Interconnection Feasibility & System Impact Study Report
Request # GI-2012-5 and GI-2014-1
Final Report

300 MW Wind Generating Facility
Missile Site 230 kV Station, Colorado

Public Service Company of Colorado
Transmission Planning
August 28, 2014

Executive Summary

Public Service Company of Colorado (PSCo) received two interconnection requests on January 3, 2014 that consisted of a new request GI-2014-1 (100 MW) and a revised request GI-2012-5 (200 MW), resulting in a combined request for aggregate 300 MW wind generating facility to be located in Lincoln County, Colorado. The point of interconnection (POI) requested for the combined GI-2012-5 & GI-2014-1 request is the 230 kV bus within PSCo's Missile Site station.

The proposed 300 MW generating facility will consist of 168 nos. of GE 1.7-100 wind turbine generators (WTG) – 112 for GI-2012-5 request and 56 for GI-2014-1 request. Each WTG is rated 1.79 MW and equipped with a 0.69/34.5 kV transformer. The WTG's will be grouped together by a 34.5 kV collector system which, in turn, will connect to a 34.5/230kV substation. This substation will connect to the POI using a customer-owned 59.4 miles long 230 kV radial transmission line.

The commercial operation date (COD) requested for the generating facility is January, 2016. Based on it, the assumed back-feed date is October, 2015. The request is to be studied as both Network Resource Interconnection Service (NRIS) and Energy Resource Interconnection Service (ERIS).

The purpose of the Feasibility & System Impact Study is to determine the network upgrades required, if any, in PSCo's interconnected transmission system for delivery of the 300 MW new generation injected at the Missile Site 230 kV bus to the PSCo network load, that is, for 300 MW NRIS. The Feasibility & System Impact Study was performed using a 2016 heavy summer (2016HS) power flow base case. The study consisted of steady state power flow, dynamic stability and short-circuit analyses for the Benchmark case (Before GI) and the Study case (After GI).

The stability and short circuit results did not identify any adverse system impacts due to the proposed generator interconnection. However, the power flow analysis results indicate that the existing 345/230 kV transformation capacity at Smoky Hill is a thermal constraint for the additional 300 MW injection during the single contingency outage of any one of the two transformers. Further, the Clark – Jordan 230 kV (underground) line

is also a thermal constraint during several single contingency outages, the worst overload resulting from the single contingency outage of Smoky Hill – Tollgate – Leetsdale 230 kV line. Potential mitigations to these thermal constraints would require transmission reinforcements consisting of the addition of a third 345/230 kV, 560 MVA auto-transformer at Smoky Hill and the replacement of the Clark-Jordan 230 kV underground cable – but neither of these are stand-alone planned projects in PSCo's five-year planning horizon. PSCo evaluated the constructability of reinforcing the Clark-Jordan 230 kV underground line and concluded that it is not a preferred alternative to pursue further as a planned project. Similarly, adding a third auto-transformer at Smoky Hill was determined to be infeasible as a planned project due to substation expansion constraints. Instead, the proposed Pawnee – Daniels Park 345 kV project♠ submitted by PSCo for approval to the Colorado Public Utility Commission (PUC), is effective in mitigating both thermal constraints.

This is because the Pawnee – Daniels Park project consists of installing a 345/230 kV auto-transformer at a new Harvest Mile substation, which is effectively the same as addition of a third auto at Smoky Hill, and hence it alleviates the 345/230 kV transformation capacity constraint at Smoky Hill (see Table A.2). The new Smoky Hill (Harvest Mile) – Daniels Park 345 kV line included in the Pawnee – Daniels Park project alleviates the thermal overload on the Clark – Jordan 230 kV line (see Table A.3), which is a more viable solution compared to the replacement of the underground cable that has significant constructability challenges. Additionally, it is evident from Table A.3 results that the new Smoky Hill (Harvest Mile) – Daniels Park 345 kV line also alleviates the Smoky Hill 345/230 kV transformation capacity constraint, although the mitigation achieved is smaller compared to installing a new auto-transformer at Harvest Mile substation. The combined mitigation effect realized from both these network upgrades (Harvest Mile auto plus Smoky Hill – Daniels Park 345 kV line) is provided in Table A.4.

Cost estimates for the entire Pawnee – Daniels Park 345 kV project are provided in Table 3 – Network Upgrades for Delivery. Since the earliest in-service date of the Pawnee – Daniels Park 345 kV project is estimated to be in 2019, the GI-2012-5 & GI-2014-1 interconnection may not achieve 300 MW NRIS until the Smoky Hill (Harvest Mile) – Daniels Park 345 kV line portion of the project is in service.
Prior to the 2019 in-service date of the Pawnee – Daniels Park 345 kV project, GI-2012-5 & GI-2014-1 may be interconnected as ERIS♣ to deliver its output using the existing firm or non-firm transmission capacity on an "as available" basis.

