Interconnection Feasibility Study Report
Request # GI-2008-13

400 MW Wind Powered Generation Interconnecting at Pawnee Substation

PSCo Transmission Planning
October 27, 2009

Executive Summary

On September 23, 2008 Public Service Company of Colorado (PSCo) Transmission Planning received a generation interconnection request to determine the potential system impacts associated with interconnecting a 400-MW wind generation facility at the Pawnee Substation through a 90-mile transmission line. The 230-kV bus at Pawnee was considered to be the primary Point of Interconnection (POI), while the 345-kV bus at Pawnee was considered as a secondary POI. The customer requested a commercial operation date for the project of December 31, 2011, and a back-feed for site energization date of September 30, 2011. Based on projected equipment lead-times and other transmission project in-service dates, both interconnections at the 230 kV bus and the commercial operation and back-feed dates requested by the Customer were not determined feasible; therefore, it is recommended that the Customer's POI ultimately be at the 345-kV bus at Pawnee. The earliest date the wind generation facility could become a network resource for PSCo would be after the completion of the Pawnee – Smoky Hill 345 kV line that is scheduled for May 2013. The study request indicated that the generation would be delivered for PSCo load. This generation interconnection request was studied as a stand-alone project only.

This request was studied as a Network Resource (NR)[1] only. This investigation included steady-state power flow and short-circuit studies. 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 are already approved and planned to be in service by the summer of 2011. The main purpose of this study was to evaluate the potential impact of GI-2008-13 on the PSCo transmission infrastructure, as well as that of neighboring entities, when injecting a total of 400 MW of generation into Pawnee, and delivering the additional generation to native PSCo loads. The costs to interconnect the project with the transmission system at Pawnee Substation have been evaluated by PSCo Engineering. This study considered facilities that are part of the PSCo

[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; 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 system as well as monitoring other nearby entities' regional transmission systems.

Stand Alone Results

The stand-alone analysis consisted of a comparative study of the system behavior with the addition of the Customer's 400-MW project to the PSCo system compared with that associated with the existing PSCo system. The power flow model used in this study is a 2011 budget model with heavy summer load and moderately heavy stressed north-to-south (HSHN) flows. A 2015 power flow model was also used, recognizing the timing issues associated with the construction of certain transmission projects.

Network Resource (NR)

Network Resource Interconnection Service is an Interconnection Service that allows the Interconnection Customer to integrate its Large Generating Facility with the Transmission Provider's Transmission System in a manner comparable to that in which the Transmission Provider integrates its generating facilities to serve native load customers. A Network Resource is any designated generating resource owned, purchased, or leased by a Network Customer under the Network Integration Transmission Service Tariff. Network Resources do not include any resource, or any portion thereof, that is committed for sale to third parties or otherwise cannot be called upon to meet the Network Customer's Network Load on a non-interruptible basis. Network Resource Interconnection Service in and of itself does not convey transmission service.

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-2008-13 wind facility as provided at the POI to PSCo native load customers. **Interconnecting at the Pawnee 230-kV bus was not determined to be feasible.** It is recommended that the Customer's POI ultimately be at 345-kV at Pawnee. Under that condition, the estimated cost of the recommended system upgrades to accommodate the project is approximately **$1,705,000** and includes:

- ***$1,205,000 for PSCo-Owned, Customer-Funded Interconnection Facilities***
- ***$500,000 for PSCo-Owned, PSCo-Funded Network Upgrades for Interconnection***
- ***$0 for PSCo Network Upgrades for Delivery. This assumes that PSCo completes the network upgrade projects that have been identified and included in the PSCo Transmission Capital Budget.***

Based upon the steady-state analysis performed for the feasibility study, the full 400-MW generation output of the GI-2008-13 project could be provided to PSCo after reinforcements to the PSCo transmission system have been completed. PSCo will complete these reinforcements through its capital budget process for transmission upgrades.

The feasibility study indicates that approximately 25 - 60 MVAR of reactors will likely be required for the Customer'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. This would be needed whenever the Customer facilities are off-line or generating at very low levels while the Customer is connected to the POI. In addition, about 230 MVAR of switched capacitors will be needed to meet the voltage criteria at the POI near maximum generation. More detailed studies should be performed by the Customer to ensure that proposed wind generation facility will display acceptable performance during the commissioning testing. If the Customer advances the request to the system impact study phase, the results of the stability analysis may modify the nature of the reactive power support that may be required of the Customer for the project to meet relevant reliability criteria.

Interconnecting to the PSCo bulk transmission system requires the Customer to adhere to certain interconnection requirements. These requirements are contained in the Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater than 20 MW (Guidelines). The Guidelines make reference to interconnection requirements resulting from FERC Order 661A. FERC Order 661A describes the interconnection requirements for wind generation plants. In addition, PSCo System Operations conducts commissioning tests prior to the commercial in-service date for a Customer's facilities. Some of the requirements that the Customer must complete include the following:

1. A wind generating plant shall maintain a power factor within the range of 0.95 leading to 0.95 lagging, measured at the POI. The Transmission Provider's System Impact Study is needed to demonstrate that such a power factor requirement is necessary to ensure safety or reliability.

