Interconnection System Impact Study Report
Request # GI-2006-2

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

Xcel Energy Transmission Planning
April 4, 2007

Executive Summary

PSCo Transmission received a generation request to determine the System Impact of interconnecting 200 MW of new Customer wind turbine generation into the PSCo transmission system at the Pawnee Station 230 kV bus. This would be a 200 MW expansion of the planned GI-2006-1(g) 400 MW wind farm[1]. 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)[2] and a Network Resource (NR)[3]. The Feasibility Study Report for this request was completed in November 2006.

Energy Resource:
The ER portion of this study determined that the Customer could provide 50 MW of energy on a firm basis without the construction of network reinforcements. Non-firm transmission capability may be available depending on marketing activities, dispatch patterns, demand levels and the status of transmission facilities for additional Transfer Capability.

Network Resource:
As an NR request, PSCo evaluated the network to determine the upgrades required to deliver the full 200 MW of the wind facility to PSCo native load customers. It was determine that the first step is for PSCo to upgrade the Pawnee to Smoky Hill and Pawnee to Daniel Park 230 kV lines to 637 MVA. These upgrades are projected to be complete in 2008, which will allow 50 MW of firm transmission service to PSCo customers from this customer. The next phase to receive Network delivery on the remaining amount requested would require the implementation of PSCo's planned

[1] The Commercial ISD for GI-2006-1(g) is 10/07.

[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 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.

[3] **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.

transmission expansion from Pawnee to the Denver Metro Load Center. The recommended transmission upgrades will accommodate the full 200 MW from this project. The total estimated cost of the these upgrades is approximately **$87.25 million** and includes:

- $0.04 million for Customer Funded PSCo Interconnection Facilities
- $0 for PSCo Network Upgrades for Interconnection
- $87.21 million for PSCo Network Upgrades for Delivery

Transmission Studies show that the basic network upgrades would consist of:

- Constructing a new 115-mile 345 kV line from Pawnee to Daniels Park Substation. The new transmission can be described in three sections:
    - The first section consists of 80-miles of new 345 kV single circuit steel structures in new right of way from Pawnee and then join the existing PSCo transmission corridor near Brick Center Substation
    - Replace 15-miles of an existing single circuit line between Brick Center and Smoky Hill (part of the Pawnee-Daniels Park 230 kV line) with double circuit 345 kV capable structures. One side will operate at 230 kV to maintain the existing circuit. The other side will operate at 345 kV and make up the second section.
    - The final (third) section consists of constructing 20 miles of new 345 kV transmission from Smoky Hill to Daniels Park.
- Two 345/230 kV autotransformers at Pawnee
- One new 345 kV line termination at Daniels Park

The PSCo's transmission expansion plan is shown in Figure 1 along with the recommended upgrades. A partial one-line of Pawnee Station can be found in Figure 2 detailing the interconnection.

There will not be any upgrades required for interconnection since the Customer is using its existing interconnection.

The estimated time required to engineer, permit, and construct the 345 kV transmission expansion for the Network Upgrade facilities for delivery is at least **60 months**; therefore, it is not feasible to construct the Network Upgrades for full Firm Delivery of this project before the required in-service date.

Additional details of the studies can be found under the Power Flow Study Results and in the appendices.

This study utilizes the existing Point of Interconnection (POI) for GI-2006-1(g) at Pawnee Substation and the associated 72-mile transmission line to deliver wind generation from this proposed expansion and the existing GI-2006-1(g).

Before the execution of any Interconnection Agreement (IA) requires that certain conditions be met: PSCo requires:

1. The conditions of the Interconnection Guidelines[4] are met.
2. A single point of contact is given to Operations to manage the Transmission System reliably.
3. Customer must be VAR neutral during periods of high power transfers over the Customer owned 230 kV line.
    a. These studies indicated that the current transmission line design at full wind output does not meet the voltage and power factor requirements.
    b. The customer needs to determine a solution to the generators or transmission line to meet the voltage and power factor guidelines described in the Interconnection guidelines.

