Interconnection System Impact Study Report
Request # GI-2007-13
Restudy 2

250-MW Wind Powered Generation Interconnecting at Missile Site

PSCo Transmission Planning
December 11, 2009

A. Executive Summary

The purpose of the second System Impact Restudy was to determine the potential system impacts associated with interconnecting a 250-MW wind powered generation facility at Missile Site[1] using the Vestas V90 1.8-MW wind turbine generators. The second System Impact Restudy was conducted at the request of the Generation Developer due to the selection of a different manufacturer for the wind turbine generators. The first System Impact Restudy of GI-2007-13 that was completed on February 10, 2009 was conducted because the Generation Developer elected to reduce the size of the GI-2007-13 Project from 300 MW to 250 MW. The Generation Developer selected GE 1.5-MW machines for that 250-MW proposal. After the first restudy was completed, the Generation Developer elected to change the units to Vestas V90 1.8-MW wind turbine generators necessitating the second restudy.

The power flow results of the second System Impact Restudy with the Vestas units indicate that the proposed 250-MW facility could be considered a network resource provided planned network upgrades by PSCo are constructed and no other transmission upgrades by neighboring utilities are completed. The proposed PSCo network upgrades include the following:

- Replace the 1272-kcmil jumpers at the Daniels Park Substation to increase the Missile Site-Daniels Park 230 kV line rating to its 734 MVA thermal rating.
- Uprate the Pawnee-Ft.Lupton 230 kV line rating to at least 590 MVA.

Several lines in the Western Area Power Administration-Rocky Mountain Region (WAPA-RMR) Balancing Authority (Area 73) around Beaver Creek experience contingency overloads. The Generator Developer will need to resolve these issues with Tri-State. Tri-State has plans to construct transmission facilities that could address potential system criteria violations in the area. Tri-State is participating with WAPA-RMR to rebuild WAPA-RMR's existing Beaver Creek-Hoyt-Erie 115 kV line as a 230x115 kV double-circuit transmission line from Beaver Creek/Story to Erie. Tri-State would interconnect the proposed Erie-Story 230 kV transmission line to the Henry Lake 230-115 kV Substation that is presently served from PSCo's Cherokee-(Riverdale)-Ft.

[1] The proposed Point of Interconnection (POI) that would tap the Pawnee-Daniels Park 230kV line

Lupton-St. Vrain 230 kV line. The project is scheduled for completion in September 2010. A sensitivity study was conducted to assess the impact of these transmission upgrades. A contingency analysis was performed (using the power flow cases with the new Tri-State reinforcements) and it was determined that the addition of the new 230 kV lines in Area 73 decreases loading of several lines. No lines in PSCo's transmission system would be overloaded under single line contingencies if the planned Tri-State projects are built. **Therefore, no network upgrades on the PSCo system are required for this request, provided the planned transmission upgrades by Tri-State are completed in September 2010.** The study also demonstrated the benefit of PSCo's proposed Pawnee-Smoky Hill 345 kV transmission line[2] that has a scheduled in-service date of June 2013.

The Intermountain Rural Electric Association (IREA) system was monitored in the power flow analysis. The analysis identified a potential contingency overload due to addition of the 250-MW wind generation facility at Missile Site. The Smoky Hill-Peakview 115 kV line experienced a 109.8% contingency overload (of its 133.5 MVA line rating) in the base case (prior to the addition of the 250-MW wind farm at Missile Site) for an outage of the Smoky Hill-Murphy Creek 230 kV line. This contingency overload increased to 114.1% after the addition of the 250-MW wind farm at Missile Site. Adding the Tri-State transmission enhancements further increases the contingency overload to 115.1% of its 133.5 MVA line rating for an outage of the Smoky Hill-Murphy Creek 230 kV line. The addition of PSCo's Pawnee-Smoky Hill 345 kV line does not mitigate the criteria violation. **Any additional reinforcements to alleviate the overload on the Smoky Hill-Peakview 115 kV line will need to be discussed with IREA.**

The transient stability study determined that the system remains stable during and after each contingency studied and all system oscillations display positive damping that decrease quickly. However, the study determined that certain criteria violations could occur when the 250-MW facility is at maximum capacity. The following issues were observed:

- Four contingencies result in the voltage at the GI-2007-13 wind farm exceeding 1.20 per unit during initial recovery, causing the wind turbines to trip.
- The final voltage at the 230-kV bus at the POI is also 5% greater than the pre-fault voltage for these contingencies.
- For a three-phase fault on the Pawnee-Story 230 kV transmission line near Pawnee and subsequent tripping of the line to clear the fault, the voltage dip at the Pawnee 230 kV bus after initial recovery is greater than the 25% of its pre-fault voltage.