♠ More information at: http://www.sb100transmission.com/projects/pawnee-daniels-park/index.asp

♣ Energy Resource Interconnection Service allows Interconnection Customer to connect the Large Generating Facility to the Transmission System and be eligible to deliver the Large Generating Facility's output using the existing firm or non-firm capacity of the Transmission System on an "as available" basis. Energy Resource Interconnection Service does not in and of itself convey any right to deliver electricity to any specific customer or Point of Delivery.

Power Flow N-1 Contingency Analysis

The 2016HS base case was updated to set the TOT-3 major path flow (north-south) at 896 MW and to dispatch the existing and planned wind generation interconnected at Pawnee and Missile Site stations at their maximum expected coincident output (based on 2012-13 winter operating data). The resulting Benchmark case was then used to create the Study case by adding GI-2012-5 at the Missile Site 230kV bus and dispatching the generator at 300 MW rated output. The wind generation dispatch used at Pawnee and Missile Site stations in the two cases is as follows:

- ✓ Peetz Logan (Pawnee 230kV) = 80% of rated capacity = 460 MW
- ✓ Limon I and Limon II (Missile Site 345kV) = 96% of rated capacity = 384 MW
- ✓ Cedar Point (Missile Site 230kV) = 96% of rated capacity = 240 MW
- ✓ Planned Limon III (Missile Site 345kV) = 96% of rated capacity = 192 MW
- ✓ Proposed GI-2012-5 (Missile Site 230kV) = 100% of rated capacity = 300 MW

Based on the results of 2016HS steady-state power flow analyses, it is determined that injecting 300 MW at Missile Site 230 kV bus results in heavy N-1 thermal overloads on the Smoky Hill 345/230 kV auto-transformers and the Clark – Jordan 230 kV (underground) line. Without any transmission upgrades to mitigate these two significant thermal constraints – that is, by only utilizing the existing transmission capability in PSCo's transmission system – GI-2012-5/GI-2014-1 may be interconnected as an NRIS/ERIS at partial output of (approx.) 30 MW.

Dynamic Stability Analysis

The GE 1.7 MW wind turbine generator is a doubly-fed induction generator that is asynchronous from the transmission system and has an inverter-connected rotor with automatic voltage control capability. Given this and the strong short circuit strength at Missile Site 230 kV bus, it is unlikely that the wind generating plant's Low Voltage Ride Through (LVRT) performance during disturbances will have adversely impact system stability. Also, extensive previous experience with performing dynamic stability analyses for GE 1.6 and GE 1.7 wind turbine generators has not produced any unacceptable stability performance by their interconnection to the transmission grid. Hence a dynamic stability study was not deemed necessary for the proposed 300 MW interconnection. It is expected that the GE 1.7 MW machines will have at least +/- 0.95 power factor capability and they will be operated in voltage control mode at all times.

Short Circuit Analysis

The short circuit study results show that no circuit breakers in the Missile Site 230kV switchyard will be over-dutied due to the proposed GI-2012-5 plus GI-2014-1 wind generation facility.