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

Figure 1: Recommended Network Upgrades For GI-2006-2.

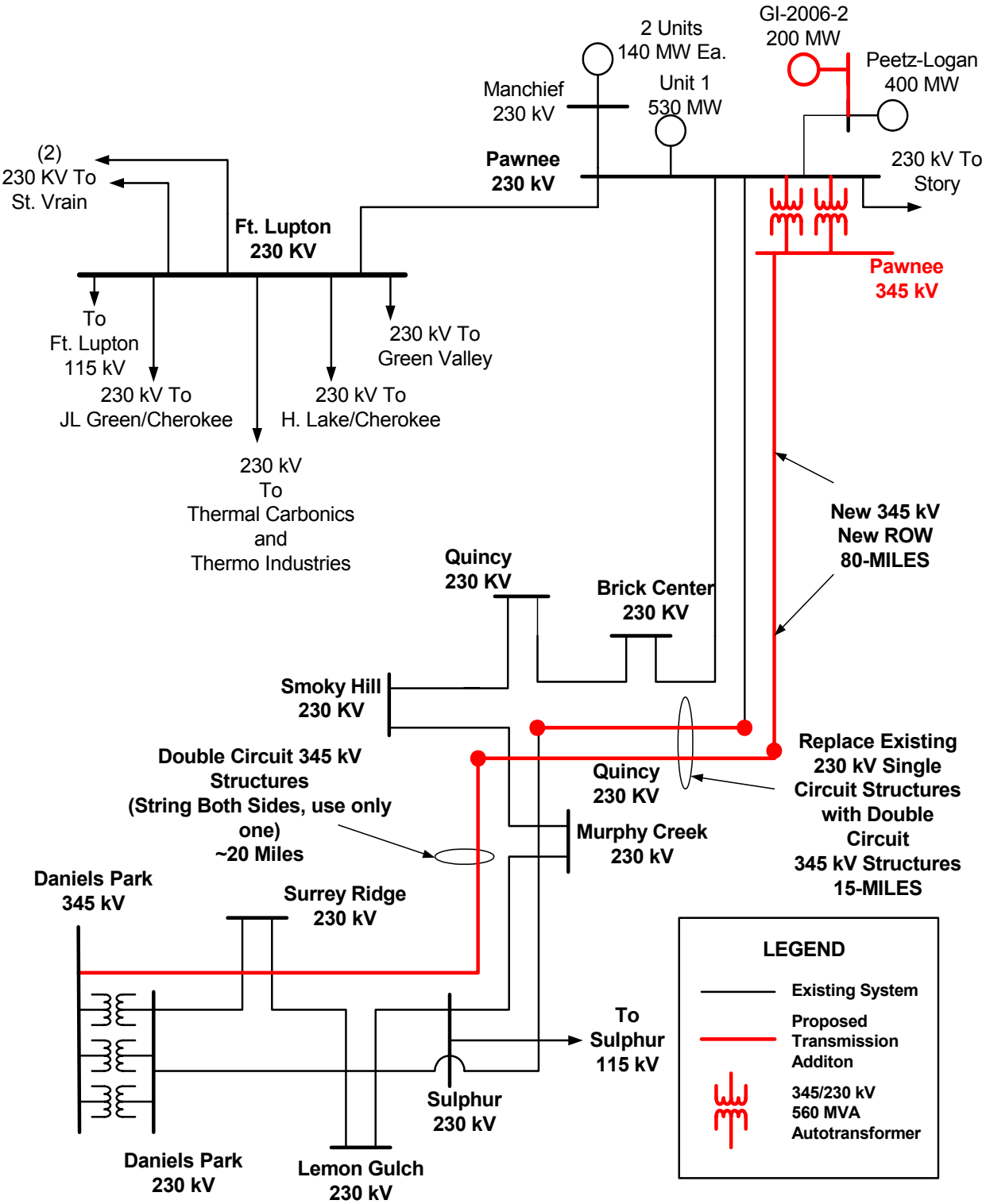
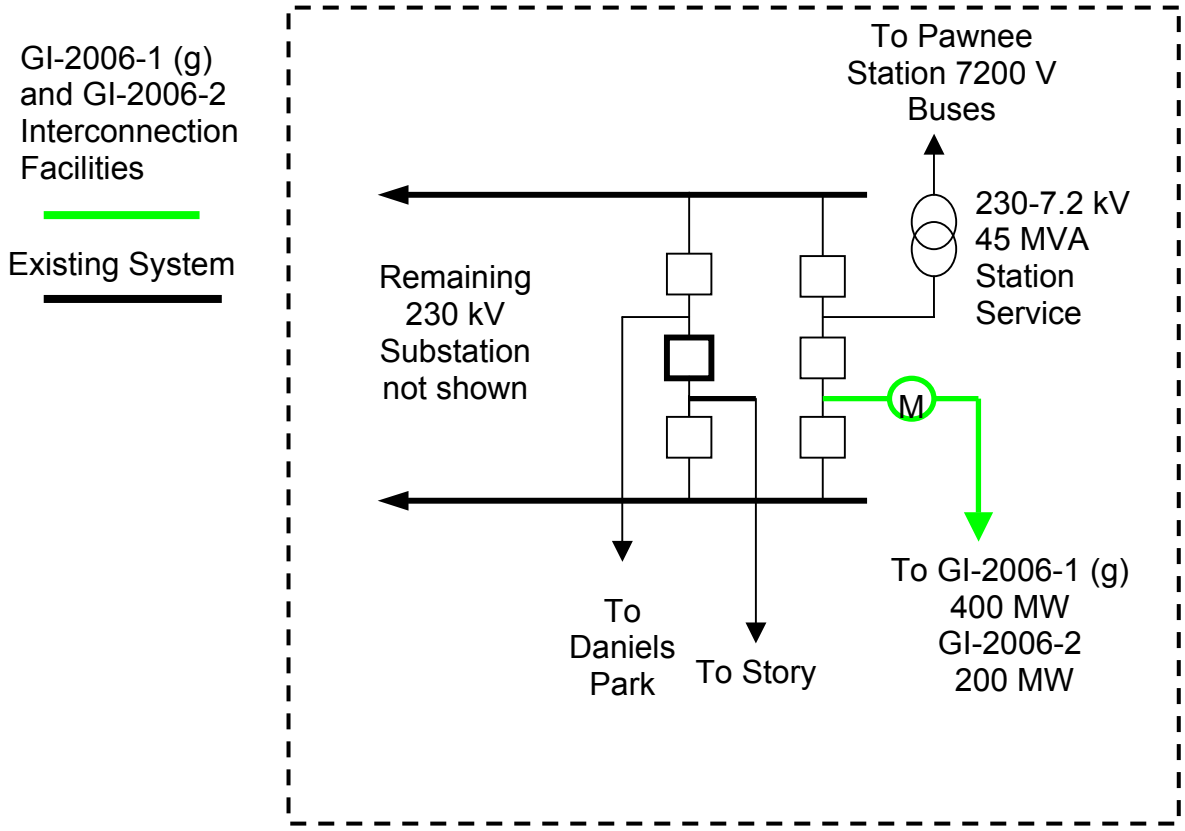