[2] The Pawnee-Smoky Hill 345kV transmission line is a Senate Bill 100 Project. The Senate Bill 100 requires PSCo to:
a) Designate energy resource zones
b) Develop plans for the construction or expansion of transmission facilities necessary to deliver electric power consistent with the timing of the development of beneficial energy resources located in or near such zones.
c) Submit proposed plans, designations, and applications for Certificates of Public Convenience and Necessity (CPCN) to the Colorado Public Utility Commission for review.

None of these issues were observed in the 2013 case. Because these issues were not observed in the 2013 case (that includes the Pawnee-Smoky Hill 345 kV line) and were observed in the 2010 case (that does not include the Pawnee-Smoky Hill 345 kV line), the report concludes the following:

The addition of the 345-kV line from Pawnee to Smoky Hill is needed to mitigate the observed criteria violations associated with the addition of the proposed 250-MW facility.

The restudy also recommends the addition of reactive support at the Missile Site 230 kV POI and at the proposed wind generation facility to meet PSCo's Planning Guidelines for Wind Generator Interconnection Studies. A 110-MVAR capacitor close to the Missile Site 230 kV POI was suggested by the Generation Developer; however, for the loss of the 230-kV line from Pawnee to Missile Site or Missile Site to Daniels Park, the voltage at Missile Site (POI) and the buses at the wind generation facility rise above 1.10 per unit. **This result suggested that it would be preferable from a reliability standpoint, to connect 40-MVAR of capacitors near the POI and connect 20-MVAR to each of the two 34.5-kV buses at the generation facility for a total of 80-MVAR, instead of connecting all capacitors close to the POI.**

The studies showed that the voltage deviation at the Missile Site 230 kV POI for either of the single line contingencies discussed earlier is still greater than 5% of the pre-fault voltage. **For operation with full output from GI-2007-13, the Generation Developer will need to install some form of dynamic reactive support for operation in the 2010 to 2013 time period to keep the voltage at Missile Site within criteria**. **A more detailed study of the reactive requirements at the Generation Developer's site and at the Missile Site 230 kV POI is recommended.**