2. The voltage at a POI shall be maintained in the ideal voltage range for the appropriate Colorado region and bus type (regulating[2] or non-regulating) as determined in the Rocky Mountain Area Voltage Coordination Guidelines[3]. The

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

[3] 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

System Impact Study will investigate pertinent demand (on-peak or off-peak), season (summer or winter), dispatch, and outage scenarios based on the defined study area that includes the proposed POI. The study will conform to the NERC Transmission System Planning Performance Requirements (TPL standards).

3. The POI for a wind generating facility cannot be declared a regulating bus unless system studies demonstrate that the designation of the POI as a regulating bus is needed for system reliability or safety.

4. The impact of the wind generating facility on the reactive power schedules of nearby generating units may need to be mitigated by the Customer if system studies demonstrate that the proposed wind generating facility causes nearby generating units to generate or absorb reactive power for voltage control[4]. It is understood that sufficient reactive power reserve must be maintained on generating units to allow them to dynamically regulate voltage for extreme system conditions.

5. If a wind generating facility is interconnected to the bulk transmission system but is operating with its generation off-line and receiving power from the bulk transmission system for its station service requirements, that facility is acting as a load and will be required to maintain the power factor at the POI within 98% lagging or leading (when the station service load is greater than 85% of maximum) per the Xcel Energy document titled Interconnection Guidelines For Transmission Interconnected Customer Loads.

6. PSCo System Operations will require the Customer to perform operational tests prior to commercial operation that would verify that the equipment installed by the Customer meets operational requirements.

7. It is the responsibility of the Customer to determine what type of equipment (DVAR, added switched capacitors, SVC, reactors, etc.), the ratings, and the locations of those facilities that may be needed for acceptable performance during the commissioning testing.

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.

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

PSCo requires the Customer to provide a single point of contact to coordinate compliance with the power factor and voltage regulation at the POI. The reactive flow at the end of the line near the POI will need to be controlled according to the Interconnection Guidelines.

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

1. The conditions of the Large Generator Interconnection Guidelines[5] (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-2008-13 that deliver power to the Pawnee POI, as indicated in the Interconnection Guidelines.

3. PSCo will require testing of the full range of 0 MW to 400 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 Pawnee POI for various generation output levels (0 to 400 MW) of the overall wind generation facility.

4. The Customer must show that the power factor at the POI is within the required +/-0.95 power factor range at all levels of generation and that the voltage levels and changes are within reliability criteria as measured at the POI for the full range of testing (including generator off-line conditions).

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

Figure 1. Simple Diagram of GI-2008-13, Point of Interconnection at 345-kV - 2013