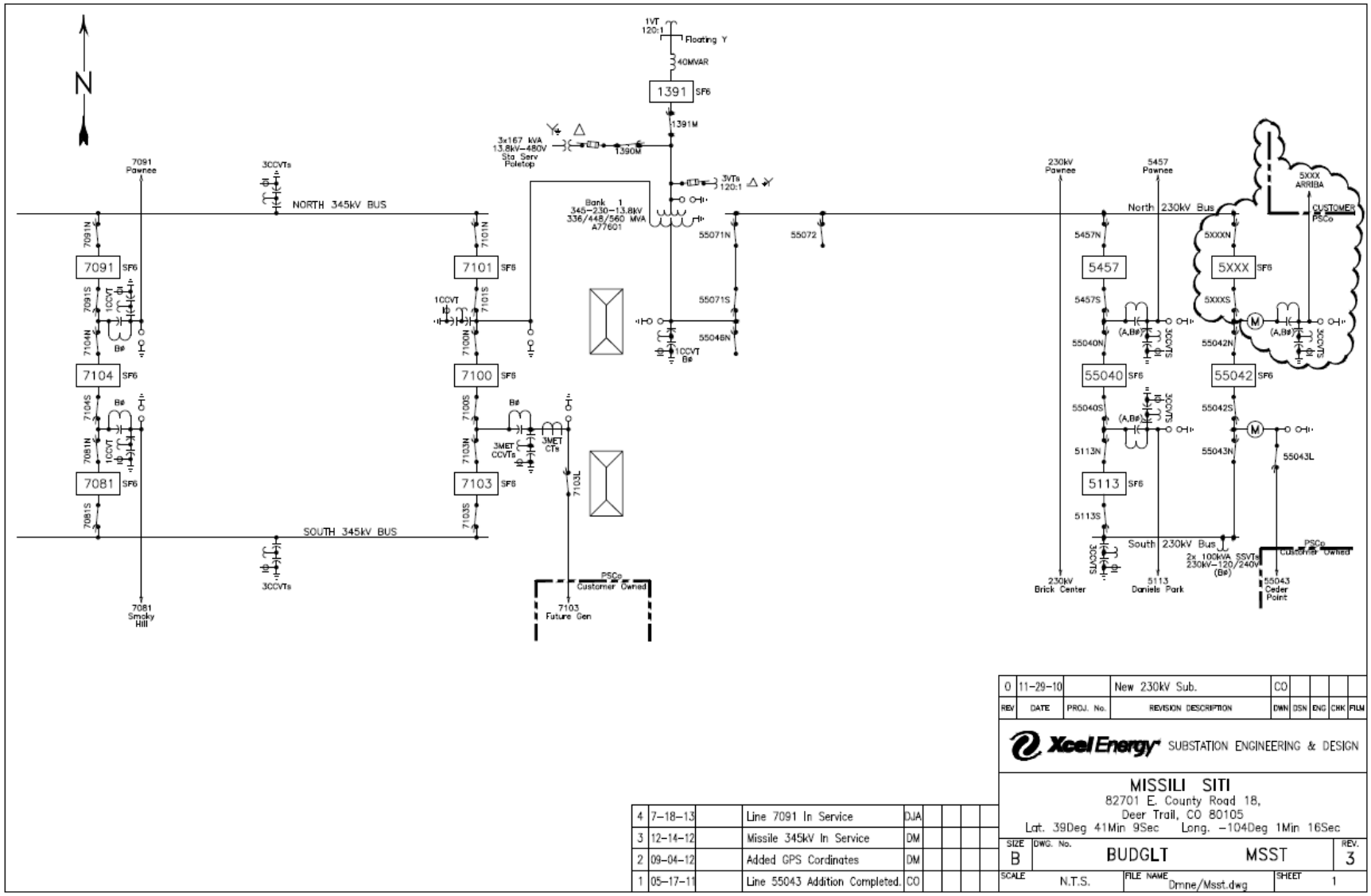
Short Circuit Levels at the Missile Site 230 kV POI Before and After GI-2012-5 plus GI-2014-1

System Condition	Three-Phase (3-Ph) Fault Level (Amps)	Single-Line-to-Ground (SLG) Fault Level (Amps)	3 Ph Fault X/R	SLG Fault X/R
Y2014 Before GI-2012-5	14,309	13,122	12.910	11.458
Y2014 After GI-2012-5	15,095	14,059	12.339	10.713

Costs Estimates and Assumptions

Scoping level cost estimates for Interconnection Facilities and Network/Infrastructure Upgrades for Delivery (+/- 30% accuracy) were developed by Public Service Company of Colorado (PSCo) Engineering. The cost estimates are in 2014 dollars with escalation and contingency included and are based upon typical construction costs for previously performed similar construction. These estimated costs include all applicable labor and overheads associated with the siting support, engineering, design, material/equipment procurement, construction and commissioning of these new substation and transmission line facilities. This estimate does not include the cost for any other Customer owned equipment and associated design and engineering.

The estimated total cost for the required Interconnection Facilities is **$1.565M** and the Network Upgrades for Delivery is **$177.8M.** The following tables list the improvements required to accommodate the interconnection and the delivery of GI-2012-5/GI-2014-1 generation output. The cost responsibilities associated with these facilities shall be handled as per current FERC guidelines. System improvements are subject to change upon a more detailed and refined design. **Figure 1** below represents a conceptual one-line of the proposed interconnection at the Missile Site Station 230 kV bus.