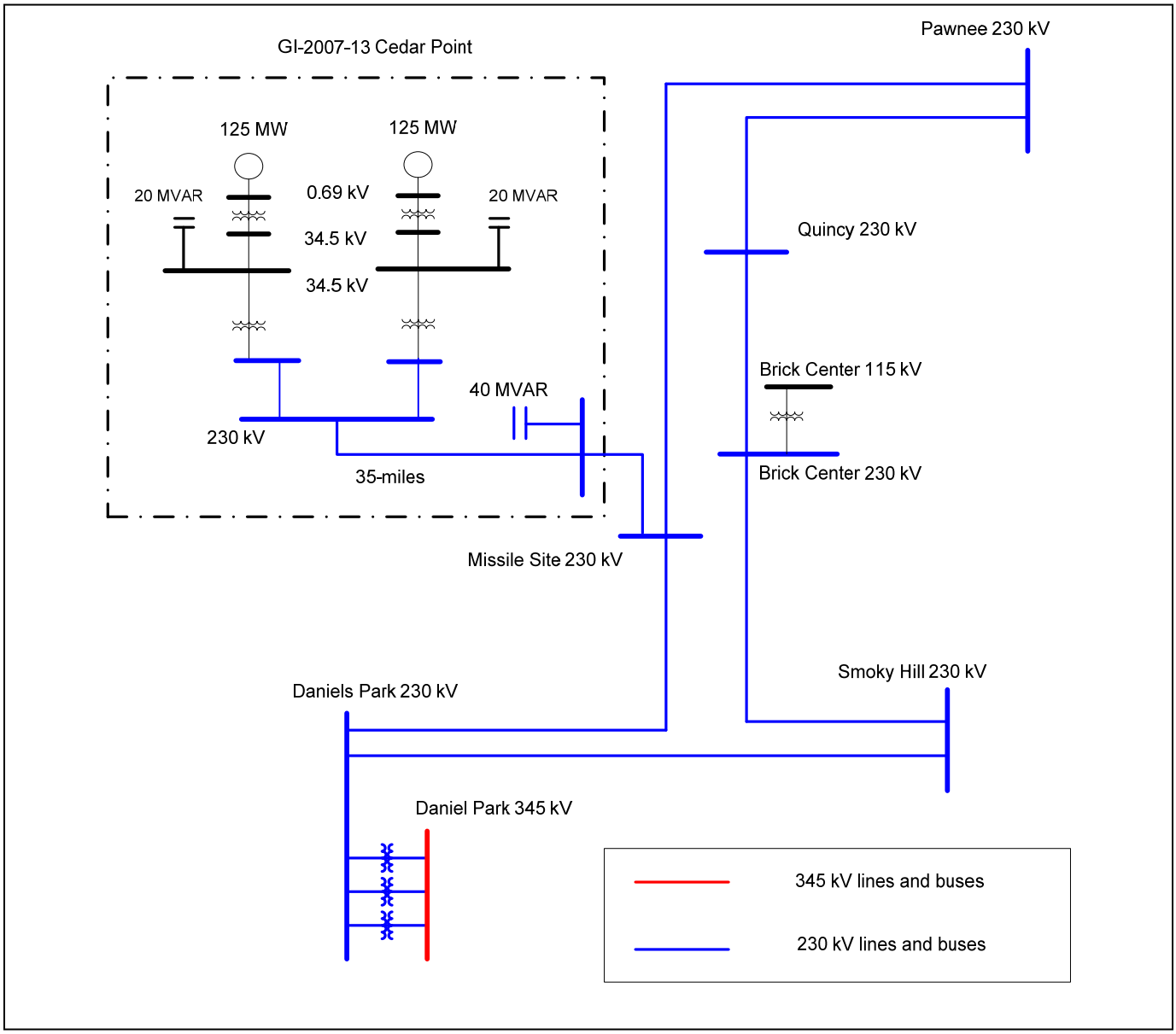
B. Introduction

The first System Impact Restudy of GI-2007-13 was completed on February 10, 2009. It was conducted because the Generation Developer elected to reduce the size of the GI-2007-13 Project from 300 MW to 250 MW. The Generation Developer selected GE 1.5-MW machines for that 250-MW proposal.

The second System Impact Restudy of GI-2007-13 was conducted at the request of the Generation Developer due to its selection of a different manufacturer for the wind turbine generators. The Generator Developer requested that the wind turbines for this project be changed from GE 1.5-MW wind turbine generators to Vestas V90 1.8-MW wind turbine generators. Therefore, the request was re-studied with the new data. The proposed facility is connected to the Point of Interconnection (a tap on the 230-kV line from Pawnee to Daniels Park at Missile Site) through a radial 230-kV 35-mile line. This request was evaluated as a stand-alone project with no other higher queued projects modeled.

A conceptual one-line of the proposed interconnection at Missile Site is shown below in Figure 1.

Figure 1. Diagram of the GI-2007-13 Interconnection at Missile Site 230 kV



C. Study Scope and Analysis

The second System Impact Restudy evaluated the transmission impacts associated with the proposed interconnection of 250-MW to the POI and schedule to native PSCo loads. The restudy involved both steady state power flow analysis and transient stability analysis. The following WECC/NERC criteria and internal company criteria are used for the power flow and transient stability analysis:

- 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 (Tri-State) and IREA. PSCo will provide Tri-State and IREA with copies of the System Impact Restudy 2 Report.

D. Power Flow Study Models

Western Electricity Coordinating Council (WECC) coordinates the preparation of regional power flow cases for transmission planning purposes. PSCo transmission developed a base case for the 2010 heavy summer peak load as a part of their annual five-year project identification process, from WECC approved models and modified for PSCo-approved projects and topology changes. In the 2010 case, the following generators in Area 70 (PSCo Transmission) were re-dispatched to simulate high north-to-south stressed system conditions.

- The generation at Peetz Logan was set to 575 MW, of which about 540 MW is delivered at its Point of Interconnection.
- The generation at the Pawnee and Manchief units was set close to maximum.
- This increase in generation was accommodated by decreasing generation at the Comanche units.
- The DC tie at Lamar has been set to export 200 MW.
- TOT3 flow in this case is 1314 MW.

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. The proposed wind generation facility would consist of 139 Vestas 1.8-MW wind turbines with a nameplate capacity of 250.2 MW. The Vestas wind turbine generators were modeled with a terminal voltage of 690 volts. These wind turbines are grouped in twelve (12) circuits, with the turbines in each circuit connected through a 34.5-kV collector system. The circuits are equally distributed among the two 230-kV substations at the generation facility. The circuits are connected through one 34.5/230-kV transformer at each substation. The generation facility is connected to the POI through a 35-mile 230-kV overhead line. A single circuit 954 kcmil Cardinal conductor is used for the line. Per the Generation Developer's diagram, a 9-MVAR reactor is connected to each 34.5-kV substation bus and a 145-MVAR capacitor is connected close to the POI to provide reactive support. The new generation at Missile Site was dispatched by increasing the generation at the proposed facility and decreasing the corresponding amount of generation at the Comanche Units 2 and 3.