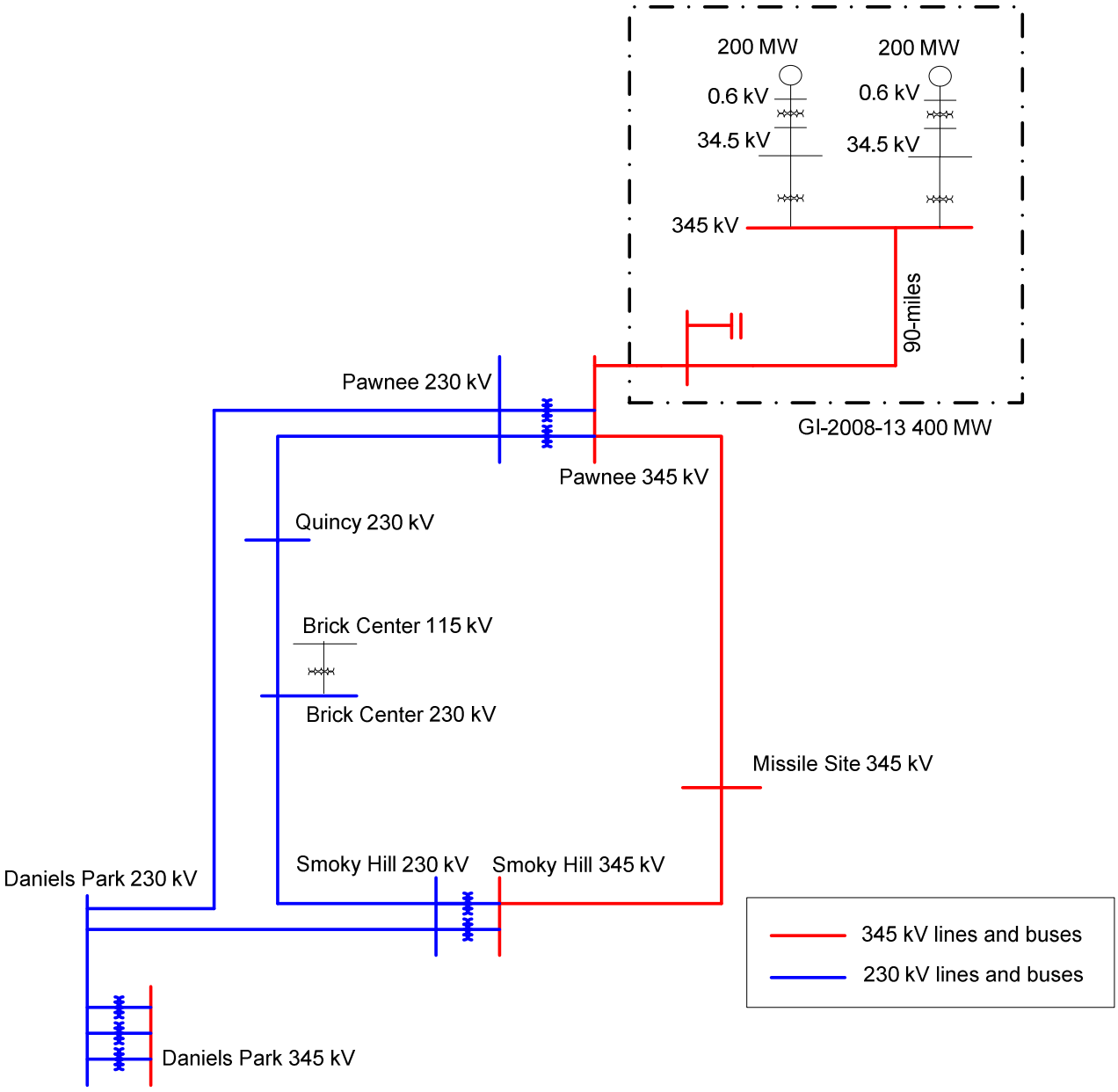


Figure 2. Preliminary One-Line of the Proposed GI-2008-13

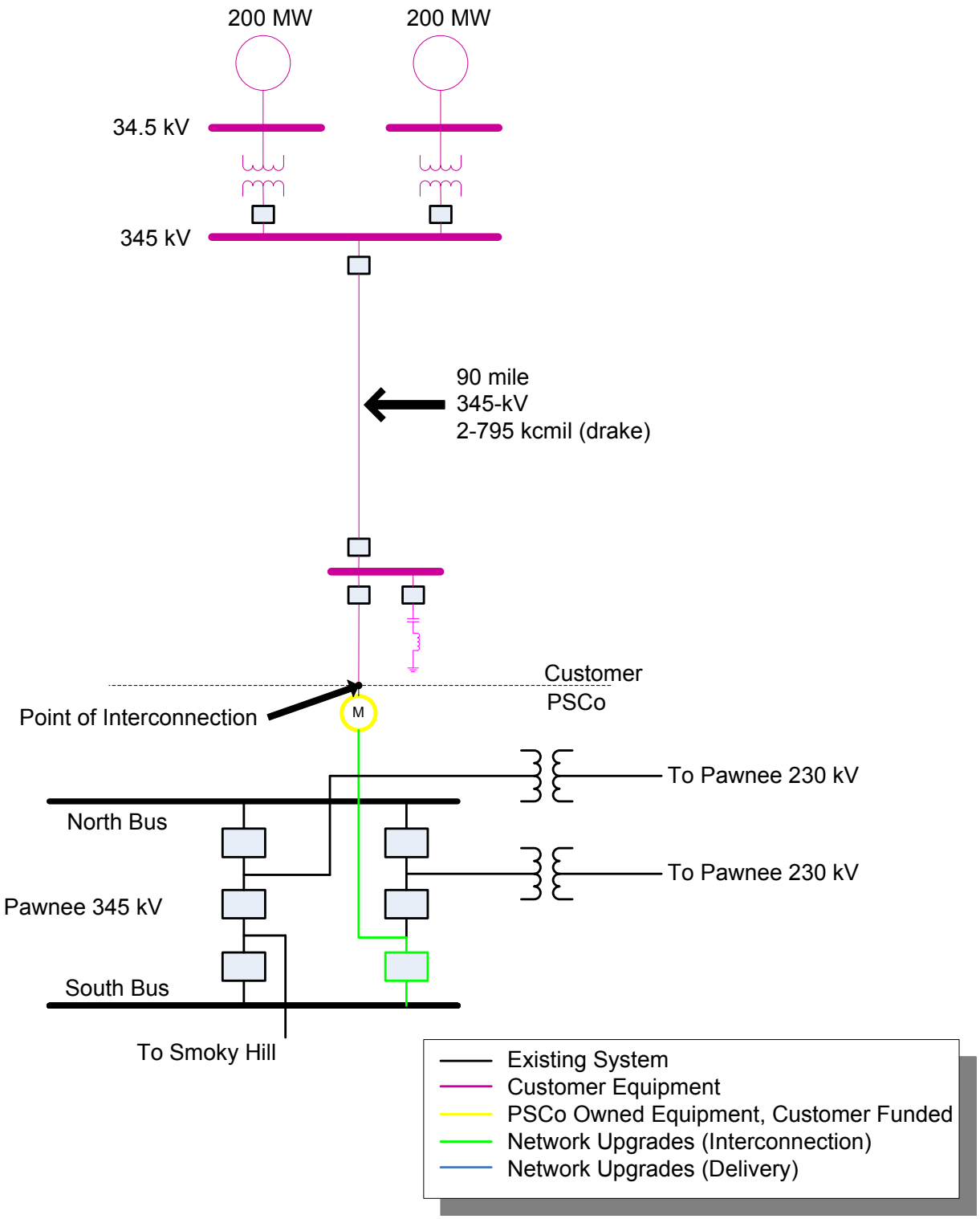
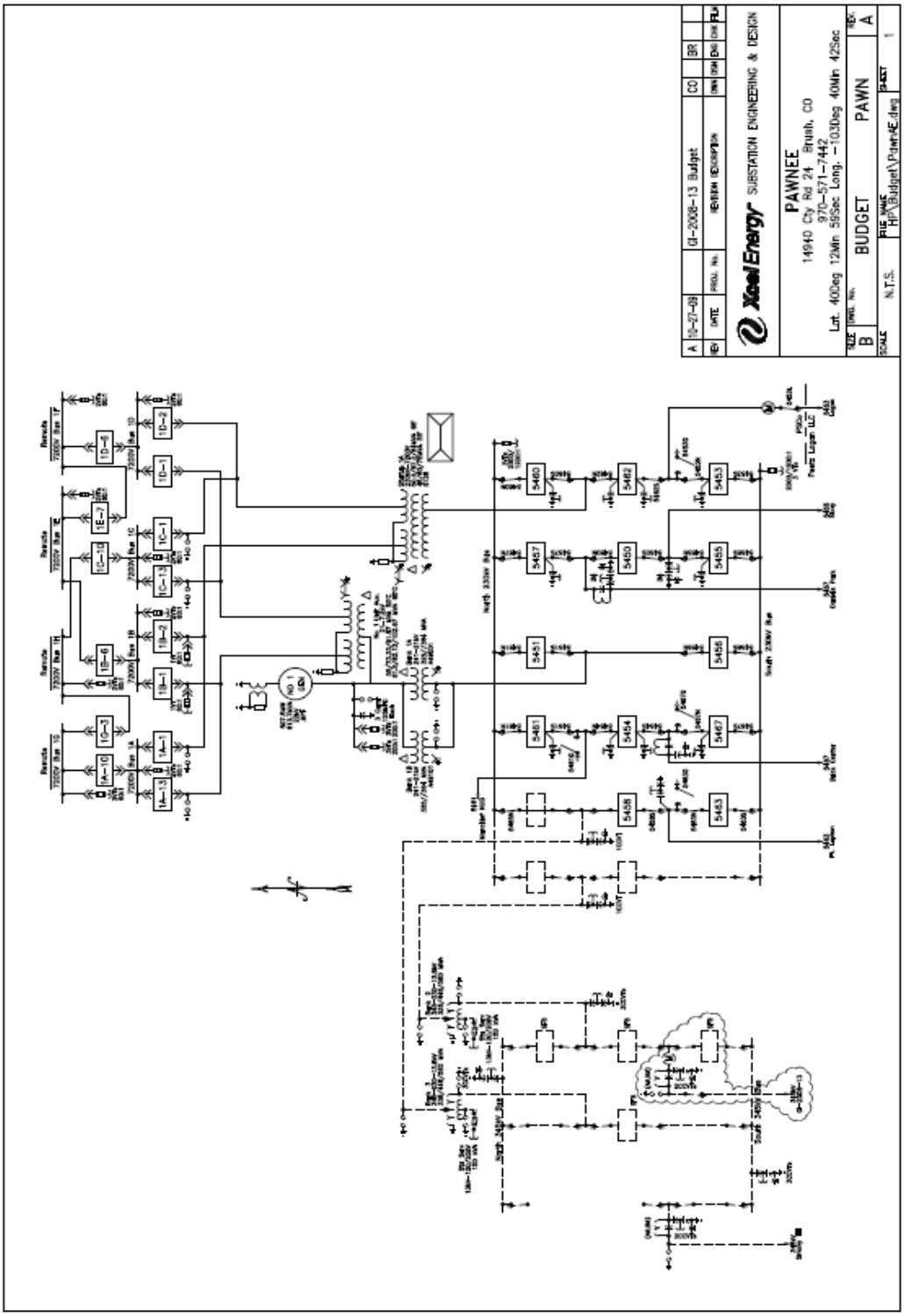


