, during the evaluation of the LVRT requirements in this present study GI-2006-4, it was determined that the Customer does not meet the FERC Order 661-A guidelines for Low Voltage Ride Through (LVRT) for a previous request evaluated in GI-2006-2[2]. PSCo Transmission Planning and the Customer agreed to a restudy of the GI-2006-2 system impact study based on a more detailed representation of the wind collector system. The results of this restudy are summarized in this report.

The results of the restudy concluded that based upon the information provided by the developer, the addition of a reduced GI-2006-2 project of 176 MW would not adversely impact the PSCO transmission system. With the nameplate capability of the entire Peetz Logan wind facility totaling 576 MW, the low-voltage ride-through criteria will be met.

Power Flow Case Set-up

The power flow cases used in this re-study started from the 2012 HS2A Approved Case modified for 2010, i.e., the 2010HS Budget case. From this case, two cases were developed, one with generation at the Peetz Logan wind farm increased to 400 MW (benchmark case), and a second case with that 400 MW plus an additional 200 MW for the GI-2006-2 project. This generation was assumed to displace power from resources in southeastern Colorado, resulting in a stressed system near the point of interconnection (POI.)

[1] **http://www.ferc.gov**
[2] The System Impact Study GI-2006-2 was issued to the Customer on April 4, 2007. The Facility Study GI-2006-2 was issued to the Customer on December 19, 2007.

The wind farm was modeled in significant detail, based upon 34.5-kV collector system data provided by the developer, for both the initial 400 MW as well as the proposed 200 MW expansion as GI-2006-2. Composite generators ranged in size between 3.0 MW and 12.0 MW. Reactors were modeled on the 34.5 kV buses by the 230/34.5 kV transformers at Peetz Logan, although they would be off during peak generation periods.

Steady State Results: Reactive Power Requirements

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 PSCO will require testing of the full range of 0 MW to 600 MW operational capability of the facility. These tests will include, but not be limited to, power factor control, and VAR control as measured at the Pawnee 230 kV bus POI for various generation output levels (0 to 600 MW) of the Customer's wind generation facility.

3 A single point of contact needs to be provided to PSCo Operations to manage the transmission system reliably for all wind projects on the proposed line.

A switched capacitor bank was located on the long Pawnee – Peetz Logan 230-kV circuit, close to Pawnee. At 200 MVAR, it was sized to provide close to unity power factor at 600 MW. This value was used for power flow and stability analyses with the proposed expansion at Peetz Logan, but not included for the benchmark case with 400 MW of wind turbine capacity installed at Peetz Logan. The following table summarizes a few relevant values from the steady state results.

Power Flow Results

Nameplate Capability	Power Delivered At POI		MW	Voltage (pu)-230 kV bus		Installed Capacitors Near POI
(MW)	MW	MVAR	Losses	at Caps	at Pawnee	(MVAR)
400	380.3	-87.1	19.7	1.0238	1.0253	0
550.5	515.4	40.9	35.1	1.0352	1.0313	200
576	537.4	24.9	38.6	1.0333	1.0300	200
588	547.7	17.0	40.3	1.0324	1.0293	200
600	557.8	9.0	42.2	1.0315	1.0287	200

Based upon the assumption of reactive support being added near the POI, approximately 175-200 MVAR of reactive power would be needed near the POI to meet unity power factor for the interconnection.

The transmission study shows that the addition of 576 MW of new wind generation connected to Pawnee may not supply the full reactive power support necessary at the Point of Interconnection (POI) to control the power factor to between +/-0.95 across the full output range of the wind generation. Based upon supplied generator data concerning reactive power capabilities, the Customer may need to supply approximately 250-280 MVAR of reactive power on the Customer's facilities in order to meet the Xcel Energy interconnection guidelines at the POI. This would make up for the reactive power losses at the Customer's 230/34.5 kV main transformer, the 230-kV transmission line between the wind farm and the POI, and the Customer's 34.5 kV collector system facilities. More detailed studies will have to be performed by the Customer to determine the specific reactive (capacitive and inductive) dynamic or static equipment that may be necessary to meet the requirements. The project costs do not reflect the addition of the reactive power requirements for interconnection.

No contingency analysis was performed for this study effort, since there was no material change in the power delivered to the POI for this re-study.

Dynamic Stability Results

Based upon information provided by the developer, the wind turbines for the existing 400 MW wind farm are GE 1.5sle units for both the existing turbines and those proposed for GI-2006-2. Dynamic models have been available for these turbines for several years and can be readily adapted to represent the low-voltage ride-through capability that may be installed. For the existing turbines, the voltage protection scheme is based upon GE's LVRTII package, while the new turbines will have ZVRT capability.