E. 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-RMR). 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.

F. Power Flow Study Results

1. Power Flow Study Results for the 2010 Case

The results of the single line contingency analysis for the 2010 power flow cases with and without the proposed generation facility were compared. The comparison shown in Table 1 indicates that several lines in Areas 70 (PSCo) and 73 (WAPA) are adversely impacted by the addition of GI-2007-13.

Table 1. AC Contingency Analysis Results for GI-2007-13 for the 2010 Case

** From Bus ** ** To Bus ** CKT	Branch Rating	Loading as % of Branch Rating		Contingency	FAC-009 Rating
		Bench-mark	With GI-2007-13		
70107 CHEROKEE 230 70324 LACOMBE 230 1	444.0	100.0	101.8	70266 LOOKOUT 230 70480 WESTPS 230 1	859
70139 DANIELPK 230 70630 MISSILE SITE 230 1	637.0	87.0	110.9	70311 PAWNEE 230 70545 BRICKCTR 230 1	
70192 FTLUPTON 230 70311 PAWNEE 230 1	478.0	107.0	122.6	70139 DANIELPK 230 70630 MISSILE SITE 230 1	518
70311 PAWNEE 230 70545 BRICKCTR 230 1	637.0	98.0	110.0	70139 DANIELPK 230 70630 MISSILE SITE 230 1	734
70395 SMOKYHIL 115 70416 STRASBRG 115 1	144.6	115.4	122.2	70343 QUINCY 230 70545 BRICKCTR 230 1	
70545 BRICKCTR 230 70546 BRICKCTR 115 T1	200.0	101.1	105.7	70343 QUINCY 230 70545 BRICKCTR 230 1	
73015 B.CK TRI 115 73016 B.CK TRI 230 1	224.0	117.5	123.9	70397 B.CK PS 115 73020 BEAVERCK 115 1	
73015 B.CK TRI 115 73020 BEAVERCK 115 1	200.0	125.3	131.9	70397 B.CK PS 115 73020 BEAVERCK 115 1	

The contingency analysis for the generation addition study case for Area 70 (PSCo system) demonstrates that the Daniels Park-Missile Site 230 kV line could experience a significant contingency overloaded (110.9% of its 637 MVA rating) due to the addition of the 250-MW wind generation facility at Missile Site. The rating of Missile Site-Daniels Park 230 kV line is 637 MVA although the thermal rating of the line based on its conductor is 734 MVA. The rating of this circuit is limited by the 1272 kcmil jumpers between the breakers and the line traps at the Daniels Park Substation and replacing these jumpers with those of a higher rating would mitigate the contingency overload.

The 230-kV lines from Cherokee to Lacombe and from Pawnee to Brick Center demonstrated contingency overloads based on the ratings for each line in the study case. However, the thermal ratings of these lines have been subsequently uprated[3] from 444 MVA to 859 MVA and from 637 MVA to 734 MVA, respectively as per studies undertaken by PSCo's Substation and Transmission Engineering groups. These lines are no longer considered overloaded with the revised ratings. The rating of the 230-kV line from Pawnee to Ft. Lupton has also been revised. However, this line would still be overloaded despite the revised ratings. Several lines in Area 73 around Beaver Creek display contingency overloads.

Tri-State plans to construct a new 230-kV transmission line[4] between Henry Lake and Story. They will also be building a new 230 kV Sipres bus that will be connected to Erie and Henry Lake. Therefore, a contingency analysis was performed for the power flow cases with the new TSGT reinforcements and the results are shown in Table 3. It is seen that the addition of the new 230-kV lines in Area 73 decreases loading of several lines. With the Tri-State additions, no lines in Area 70 are overloaded under single line contingencies. Therefore, no network upgrades would be required for this request with those facilities in operation.

[3] Transmission Facility Equipment Rating FAC-009 list.

[4] Tri-State plans to interconnect the proposed Erie-Story 230 kV transmission line to the Henry Lake 230-115 kV Substation that is presently served from PSCo's Cherokee-(Riverdale)-Ft. Lupton-St. Vrain 230 kV line. Tri-State is participating with Western Area Power Administration (WAPA) to rebuild WAPA's existing Beaver Creek-Hoyt-Erie 115 kV line as a 230x115 kV double-circuit transmission line from Beaver Creek/Story to Erie.