Figure 3 Preliminary One-Line of the Proposed GI-2008-13 at Pawnee



Introduction

Public Service Company of Colorado (PSCo) received a large generator interconnection request (GI-2008-13) to interconnect 270 GE 1.5 MW wind turbines, with a total generator nameplate capacity of 400 MW and a commercial operation date of December 31, 2011, and a back-feed for site energization date of September 30, 2011. The proposed project would be located in Sedgwick County, Colorado. The GI-2008-13 project would be connected with a new 90-mile transmission line to the Pawnee Substation. As per the customer's request, the 230-kV bus at Pawnee was considered to be the primary Point of Interconnection (POI), while the 345-kV bus at Pawnee was considered as a secondary POI. **Interconnection at the 230 kV bus was not determined feasible; therefore, it was recommended that the Customer's POI ultimately be at the 345-kV bus at Pawnee.** This request was evaluated as a stand alone project with no other higher queued projects modeled.

The Customer has requested that this project be evaluated as a Network Resource (NR) only, with the energy delivered to PSCo native load customers.

Study Scope and Analysis

This feasibility study evaluates the feasibility of providing 400 MW of energy from GI-2008-13 through the point of interconnection at Pawnee to PSCo native loads. This request was studied as a Network Resource (NR) only. This feasibility study consisted of both steady state power flow analysis and short circuit analysis. The power flow analysis provides 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. The short circuit analysis identifies any circuit breakers with 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.