Figure 2: Simple Diagram of the Pawnee Interconnection



Introduction

PSCo Transmission received a large generator interconnection request (GI-2006-2) 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 planned Customer 72-mile radial 230 kV line terminating at the PSCo Pawnee Station. This line is under construction and is part of GI-2006-1 (g) interconnection and the proposed GI-2006-2 200 MW expansion project. GI-2006-2(g) has an in-service date of October 1, 2007. 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, short circuit, and dynamic stability 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 short circuit analysis identified any circuit breaker short circuit capability limits exceeded as a result of the Interconnection and for a NR request, the delivery of the proposed generation to PSCo loads. The dynamic stability analysis identified any limitations due to angular instability of the system for regional disturbances

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.

Pertinent modeling adjustments:

- Other wind generation at Pawnee was modeled at full output, which was approximately 400 MW.
- 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, and will allow 50 MW of firm transmission service to PSCo customers from this customer.
- Network upgrades for GI-2006-1 were implemented.

The Point of Interconnection (POI) between the Customer and PSCo is assumed to be the point at which the Customer 72-mile 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 700 MVA rating.
- One 230-34.5 kV, 133/177/222 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 simulate TOT3 path flows at approximately 1,280 MW. Efforts were made to include in the models all transmission projects expected to be in service for the 2010 heavy summer season. The studies assumed 2010 peak summer demand conditions in the PSCo system and in other utility systems.

Power Flow Study Results and Conclusions

Regional Transmission System

Studies show that the WAPA Beaver Creek area shows some potential of overloads under contingency scenarios. However, after coordinating with WAPA Transmission Planning it was discovered that a particular project in the Beaver Creek 230 kV expansion[5] plan was not modeled in the power flow. After incorporating the project in this study, all contingency overloads are mitigated.

Similarly, Intermountain Rural Electric Association (IREA) has several projects[6] including new 115 kV Transmission in the region that has significant benefits to the regional transmission system. After modeling the proposed IREA projects, all regional contingency overloads are significantly reduced.

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 230 kV bus. The Customer needs to demonstrate that the Guidelines are met. In

[5] This project consists of an underground 230 kV Tie between the Story and the expanded Beaver Creek 230 kV WAPA Substations.
[6] Projects include a 115 kV transmission line from Strasburg to Kiowa in 2010-11 time frame that unloads the Smoky Hill region.

addition, PSCo requires that the Customer provide a single point of contact[7] 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 Guidelines.

Short Circuit Study Results

The short circuit study results show that the fault current levels for all buses studied are within the interrupting ratings of the breakers; therefore, the Project and associated infrastructure will not cause fault current to exceed the circuit breaker ratings.

The faults currents at Pawnee are 22,792 Amps for a single-line to ground fault and 19,859 Amps for a three-phase fault. These values assume little to no fault current contribution from the proposed wind facility.

Dynamic Stability Results

Transient stability analyses were performed by modeling three-phase fault contingencies in the region of study. Dynamic models for the proposed project were prepared using Customer supplied data that assumed to use the GE 1.5 MW DFIG with low voltage ride through (LVRT) capability as low as 0% of nominal voltage[8]. The analysis indicated the system is stable before, during, and after contingencies once network upgrades were implemented.

The models for the initial 400 MW, GI-2006-1(g), used wind generators with LVRT as low as 15%, the models showed that the entire Peetz Logan project (existing and new) would stay on-line for faults at or near Pawnee and Story. The tables in Appendix B show stability results before and after the project and Network Upgrades are added to the system.

Costs Estimates and Assumptions

The estimated total cost for the required upgrades is **$87,250,000.**

The estimated costs shown are (+/-30%) estimates in 2007 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.

The following tables list the improvements required to accommodate the interconnection and the delivery of the Project. The cost responsibilities associated

[7] The POI will provide a point of injection of wind generation from several different entities.

[8] FERC Order Number 661

with these facilities shall be handled as per current FERC guidelines. System improvements are subject to change upon more detailed analysis.

Since this project intends to use the interconnection from the 600 MW Wind Facility GI-2006-1(g) and GI-2006-2 at Pawnee Station, there will be only minimal costs of $40,000 associated with the interconnection required for this 200 MW expansion project GI-2006-2.