Table 2. AC Contingency Analysis for GI-2007-13 for the 2010 Case with Tri-State Upgrades

** From bus ** ** To bus ** CKT	Branch Rating	Loading as % of Branch Rating		Contingency
		Bench-mark	With GI-2007-13	
70122 COMANCHE 230 70459 WALSENBG 230 1	159.0	142.5	146.6	70336 PUEB-TAP 115 70456 W.STATON 115 1
70336 PUEB-TAP 115 70412 STEM BCH 115 1	77.0	201.7	208.6	70122 COMANCHE 230 70459 WALSENBG 230 1
70336 PUEB-TAP 115 70456 W.STATON 115 1	95.0	216.0	221.8	70122 COMANCHE 230 70459 WALSENBG 230 1
73015 B.CK TRI 115 73016 B.CK TRI 230 1	224.0	98.7	101.2	70397 B.CK PS 115 73020 BEAVERCK 115 1

2. Power Flow Study Results for the 2013 Case

This request was also analyzed using a 2013 heavy summer base case. The Pawnee-Smoky Hill 345 kV line is a Senate Bill 100 Project that is expected to be in-service in June of 2013 and has a significant impact on reliability in the study area. The WECC 2013 HS power flow base case was modified to simulate high north-to-south stressed system conditions in Area 70. The flow across TOT3 in this case is 1193 MW. The 230-kV line from Pawnee to Daniel Park was tapped at Missile Site to connect the 250-MW wind powered generation facility and the Pawnee-Smoky Hill 345 kV transmission line was added to the case. A contingency analysis was performed for the 2013 cases without and with the proposed Tri-State upgrades and the results are shown in Table 3.

Table 3. Contingency Analysis Results for GI-2007-13 for the 2013 Case with the Pawnee-Smoky Hill 345 kV Line and Without Tri-State Facility Additions

** From Bus ** ** To Bus ** CKT	Branch Rating	Loading as % of Branch Rating			Contingency	FAC-009 Rating
		Bench-mark	Without Tri-State Upgrades	With Tri-State Upgrades		
70067 BUCKLY12 230 70396 SMOKYHIL 230 1	435	96.9	100.6	101.4	70283 MEADOWHL 230 70396 SMOKYHIL 230 1	490
70395 SMOKYHIL 115 70521 PEAKVIEW 115 1	133.5	109.8	114.1	115.1	70396 SMOKYHIL 230 70551 MURPHY 230 1	
73192 STORY 230 73537 BEAVERCK 230 1	413	100.1	110.0		70396 SMOKYHIL 230 70599 SMOKYHIL 345 T1	

The Buckley-Smoky Hill 230 kV line contingency overload increases slightly from 100.6% to 101.4% of its 435 MVA rating in the base case after the addition of the Tri-State upgrades. However, the line rating has been increased to 490 MVA and the contingency overload is mitigated with this line rating increase. The 115-kV IREA line from Smoky Hill-Peakview 115 kV line experiences a contingency overload increase from 114.1% to 115.5% and this potential overload issue will need to be discussed with IREA. The contingency overload of Tri-State's Story-Beaver Creek 230 kV line is completely resolved after the addition of Tri-State's proposed transmission enhancements. would be overloaded under contingencies. Any reinforcements to alleviate the overload on the Smoky Hill- Peakview line will need to be discussed with IREA.

3. Sensitivity Analysis for Flows Across TOT3 for the 2010 Case

TOT3 is a transmission interface along the Colorado – Wyoming border. One of the lines along this interface is the 345-kV line from LRS to Story. Therefore, the flow across TOT3 influences the total amount of power that can be injected around Pawnee without causing overloads. The flow across TOT 3 in the 2010 benchmark case is around 1,314 MW. This is relatively high, as the flow across it is usually around 1,100 MW. To determine how much influence the TOT3 flow level has on the identified heavily loaded circuits, the flow across TOT3 was lowered to 1,090 MW in the benchmark case and a contingency analysis was performed. The result of the contingency analysis is shown in Table 4.

Table 4. Contingency Analysis Results for GI-2007-13 for the 2010 case with TOT3 = 1,090 MW

** From Bus ** ** To Bus ** CKT	Branch Rating	Loading as % of Branch Rating		Contingency	FAC-009 Rating
		Benchmark	With GI-2007-13		
70139 DANIELPK 230 70630 MISSILE SITE 230 1	637.0	N/A	104.5	70311 PAWNEE 230 70545 BRICKCTR 230 1	
70192 FTLUPTON 230 70311 PAWNEE 230 1	478.0	N/A	116.5	70139 DANIELPK 230 70630 MISSILE SITE 230 1	518
70311 PAWNEE 230 70545 BRICKCTR 230 1	637.0	N/A	103.8	70139 DANIELPK 230 70630 MISSILE SITE 230 1	734
70395 SMOKYHIL 115 70416 STRASBRG 115 1	144.6	108.9	115.1	70343 QUINCY 230 70545 BRICKCTR 230 1	
70545 BRICKCTR 230 70546 BRICKCTR 115 T1	200.0	97.0	101.3	70343 QUINCY 230 70545 BRICKCTR 230 1	
73015 B.CK TRI 115 73016 B.CK TRI 230 1	224.0	113.7	120.0	70397 B.CK PS 115 73020 BEAVERCK 115 1	
73015 B.CK TRI 115 73020 BEAVERCK 115 1	200.0	120.7	127.2	70397 B.CK PS 115 73020 BEAVERCK 115 1	