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.
- The ideal voltage range for the buses at the Pawnee substation is between 1.03 per unit to 1.04 per unit.
- 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 this project, the potential affected parties are Tri-State Generation and Transmission (TSG&T) and Western Area Power Administration (WAPA). PSCo will provide the affected parties with a copy of this feasibility study report and will work with them during the system impact study phase.

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 2011 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 2011 case, the following generators in Area 70 (PSCo Transmission) were re-dispatched to simulate high north-to-south stressed system conditions.

- Wind generation at Peetz Logan was raised to its current maximum value of 550 MW. A 200 MVAR capacitor is connected at the Peetz Logan facility close to the POI, in order to maintain the voltage at the Pawnee 230 kV bus.
- The generation at Pawnee and Manchief units was raised to their maximum capacity.
- To accommodate these increases in generation, the generation at Comanche was decreased.

Implementation of these changes resulted in the benchmark case used for this study. Comanche Unit 1 was designated as the slack bus for Area 70.

Using the 2011 benchmark case as the starting point, two power flow models were developed to reflect the GI-2008-13 project with the two potential transmission line alternatives and POIs, at 230-kV and 345-kV. The proposed wind generation facility consists of 270 General Electric (GE) 1.5 MW wind turbines. The turbines have a terminal voltage of 575 volts. For this feasibility study, the turbines have been represented as two equivalent generators of 200 MW each with a terminal voltage of 575 volts, which is stepped up to 34.5 kV.

The Customer has requested that the study consider both a 230-kV and 345-kV interconnection alternative at Pawnee. The wind generation facility would be connected to Pawnee substation by a radial transmission line, 90 miles long, at either the 230-kV or 345-kV bus. In the 2011 timeframe, there is no 345-kV bus at Pawnee. Therefore, for the customer's 345-kV transmission line alternative, a 560-MVA 345/230-kV transformer has been assumed to be added to the PSCo transmission system at the Pawnee substation. For the 230-kV interconnection, the following has been added to the benchmark power flow case for 2011:

1. The GI-2008-13 generation and a simplistic 34.5-kV collector system
2. Two 200-MVA 34.5/230-kV transformers at the wind farm site
3. 90-mile transmission line built for and operated at 230-kV operation

In the 345-kV interconnection alternative, the 2011 benchmark power flow case was modified to include:

1. The GI-2008-13 generation and 34.5-kV collector system
2. Two 200-MVA 34.5/345-kV transformers at the wind farm site
3. 90-mile transmission line built for and operated at 345-kV operation
4. One 560-MVA 345/230-kV transformer at the Pawnee substation

A bundled 795-kcmil ACSR (Drake) conductor was used for the radial line connecting the proposed facility to the PSCo system. The line impedance parameters for the 90-mile line were calculated for each voltage level using the PSS®E program TMLC. The new generation from GI-2008-13 was accommodated by decreasing the generation at Comanche unit 2 and unit 3.

Power Flow Study Process

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.

Power Flow Results

Thermal Overloads

The results for the single line contingency analysis when 400 MW are connected to the Pawnee substation are shown in Table 1. Connecting the new wind generation facility to the 230-kV bus at Pawnee without any reinforcements causes several lines in PSCo's system as well as in the TSG&T's system to overload. In comparing the results of the contingency analysis with the benchmark case for Area 70 (PSCo system), the Pawnee-Ft. Lupton 230-kV circuit, the 230-kV line from Pawnee to Story and the 115-kV line from Smoky Hill to Strasburg are significantly overloaded under contingency conditions. For Area 73 (TSG&T), the lines around Beaver Creek would also become overloaded under certain contingencies.

The 230-kV lines from Barr Lake to Green Valley and from Ft. Lupton to JL Green are also overloaded. However, the thermal ratings of these lines have been revised from 159 MVA to 518 MVA and from 478 MVA to 490 MVA, respectively, as per the

Substation/Transmission Facility Equipment Rating FAC-009 list. These lines would no longer be overloaded because of the revised ratings. While the rating of the 230-kV line from Pawnee to Ft. Lupton has been revised from 478 MVA to 508 MVA, that line would still be significantly overloaded with the loss of the Pawnee-Story 230-kV circuit.

Table 1. AC Contingency Analysis for the 2011 Base Case

** From bus ** ** To bus ** CKT	Branch Rating	Loading as % of branch rating			Contingency
		bench-mark	POI Pawnee 230kV	POI Pawnee 345kV	
70047 BARRLAKE 230 70048 GREENVAL 230 1	159.0	164.2	173.2	173.4	70192 FTLUPTON 230 70529 JLGREEN 230 1
70192 FTLUPTON 230 70311 PAWNEE 230 1	478.0	77.9	110.6	110.6	70311 PAWNEE 230 73192 STORY 230 1
70192 FTLUPTON 230 70529 JLGREEN 230 1	478.0	95.4	101.9	102.1	70192 FTLUPTON 230 70605 HENRYLAK 230 1
70311 PAWNEE 230 73192 STORY 230 1	625.0	73.3	107.9	108.6	Circuit 5165 (Pawnee-BrickCenter-Quincy-SmokyHill)
70395 SMOKYHIL 115 70416 STRASBRG 115 1	144.6	85.3	102.9	103.4	70343 QUINCY 230 70545 BRICKCTR 230 1
73020 BEAVERCK 115 73537 BEAVERCK 230 1	224.0	83.1	100.7	101.2	73192 STORY 230 73537 BEAVERCK 230 1
73192 STORY 230 73537 BEAVERCK 230 1	454.0	131.3	156.8	157.1	73012 AULT 345 73108 LAR.RIVR 345 1
73196 TERRY 115 73503 ERIE SW 115 1	109.0	86.5	104.3	104.7	73502 DACONO 115 73503 ERIE SW 115 1