Table 1: Transmission Provider Interconnection Facilities (Customer Funded)

Substation	Description	Cost Millions
Pawnee 230kV Switchyard	Interconnect Customer's 230kV line to the existing Pawnee Switchyard. The major work required includes: • Engineering and design • Transmission line relaying and testing	**$0.02**
Lookout Operations Center	Add additional status/weather monitoring points for the Customer's generation at Lookout Operations Center. The major work required includes: • Programming and wiring changes	**$0.02**
	Total Estimated Cost for PSCo Interconnection Facilities	**$0.04**
Time Frame		**3 Months**

Table 2: PSCo Network Upgrades for Delivery

Element	Description	Cost Millions
Pawnee Station	Upgrades and modifications required at Pawnee Switchyard for adding a 345 kV yard. The major equipment required includes: • Four 345 kV 40 kA Circuit Breakers • Ten 345 kV Gang Switches • Two 345/230 kV 560 MVA autotransformers • Four 230 kV 40 kA, 3000 A, Circuit Breakers • Eight 230 kV Gang Switches • Transmission line relaying and testing • Major Yard Expansion for 345 kV	**$13.41**
Daniels Park Substation	345 kV Line Termination equipment that includes: • Two 345 kV 40 kA Circuit Breakers • Four 345 kV Gang Switches • Transmission line relaying and testing	**$1.76**
Lookout Center	EMS Changes	**$0.09**

Element	Description	Cost Millions
Pawnee – Daniels Park 345 kV line	Add a new single circuit 345 kV line from Pawnee -Daniels Park. This includes: • Single Circuit 345 kV from Pawnee to just outside of Brick Center Switching Station including new ROW (80 –Miles). • Rebuild existing Pawnee-Daniels Park single circuit 230 kV line from Brick Center to outside of Smoky Hill (15-miles) to double circuit 345 kV line One side operated at 345 and the other operated at 230 kV for the Pawnee-Daniels Park line. • Construct new double circuit 345 kV line from just outside of Smoky Hill to Daniels Park utilizing existing ROW (20-miles). String both sides of double circuit tower.	**$65.48**
Pawnee-Daniels Park 230 kV Line	Removal of Brick Center to Smoky Hill Section (15 Miles)	**$1.01**
	Siting and Land Rights land acquisition & permitting for all above	**$5.46**
	Total Estimated Cost for PSCo Delivery Infrastructure Upgrades	**$87.21**
Time Frame		**60 Months**
	TOTAL PROJECT COST	**$87.25**

Assumptions

- The estimated costs provided are with an accuracy of +/- 30%.
- All applicable overheads are included. AFUDC has not been included.
- There is no contingency added to the estimates.
- Estimates have not been escalated. All estimates are in 2007 dollars.
- Labor is estimated for straight time only – no overtime included.
- Customer will be expanding their 3-breaker ring bus to a 4-breaker ring bus.
- No additional metering will be required.
- The Generator is not in PSCo's retail service territory. Therefore no costs for retail load metering are included in these estimates.
- PSCo (or its Contractor) crews will perform all work associated with PSCo owned and maintained equipment.

- All required transmission outages necessary to support construction will be obtained as needed.

- This additional wind generation will utilize the existing/planned Peetz Logan Interconnect 230 kV transmission line.

- New 345 kV line requires new ROW from Pawnee to Near Brick Center

- **Extensive public involvement anticipated. Assume a minimum 28-month process for Permitting and Land Rights issues.**

Appendix A
Contingency Results

Table 3: Contingency Comparison Table of Most Significant Contingencies

OVERLOADED ELEMENT					Case	bench mark TOT 3= 1280 MW	new generation added TOT 3= 1281 MW	new generation plus network upgrades TOT 3 = 1300 MW						
FROM bus ---name---	TO bus ---name---	----- -kv-	---- ar	ID	rating [MVA]	Loading	Loading	Loading	CONTINGENCY FROM	TO	kV	CKT #	Contingency Difference	Cont. w/ upgrades
"B.CK PS "	"BEAVERCK"	115	73	"1 "	**319**	104%	109%	95%	B.CK TRI	BEAVERCK	115	"1 "	5%	-9%
BIJOUTP	FMWEST	115	73	1	**80**	100%	107%	81%	BEAVERCK	ADENA	115	"1 "	7%	-19%
SMOKYJIL	STRASBRG	115	70	1	**144.6**	99%	109%	74%	QUINCY	BRICKCTR	230	"1 "	10%	-25%