When Table 4 is compared with Table 1, it is seen that the same elements are overloaded in both cases. However, the loading on the lines decreases when the flow across TOT 3 is lowered. The proposed additions by TSGT will similarly resolve these overloads

4. Voltage Criteria Violations

Interconnecting to the PSCo bulk transmission system involves the Generation Developer 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's Transmission Planning Group has developed a document titled Planning Guidelines for Wind Generator Interconnection Studies that contains guidelines for wind generation interconnections. Some of the guidelines 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 Point Of Interconnection shall be maintained in the ideal voltage range for the appropriate Colorado region and bus type (regulating[5] or non-regulating) as determined in the Rocky Mountain Area Voltage Coordination Guidelines[6]. The 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 should not 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 generation units may need to be mitigated by the Generation Developer if system studies demonstrate that the proposed wind generating facility causes nearby generating units to generate or absorb reactive power for voltage control. It is understood that sufficient power reserve must be maintained on existing generating units to allow them to 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 Generation Developer Loads.
6. PSCo System Operations will require the Generation Developer to perform operational tests prior to commercial operation that would verify that the equipment installed by the Generation Developer meets operational requirements.
7. It is the responsibility of the Generation Developer 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.
8. PSCo requires the Generation Developer to provide a single point of contact to coordinate compliance with the power factor and voltage regulation at the POI. The reactive flow at the end of the line near the POI will need to be controlled according to the Interconnection Guidelines.

[5] 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, synchronous condensers, switchable capacitors, switchable reactors, and load tap changing transformers.

[6] The Voltage Coordination Guidelines Subcommittee (VCGS) of the Colorado Coordinated Planning Group developed the guidelines. The subcommittee consisted of representatives from major Colorado utilities including Colorado Springs Utilities, Platte River Power Authority, Tri-State Generation and Transmission, Public Service Company of Colorado, and Western Area Power Administration-Rocky Mountain Region. Other major utilities outside of Colorado were also involved in the development of these guidelines.

The second guideline listed above makes reference to the Rocky Mountain Voltage Coordination Guidelines that were developed by the Voltage Coordination Guideline Subcommittee of the Colorado Coordinated Planning Group. The guidelines (see Region 7 - Northeast Colorado) define the ideal voltage range for the 230-kV bus voltage at Pawnee as between 1.03 and 1.04 per unit. For 230-kV regulating buses in Region 7 (like the Pawnee 230 kV bus), the ideal voltage range is between 1.02 and 1.03 p.u. The system intact voltage at the Pawnee 230 kV bus in the 2010 benchmark case is 1.024 per unit while the system intact voltage at the Pawnee 230 kV bus in the 2013 benchmark case is 1.029 per unit. Both voltages are within the ideal voltage range for 230-kV buses in Region 7; however, they are outside the target voltage range for Pawnee 230 kV(1.03 to 1.04 p.u.).

The Vestas V90 units provide no reactive support (power factor = 1.0); therefore, when 250 MW of energy is injected at the 230-kV bus at Missile Site in the 2010 case, the voltage at the POI is 0.956 per unit and the Pawnee 230 kV voltage falls to 1.019 per unit. The voltage levels at several buses at the generation facility site fall to 0.90 per unit. Therefore, capacitors or other reactive support are required to maintain the voltage at Pawnee and to keep the voltage at the POI at or above 1.00 per unit. A 110-MVAR capacitor close to the POI suggested by the Generation Developer brings the voltage at the POI to 1.004 per unit, the voltage levels at the buses on the wind farm to around 0.95 per unit, and the voltage at the 230-kV bus at Pawnee to 1.025 per unit. The power factor at the POI remains within the range of 0.95 leading to 0.95 lagging. However, for the loss of the 230-kV line from Pawnee to Missile Site or Missile Site to Daniels Park, the voltage at Missile Site (POI) and the buses at the wind generation facility rise above 1.10 per unit.

The results described above suggest that it would be preferable from a reliability standpoint, to connect 40-MVAR of capacitors near the POI and connect 20-MVAR to each of the two 34.5-kV buses at the generation facility for a total of 80-MVAR, instead of connecting all capacitors close to the POI. Unfortunately, the studies show that the voltage deviation at the POI for either of the single line contingencies discussed earlier is still greater than 5% of the pre-fault voltage. Therefore, some kind of dynamic reactive support may be required to keep voltage at the POI within criteria.