When the proposed generation facility is connected with a 345-kV transmission line to the POI at Pawnee, all the lines that would be overloaded when the Pawnee 230-kV bus is the POI, are also overloaded. The loading on the lines is higher with the 345-kV POI under contingency conditions, due to lower losses on the Customer's transmission as seen above in Table 1.

Since several lines would be overloaded under contingency conditions when the GI-2008-13 facility is connected to the Pawnee substation, network upgrades are necessary to accommodate the injection of 400 MW at Pawnee. A 345-kV line from Pawnee to Smoky Hill is planned as a network upgrade in the PSCo capital budget, as PSCo has recently received the CPCN necessary construct this transmission line. It is expected that the 345-kV line along with the necessary 345/230-kV transformation will not be operational prior to the May 2013 timeframe.

Power Flow Study Results for the 2015 Case

For this study, we have recognized the Pawnee – Smoky Hill 345-kV reinforcement and its timing by utilizing a second power flow model, for 2015. The heavy summer peak load power flow model was developed by PSCo in a similar manner as the 2011 power flow model, and includes the 345-kV Pawnee – Smoky Hill line.

The 2015 power flow case without GI-2008-13 was used as the benchmark case and reflects the loads, generation, and transmission configuration that are expected to be in operation at that time. To this 2015 benchmark case the GI-2008-13 project was added, with two power flow cases created to analyze the 230-kV and 345-kV transmission line alternatives. The contingency analysis was then repeated using the 2015 cases to determine the adverse impacts to the PSCo system associated with the GI-2008-13 project.

The AC contingency analysis was performed for both POI's and the results were compared to the results of the AC contingency analysis of the 2015 benchmark case. The results of this comparison are given in Table 2.

As mentioned earlier, the rating of the line from Ft. Lupton to JL Green has been revised as per the FAC-009 list and it is no longer overloaded. In addition, the rating of the line from Buckley to Smoky Hill has been revised from 479 MVA to 506 MVA and it is also no longer overloaded. Furthermore, although the Clark to Jordan line still remains overloaded under contingency conditions, due to the fact the line is underground, the emergency line rating allows for the line to operate for over 100 hours when overloaded at 7%. Finally, an automatic switching procedure has been established, preventing the 230/115-kV transformer at Brick Center from overloading in the loss of the 230-kV line form Quincy to Brick Center.

Table 2. Contingency Analysis for the 2015 Base Case

** From bus ** ** To bus ** CKT	Branch Rating	Loading as % of branch rating			Contingency
		Bench-mark	Pawnee 230kV	Pawnee 345kV	
70067 BUCKLY12 230 70396 SMOKYHIL 230 1	479.0	91.4	103.3	104.7	70283 MEADOWHL 230 70396 SMOKYHIL 230 1
70112 CLARK 230 70241 JORDAN 230 1	398.0	87.5	105.2	107.2	70067 BUCKLY12 230 70396 SMOKYHIL 230 1
70192 FTLUPTON 230 70529 JLGREEN 230 1	478.0	95.1	100.8	100.3	70192 FTLUPTON 230 70605 HENRYLAK 230 1
70545 BRICKCTR 230 70546 BRICKCTR 115 T1	200.0	99.7	113.6	112.7	70343 QUINCY 230 70545 BRICKCTR 230 1
70067 BUCKLY12 230 70512 JEWELL1 230 1	439.0	86.3		100.7	70283 MEADOWHL 230 70396 SMOKYHIL 230 1
70396 SMOKYHIL 230 70599 SMOKYHIL 345 T1	750.0	81.4		100.4	70311 PAWNEE 230 70545 BRICKCTR 230 1

When the proposed generation facility is interconnected at the 345-kV bus at Pawnee, in addition to the lines that would be overloaded when the Pawnee 230-kV bus is the POI, the 230/345-kV transformer at Smoky Hill and the 230-kV line from Buckley to Jewell are also slightly overloaded under contingency conditions. This is due to lower losses on the Customer's transmission at 345-kV. The overloads seen on the 230/345-kV transformer at Smoky Hill and the 230-kV line from Buckley to Jewell are minor and may be the result of computational error; therefore, they have been excluded as necessary network upgrades.