Appendix B
Dynamic Stability Results

Table 4: Transient Stability Results – Bench Mark Case before GI-2006-2

	Fault Location	Action	Result
1	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee-Brick Center 230 kV line	System Stable
2	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee-Daniels Park 230 kV line	System Stable
3	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee–Ft. Lupton 230 kV line	System Stable
4	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee–Story 230 kV line	System Stable
5	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee–Peetz Logan 230 kV line	System Stable
6	3PH at Brick Center 230 kV bus; 6 cycles	Trip Pawnee-Brick Center 230 kV	System Stable
7	3PH at Brick Center 230 kV bus; 6 cycles	Trip Brick Center – Quincy - Smoky Hill 230 kV line	System Stable
8	3PH at Ft. Lupton 230 kV bus; 6 cycles	Trip Pawnee–Ft. Lupton 230 kV line	System Stable
9	3PH at Daniels Park 230 kV bus; 6 cycles	Trip Pawnee-Daniels Park 230 kV line	System Stable
10	3PH at Story 230 kV bus; 6 cycles	Trip Pawnee–Story 230 kV line	System Stable
11	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee-Brick Center 230 kV line and 3PH at Daniels Park 230 kV bus; 6 cycles	System Stable
12	3PH at Daniels Park 230 kV bus; 6 cycles	Trip Pawnee-Daniels Park 230 kV line and Trip Daniels Park-Surrey Ridge-Lemon – Sulphur 230 kV line	System Stable
13	3PH at Pawnee 230 kV bus; 6 cycles	Trip Entire Pawnee Station	System Stable
14	3PH at LRS 345 kV bus, 4 cycles	Trip LRS-AULT 345 kV line	System Stable

Table 5: Transient Stability Results – Case with GI-2006-2 and Network Upgrades for Delivery

#	Fault Location	Action	Result
1	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee-Brick Center 230 kV line	System Stable
2	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee-Daniels Park 230 kV line	System Stable
3	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee–Ft. Lupton 230 kV line	System Stable
4	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee–Story 230 kV line	System Stable
5	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee–Peetz Logan 230 kV line	System Stable
6	3PH at Brick Center 230 kV bus; 6 cycles	Trip Pawnee-Brick Center 230 kV	System Stable
7	3PH at Brick Center 230 kV bus; 6 cycles	Trip Brick Center – Quincy - Smoky Hill 230 kV line	System Stable
8	3PH at Ft. Lupton 230 kV bus; 6 cycles	Trip Pawnee–Ft. Lupton 230 kV line	System Stable
9	3PH at Daniels Park 230 kV bus; 6 cycles	Trip Pawnee-Daniels Park 230 kV line	System Stable
10	3PH at Story 230 kV bus; 6 cycles	Trip Pawnee–Story 230 kV line	System Stable
11	3PH at Pawnee 230 kV bus; 6 cycles	Trip Pawnee-Brick Center 230 kV line and 3PH at Daniels Park 230 kV bus; 6 cycles	System Stable
12	3PH at Daniels Park 230 kV bus; 6 cycles	Trip Pawnee-Daniels Park 230 kV line and Trip Daniels Park-Surrey Ridge-Lemon – Sulphur 230 kV line	System Stable
13	3PH at Pawnee 230 kV bus; 6 cycles	Trip Entire Pawnee Station	System Stable
14	3PH at LRS 345 kV bus, 4 cycles	Trip LRS-AULT 345 kV line	System Stable
15	3PH at Pawnee 345 kV bus	Trip Pawnee-Daniels Park 345 kV line	System Stable
16	3PH at Daniels Park 345 kV bus	Trip Pawnee-Daniels Park 345 kV line	System Stable