In the 2013 summer case with GI-2007-13, only a 40-MVAR capacitor needs to be connected close to the POI to keep the voltage at the POI above 1.0 per unit. No voltage violations were observed for any single line contingency close to the POI in this case.

The Generation Developer has proposed 9-MVAR reactors at each 34.5-kV substation bus at the generation facility. In the 2010 case, when the generation for the GI-2007-13 Project is offline or near minimum generation levels, the reactors keep the voltage at the POI at 1.008 per unit and the connection remains basically VAR neutral. The voltage at the 230-kV bus at Pawnee is 1.024 per unit. Therefore, the reactors provide adequate reactive support when the proposed generation is offline or at low generation levels. The 18-MVAR of reactors are sufficient even in the 2013 case.

G. Dynamic Analysis

The re-study of the transient stability analysis determines the response of the transmission system to system disturbances such as the occurrences of faults, tripping of generator units, tripping of transmission lines or tripping of loads in the area around the POI. These studies evaluate generator frequency, generator rotor angles, bus voltages and power flows before, during and after a disturbance to determine if the system remains stable after the disturbance. In addition FERC 661A requires the wind powered generators to remain online during voltage disturbance up to the time periods and voltage levels set for Low Voltage Ride-Through (LVRT) capability standard.

Transient stability analysis was performed for a number of three-phase faults near the CGI-2007-13 POI, including Pawnee, Missile Site and Daniel Park. Normal fault clearing times of 5 cycles for 230-kV facilities and 4 cycles for 345-kV facilities were used in this study. The 575-MW generation at Peetz Logan was modeled as five equivalent generators, reflecting the types of wind turbines installed at this site along with the equivalent feeder feeder impedances. GI-2007-13 was modeled at 0.69-kV, with the Vestas V90 turbines connected through generator step-up transformers to 34.5-kV. The 34.5-kV collector system at the GI-2007-13 site consists of 12 circuits connected to two 34.5-kV substation buses. Two of these circuits were represented in detail, while the turbines for the other circuits were represented by a composite generator connected to feeders with equivalent impedance for each circuit. The wind farm is connected to the 230-kV bus at Missile Site through a 35-mile transmission line. In the 2010 case, a 20-MVAR capacitor was connected at each of the 34.5-kV substation buses and a 40-MVAR capacitor was connected close to the POI. The transmission reinforcements proposed by TSGT were included in the power flow cases for this analysis.

Most of the system disturbances were three-phase faults by the indicated locations, shown in Table 5. For each of these contingencies, a three-phase fault was applied for 5 cycles and appropriate action was taken to clear the fault. This procedure was done for both cases with and without the proposed generation in the 2010 case. Stability analysis was also performed for the 2013 case with the 345-kV line from Pawnee to Smoky Hill. For two contingencies the sudden loss of generation without a fault was also studied.

Table 5. Results of Transient Stability Analysis

Num	Fault Location	Action	Benchmark cases 2010 and 2013	With generation at the GI-2007-13 Site 2010 case	With generation at the GI-2007-13 Site 2013 case
1	Pawnee 230	Trip Pawnee - Daniel Park 230 KV	stable, no viol	-	-
2	Pawnee 230	Trip Pawnee - Ft. Lupton 230 KV	stable, no viol	stable, no viol	stable, no viol
3	Pawnee 230	Trip Pawnee – Brick Ctr 230 KV	stable, no viol	stable, no viol	stable, no viol
4	Daniel Park 230	Trip Pawnee - Daniel Park 230 KV	stable, no viol	-	
5	Ft.Lupton 230	Trip Pawnee - Ft. Lupton 230 KV	stable, no viol	stable, no viol	stable, no viol
6	Pawnee 230	Trip Pawnee 22/230 KV Transformer Drop Pawnee Unit G1	stable, no viol	stable, no viol	stable, no viol
7	Daniel Park 230	Trip Daniel Park 230/345 KV ckt 1	stable, no viol	stable, no viol	stable, no viol
8	Pawnee 230	Trip Pawnee - Story 230 KV	stable, no viol	max voltage dip > 25% Vpre-fault	stable, no viol
9	-	Drop Pawnee Unit G1	stable, no viol	stable, no viol	stable, no viol
10	Pawnee 230	Trip Pawnee – Pawnee-PtzCap 230 KV Trip PtzCap -Peetz Logan 230 kV	stable, no viol	stable, no viol	stable, no viol
11	-	Trip Pawnee - PtzCap 230 KV Trip PtzCap - Peetz Logan 230 KV	stable, no viol	stable, no viol	stable, no viol
12	Story 230	Trip Pawnee - Story 230 KV	stable, no viol	stable, no viol	stable, no viol
13	CP 34KV 1 34.5	Trip GI-2007-13 Site 34.5/230kV Transformer	-	stable, no viol	stable, no viol
14	CP_SUB2 230	Trip CP230SUB1- CP230SUB2 230 KV	-	stable, no viol	stable, no viol
15	Missile Site	Trip Missile Site - CP230SUB2 230 KV	-	stable, no viol	stable, no viol
16	Missile Site	Trip Missile Site - Daniel Park 230 KV	-	final ΔV>5% at POI, wind turbines trip	stable, no viol
17	Missile Site	Trip Missile Site - Pawnee 230 KV	-	final ΔV>5% at POI, wind turbines trip	stable, no viol
18	Pawnee 230	Trip Pawnee - Missile Site 230 KV	-	final ΔV>5% at POI, wind turbines trip	stable, no viol
19	Daniel Park 230	Trip Missile Site- Daniel Park 230 KV	-	final ΔV>5% at POI, wind turbines trip	stable, no viol
20	Pawnee 345	Trip Pawnee-Smoky Hill 345 kV	-	-	stable, no viol
21	Smoky Hill 345	Trip Pawnee-Smoky Hill 345 kV	-	-	stable, no viol