Voltage Criteria Violations

Interconnecting to the PSCo bulk transmission system involves the Customer adhering to certain interconnection requirements. These requirements are contained in the Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater than 20 MW (Guidelines). The Guidelines make reference to interconnection requirements from FERC Order 661A. FERC Order 661A describes the interconnection requirements for wind generation plants. In addition, PSCo System Operations conducts commissioning tests prior to the commercial in-service date for a Customer's facilities. Some of the requirements that the Customer must complete include the following:

1. A wind generating plant shall maintain a power factor within the range of 0.95 leading to 0.95 lagging, measured at the POI, if the Transmission Provider's System Impact Study shows that such a requirement is necessary to ensure safety or reliability.
2. The System Impact Study will investigate pertinent demand, dispatch, and outage scenarios based on the defined study area that includes the proposed POI. The study will conform to the NERC Transmission System Planning Performance Requirements (TPL standards).
3. The results of the System Impact Study (mentioned in Item 1 and 2 above) do not absolve the Customer from its responsibility to demonstrate to the satisfaction of PSCo System Operations prior to the commercial in-service date that it can safely operate within the required power factor and voltage ranges.
4. Reactive Power Control at the POI is the responsibility of the Customer. Additional Customer studies should be conducted by Customer to ensure that the facilities can meet the power factor control test and the voltage controller test when the facility is undergoing commissioning testing.
5. PSCo System Operations will require the Customer to perform operational tests prior to commercial operation that would verify that the equipment installed by the Customer meets operational requirements.
6. It is the responsibility of the Customer to determine what type of equipment (DVAR, added switched capacitors, SVC, reactors, etc.), the ratings (MVAR, voltage--34.5 kV or 230-kV), and the locations of those facilities that may be needed for acceptable performance during the commissioning testing.
7. PSCo requires the Customer to provide a single point of contact to coordinate compliance with the power factor and voltage regulation at the POI. The reactive flow at the end of 230-kV line near the POI will need to be controlled according to the Interconnection Guidelines

According to WECC/NERC criteria, it is necessary to maintain voltages at all buses in the system between 0.95 per unit to 1.05 per unit under operating conditions. In the Rocky Mountain Voltage Coordination Guidelines that were developed by the Voltage Coordination Guideline Subcommittee of the Colorado Coordinated Planning Group, the ideal voltage range for the 230-kV bus voltage at Pawnee is 1.03 – 1.04 per unit.

From the 2011 benchmark case, the voltage at the 230-kV bus at Pawnee is 1.028 per unit with Peetz Logan generation at 550 MW. The voltage at this bus decreases to 1.013 per unit when the new GI-2008-13 generation facility is connected to the PSCo system with the Customer's 230-kV transmission line and operating at full output. The voltage at the 345-kV bus at Pawnee (POI) is 1.011 per unit when the proposed facility is connected with the Customer's 345-kV transmission line. In order to restore the Pawnee bus voltages to the benchmark levels, a significant amount of switched capacitors, or other reactive power source, would need to be added. Similar results were observed for the 2015 summer case as shown in Table 3.

During periods of minimal wind generation, line charging associated with the 90-mile lightly-loaded Customer transmission line results in the power factor at the POI to be outside the range of 0.95 leading to 0.95 lagging. In addition, with a Customer 345-kV line, voltages on the wind farm will likely rise above 1.06 per unit. To restore the power factor at the POI to near unity and minimize the potential of high voltage on the wind farm, either 25 MVAR or 60 MVAR of switched reactors would be needed, dependent upon the Customer's transmission line voltage, as indicated in Table 3.

Table 3. Reactive Power Requirements

	2011 Case		2015 Case	
	POI - 230kV Pawnee	POI - 345kV Pawnee	POI - 230kV Pawnee	POI - 345kV Pawnee
Voltage at the POI kV bus in the benchmark case without GI-2008-13 (p.u.)	1.028	-	1.024	1.021
Voltage at the Pawnee 230 kV bus in the benchmark case without GI-2008-13 (p.u.)	1.028	1.028	1.024	1.024
Voltage at the POI in the case with maximum GI-2008-13 generation (p.u.)	1.013	1.011	1.012	1.010
Voltage at the Pawnee 230kV bus in the case with maximum GI-2008-13 generation (p.u.)	1.013	1.018	1.012	1.019
Reactive power drawn at the POI at maximum GI-2008-13 generation (MVAR)	141.3	39.1	141.0	38.8
Switched shunt capacitor size to maintain voltage at POI at full generation (MVAR)	230.0	170.0	210.0	100.0
Reactor size to maintain VAR neutrality at POI at 0 MW GI-2008-13 generation (MVAR)	-25.0	-60.0	-25.0	-60.0

The results of the steady state contingency analysis do not indicate high or low voltage violations or any voltage deviation criteria violations as a result of the studied contingencies.

It is the responsibility of the Customer to determine what type of equipment (CVAR, added switched capacitors, STATCOM, SVC, reactors, etc.), at what overall ratings (MVAR, voltage-34.5 kV, 230 kV, 345 kV), and at what locations (at the wind farm, near the POI) will be added to meet these reactive power control requirements. The voltage-tap settings on the main power transformers that connect the 34.5-kV system to the Customer's transmission line will impact the operating voltages and related reactive power capabilities and requirements for the GI-2008-13 facility. This should also be considered by the Customer in determining the final design equipment and parameters.

If the Customer advances the request to the system impact study phase, the results of the stability analysis may modify the nature of the reactive power support that may be required of the Customer for the project to meet relevant reliability criteria. For the system impact study, especially for the stability analysis portion, technical details of the collector system, transformers and transmission line will be necessary to proceed.