With ZVRT capability, the GE turbines can continue to operate with the voltage at the point of interconnection at 0.0 pu for a period of up to 0.2 seconds and with voltage below 0.90 pu for at least 3.0 seconds. In contrast, the turbines with LVRTII will be tripped if the voltage levels are below 0.15 per unit for more than 0.2 seconds or if the voltage is below 0.70 pu for over 0.625 seconds,

While the documentation for the GE turbines indicates that this is measured at the point of interconnection, the voltage levels at the 230-kV buses at Peetz would be more appropriate in this case, given the 79 miles of 230-kV transmission line to the POI at Pawnee. During the course of the dynamics analysis, the simulations indicated that the voltage at Pawnee would recover very quickly after a nearby fault has been cleared. However, with high levels of wind generation at Peetz Logan, the voltage at any of the Peetz Logan 230-kV buses may remain depressed for a relative long period of time and may decay, leading to voltage collapse throughout the wind farm. By monitoring the voltages at the 230-kV buses at the wind farm rather than at the POI, and tripping the

turbines when the voltage is depressed, voltage collapse at the wind farm is avoided and the turbines with ZVRT can remain online.

In the dynamics analysis, a total of eight contingencies were studied. Seven of the contingencies studied reflected 3-phase faults on the 230-kV system that were cleared in 5 cycles. One contingency considered the sudden loss of the generation at Pawnee. For the six of the seven fault conditions studied, the fault was assumed to be at the Pawnee end of the circuit as indicated in the following table and subsequently cleared by opening the indicated branch. The remaining fault contingency reflected a fault on one of the 230-kV circuits at Peetz Logan that would result in the disconnection of 200 MW of wind generation when the fault was cleared.

For all of the faults studied, the PSCO system remains stable with all oscillations positively damped. Two of the contingencies do cause the expected loss of generation through disconnection, but no other adverse impacts. However, with the addition of 200 MW of new generation for GI-2006-2, the total Peetz Logan facility does not meet the low-voltage ride through criteria for system disturbances on the PSCO system. With a fault on the Pawnee – Story 230-kV circuit, the voltage seen by the original 400 MW of wind generation is continuing to decline at 0.625 seconds after the initialization of the fault, thereby resulting in the tripping of those wind turbines. With the reduction in power flowing over the long radial circuit after the tripping of a significant number of wind turbines, the voltage levels seen by the GI-2006-2 units rapidly increase. Thus after the disturbance and subsequent fault clearing, only 200 MW of the initial 600 MW remain on line.

After a fault on the Pawnee – Ft. Lupton 230-kV circuit is cleared, the voltage levels on the Peetz Logan 34.5 kV collector system and local 230-kV system remain depressed and are close to collapsing. These voltages do recover just within the 0.625 seconds allowed by LVRTII. In the following summary table, this situation is indicated by “marginal”.

Appendix A
Dynamic Stability Results
Restudy Results

Table 1: Transient Stability Results – Bench Mark Case before GI-2006-2
Results of Dynamics Analysis

No.	Faulted End	From Bus	To Bus	400	600	588	576	550
1	Pawnee	Pawnee 230 kV	Ft. Lupton 230 kV	Stable	Marginal	Stable	Stable	Stable
2	Pawnee	Pawnee 230 kV	Brick Center 230 kV	Stable	Stable	Stable	Stable	Stable
3	Pawnee	Pawnee 230 kV	Story 230 kV	Stable	Loss of 400 MW	Marginal	Stable	Stable
4	Pawnee	Pawnee 230 kV	Peetz Capacitor 230 kV	Stable	Stable	Stable	Stable	Stable
5	Pawnee	Pawnee 230 kV	Pawnee 22 kV	Stable	Stable	Stable	Stable	Stable
6	Pawnee	Pawnee 230 kV	Daniels Park 230	Stable	Stable	Stable	Stable	Stable
7	Peetz Switch 230 kV	Peetz Switching 230 kV	Peetz No. & So. 230 kV	Stable	Stable	Stable	Stable	Stable
8	n/a	Loss of Pawnee Generation		Stable	Stable	Stable	Stable	Stable

Based upon these results, subsequent analysis was performed with a reduction in the number of turbines added as part of GI-2006-2. The first case removed 33 turbines along with the related GSU and 34.5-kV feeder system, resulting in nameplate generating capability of 550.5 MW. The results of the stability analysis indicate that the reduction on total power generation capability will allow for more rapid voltage recovery and that the entire Peetz Logan facility will remain on line, meeting relevant criteria. The same general results were observed when 16 turbines were removed from the GI-2006-2 expansion, with total generation of 576 MW.

If only 8 turbines were eliminated from the proposed GI-2006-2 expansion, resulting in total generation of 588 MW, voltage levels at the initial facility would just recover in time to prevent the low voltage protection relays from tripping up to 400 MW of generation. The simulation indicates that the voltage levels are slow to recover after the fault is cleared.

In conclusion, based upon the information provided by the developer, the addition of a reduced GI-2006-2 project would not adversely impact the PSCO transmission system. With the nameplate capability of the entire Peetz Logan wind facility totaling 576 MW, the low-voltage ride-through criteria will be met.