The Vestas V90 model VCUS version 6.0.2 was used for wind turbines at GI-2007-13. When a three-phase fault was applied at Missile Site, the dynamic solution did not converge for the duration of the fault and spikes were observed in the plots of various generator parameters. However, no issues were seen after the fault was cleared. This was conveyed to Vestas and they suggested a modification to the "DYRE file" by changing the current injection threshold during a fault from 0.5 per unit to 0.1 per unit for the VWLVRT user-model. This resolved the issues observed.

The results of the re-study for the 2010 case indicate that the system remains stable during and after each contingency studied and all system oscillations damp out quickly. However, for contingencies 16, 17, 18 and 19 the voltage at the GI-2007-13 wind farm exceeds 1.2 per unit during initial recovery, causing the wind turbines to trip. The final

voltage at the 230-kV bus at POI is also greater than 5% of the pre-fault voltage for these contingencies. For the loss of the 230-kV line from Pawnee to Story for a fault at the Pawnee 230 kV bus (contingency 8), it is seen that the voltage dip at the Pawnee 230 kV bus after initial recovery is greater than the 25% of its pre-fault voltage. None of these issues are observed in the 2013 case. This shows that the addition of the 345-kV line from Pawnee to Smoky Hill enables the regional transmission system to operate within reliability criteria after severe disturbances.

Dynamic Reactive Support

Since the 345-kV line from Pawnee to Smoky Hill will not be in operation before the summer of 2013, some kind of dynamic reactive support is required from 2010 to 2013. For this study, we have assumed that the dynamic reactive support would be in the form of DVAR units, but the Generation Developer could consider other options. For this study, the DVAR system was connected close to the POI, in addition to the 80-MVAR of switched capacitors connected at the wind farm. The DVAR was set to control the voltage at the POI to 1.00 per unit. It was seen that a 16-MVAR DVAR system connected close to the POI keeps the final voltage deviation at the POI and other nearby buses in the PSCo system within 5% of the pre-fault voltage. It also decreases the voltage dip at Pawnee 230 kV for the loss of the 230-kV line from Pawnee to Story. However, the voltage at Pawnee still violates criteria. Decreasing the generation at the Manchief units to 240 MW (from 280 MW) and with the DVAR system, the voltage dip at Pawnee is just within criteria.

Tripping the Generation Developer's capacitor close to the POI for the loss of the 230-kV line from Missile Site to Pawnee or Missile Site to Daniels Park, prevents high voltage at the POI. However, it does not address the criteria violation observed at Pawnee for the loss of the Pawnee-Story 230 kV line.

Dynamic Analysis with GE Turbines

The previous re-study for this request used GE 1.5-MW wind turbines at the GI-2007-13 Site while the generation at Peetz Logan was at 400-MW. This request was analyzed with the old configuration for GI-2007-13, but with 575 MW at Peetz Logan for the 2010 summer case. Since the GE units provide some reactive support (power factor between 0.95 leading to 0.95 lagging), only 30-MVAR of capacitors need to be connected close to the POI to keep the voltage at the POI above 1.0 per unit. Dynamic transient analysis was performed for the same contingencies discussed above for both the 2010 and 2013 system configurations. The system remained stable for all the contingencies studied. All system oscillations were damped quickly and all expected generation remained online. No WECC/NERC criteria violations were observed in any case with the GE turbines.