Network Resource (NR):

The results of this study indicate that the 400 MW GI-2008-13 generation project delivered to the Pawnee POI could result in the overloading of facilities in the PSCo regional transmission system. Therefore, the 400 MW NR value requested will require interconnection and Transmission Network Upgrades. After these upgrades are complete, the 400 MW generating facility could be considered a network resource with firm transmission capability for the entire output of the plant to be delivered to load.

Short Circuit Analysis

A short circuit study was conducted to determine if the fault currents (single line-to-ground or three-phase) exceeds the interrupt ratings of any circuit breakers at the Pawnee substation. The duty study compared the short-circuit model with the proposed new generation injected at the Pawnee substation and the addition of the Pawnee – Smoky Hills 345-kV line to a model without the generation and network upgrade, and identified which breakers are within 5% of their fault interruption rating as a result of the added generation. Per PSCo policy, these breakers would require replacement and would be categorized as network upgrades. The approximate fault currents at Pawnee with the addition of the GI-2008-13 400 MW wind facility are summarized in Table 4.

Table 4. Short-Circuit Study Results With the Proposed GI-2008-13

System Condition	Three-phase (amps)	Thevenin System Equivalent Impedance (R,X) (ohms)	Single-line-to-ground (amps)	Thevenin System Equivalent Impedance (R,X) (ohms)
Pawnee 345 kV Bus **After** to the Addition of GI-2008-13 and Network Upgrades	I_1=12364.6 I_2=I_0=0 I_A=I_B=I_C=12364.6	Z1(pos)= 0.85438,16.0868 Z2(neg)= 0.86823,16.1086 Z0(zero)= 0.98663,15.1175	I_1=I_2=4203.09 3I_0=12609.3 I_A=12609.3 I_B=I_C=0	Z1(pos)= 0.85438,16.0868 Z2(neg)= 0.86823,16.1086 Z0(zero)= 0.98663,15.1175

The results of the short-circuit analysis faulted at the Pawnee 345-kV bus show that none of the circuit breaker's fault interruption ratings at the Pawnee substation would be exceeded as a result of the new generation.

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 fault currents at the Pawnee substation are 12609.3 amps for a single-line to ground fault and 12364.6 amps for a three-phase fault. These values assume little to no fault current contribution from the proposed wind facility.

Costs Estimates and Assumptions

The estimated total cost for the required upgrades is approximately **$1,705,000.**

The estimated costs shown are (+/-30%) estimates in 2008 dollars. No escalation was applied. The costs are based upon typical construction costs for previously performed similar construction. These estimated costs include all applicable labor and overheads associated with the engineering, design, and construction of these new PSCo facilities. This estimate did not include the cost for any other Customer owned equipment and associated design and engineering.

This estimate does not include any network 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, including the required Pawnee – Smoky Hill 345-kV line, are included in the PSCo Capital Budget process and are assumed to be in-service by the commercial in-service date of the 400 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; Customer Funded Interconnection Facilities

Element	Description	Cost Est. Millions
PSCo's Pawnee 345kV Substation	Interconnect Customer at PSCo's Pawnee Substation. The new equipment includes a 345kV gang switch, bi-directional metering, relaying and associated equipment and material.	**$0.799**
	Transmission tie line into substation.	**$0.232**
	Customer Generator Communication to Lookout.	**$0.010**
	Load Frequency and Generation Control and Generator Witness Testing.	**$0.154**
	Siting and Land Rights for required easements, reports, permits and licenses.	**$0.010**
	Total Cost Estimate for Customer Interconnection Facilities	**$1.205**
Time Frame		**18 Months**

Table 6 PSCo Owned; PSCo Funded Interconnection Facilities

Element	Description	Cost
PSCo's Pawnee 345kV Substation	Interconnect Customer at PSCo's Pawnee 345kV Substation. New 345kV line termination requiring the following equipment: • one 345kV 40 kA, dead tank circuit breaker • one 345kV gang switch • electrical bus work • required steel and foundations • minor site work (station wiring, grounding)	**$0.500**
Time Frame		**4 Months**

Table 7 Total Project Cost

	Total Cost of Project	**$1.705**
Time Frame		**18 Months**

Assumptions

- The cost estimates provided are "scoping estimates" with an accuracy of +/- 30%.
- Estimates are based on 2009 dollars (no escalation applied) for the customer responsibility costs and on 2008 dollars for the PSCo responsibility costs.
- There is no contingency added to the estimates.
- AFUDC is included for network upgrades, excluded in delivery upgrades.
- Labor is estimated for straight time only – no overtime included.
- PSCo (or its Contractor) crews will perform all construction and wiring associated with PSCo owned and maintained facilities.
- Project feasibility and ISD is contingent upon the completion of the Pawnee – Smoky Hill 345 kV Project: A 345 kV transmission line that will be installed between Pawnee Substation and Smoky Hill Substation, proposed in accordance to SB07-100, with an approximate in service date of May 2013.
- Due to customer's transmission line length, dual power line carrier will be installed for relay communications.
- Addition of generation does not require any breakers to be replaced due to fault interruption rating.
- The Wind Site is not in PSCo's service territory. The local utility will provide station service power to the generator.
- The estimated time for design and construction of PSCo network upgrades for interconnection is at least 18 months and is completely independent of other queued projects and their respective ISD's.