REV	DATE	PROJ. No.	REVISION DESCRIPTION	DWN	DSN	ENG	CHK	FILM
0	11-29-10		New 230kV Sub.	CO				
4	7-18-13		Line 7091 In Service	DJA				
3	12-14-12		Missile 345kV In Service	DM				
2	09-04-12		Added GPS Cordinates	DM				
1	05-17-11		Line 55043 Addition Completed.	CO				

Xcel Energy SUBSTATION ENGINEERING & DESIGN

MISSILI SITI
82701 E. County Road 18,
Deer Trail, CO 80105
Lat. 39Deg 41Min 9Sec Long. -104Deg 1Min 16Sec

SIZE	DWG. No.	REV.
B	BUDGLT MSST	3

SCALE N.T.S. FILE NAME Dmne/Msst.dwg SHEET 1

Figure 1 Missile Site Substation Interconnection

Table 1: PSCo Owned; Customer Funded Transmission Provider Interconnection Facilities

Element	Description	Cost Est. (Millions)
PSCo's Missile Site 230 kV Transmission Substation	Interconnect Customer to the 230kV bus at the Missile Site Substation. The new equipment includes: • One 230kV, 3000 amp gang switch • One 230kV combination CT/PT metering unit • Three 230kV lightning arresters • Primary metering for Load Frequency/Automated Generation Control • Power Quality Metering • Associated electrical equipment, bus, wiring and grounding • Associated foundations and structures • Associated transmission line communications, fiber, relaying and testing	**$0.760**
	Transmission line tap from Customer's last line structure outside of PSCo's yard into new bay position (assumed 300' span, conductor, hardware and labor).	**$0.075**
	Siting and Land Rights support for siting studies, land and ROW acquisition and construction.	**$0.010**
Customer's 230 kV Substation	Load Frequency/Automated Generation Control (LF/AGC) RTU and associated equipment.	**$0.120**
	Total Cost Estimate for PSCo-Owned, Customer-Funded Interconnection Facilities	**$0.965**
Time Frame	**Site, design, procure and construct**	**18 Months**

Table 2: PSCo Owned; PSCo Funded Interconnection Network Facilities

Element	Description	Cost Estimate (Millions)
PSCo's Missile Site 230kV Transmission Substation	Interconnect Customer to the bus at the Alamosa Terminal Substation. The new equipment includes: • One 230kV, 3000 amp circuit breaker • One 230kV, 3000 amp gang switch • Associated station controls, communications, supervisory and SCADA equipment • Associated electrical equipment, bus, wiring and grounding • Associated foundations and structures • Associated equipment and system testing	**$0.600**

	Total Cost Estimate for PSCo-Owned, PSCo-Funded Interconnection Facilities	**$0.600**
Time Frame	**Site, design, procure and construct**	**18 months**

Table 3: PSCo Network Upgrades for Delivery

Element	Sub Cost (Millions)	Cost Est. (Millions)
Siting and Land Rights Permitting / Acquisition		**$ 6.1**
Substation Costs		**$ 52.8**
Pawnee Substaton	$ 5.8	
Smoky Hill Substation	$ 5.4	
Daniels Park Substation	$ 6.9	
Harvest Mile Substation	$27.7	
Missile Site Substaton	$ 7.0	
Transmission Line Costs		**$118.9**
Pawnee – Daniels Park		
Time Frame to site, design, procure and construct		**54 months**
Total Cost Estimate for PSCo Network Upgrades for Delivery		**$177.8**

Cost Estimate Assumptions

- Scoping level project cost estimates for Interconnection Facilities and Network/Infrastructure Upgrades for Delivery (+/- 30% accuracy) were developed by PSCo Engineering.
- Estimates are based on 2014 dollars (appropriate contingency and escalation included).
- AFUDC has been excluded.
- Labor is estimated for straight time only – no overtime included.
- Lead times for materials were considered for the schedule.
- The Solar Generation Facility is not in PSCo's retail service territory. Therefore, no costs for retail load (distribution) facilities and metering required for station service are included in these estimates.
- Tri-State and/or Xcel (or our Contractor) crews will perform all construction, wiring, testing and commissioning for PSCo owned and maintained facilities.
- The estimated time to site, design, procure and construct the interconnection facilities is approximately 18 months after authorization to proceed has been obtained.
- A CPCN will not be required for the interconnection facilities construction.
- Customer will string OPGW fiber into substation as part of the transmission line construction scope.
- No new substation land will need to be acquired.
- Breaker duty study determined that no breaker replacements are needed in neighboring substations.

Appendix – Power Flow N-1 Contingency Analysis Results

Differentially Overloaded Facilities[1] for High Coincidence Wind Generation Dispatch at Pawnee and Missile Site
Pawnee 230kV = 460 MW (80%); Missile Site 345kV = 576 MW (96%); Missile Site 230kV = 235 MW (96%)
300 MW from GI-2012-5 & GI-2014-1 dispatched to Ft St Vrain, RMEC and Cherokee (100 MW each)

Table A.1 – Without any Network Upgrades

				Branch N-1 Loading Before 300 MW GI		Branch N-1 Loading After 300 MW GI			
Monitored Facility (Line or Transformer)	Type	Owner	Summer Normal (Continuous) Facility Rating MVA	Flow in MVA	Flow in % of Summer Normal Rating	Flow in MVA	Flow in % of Summer Normal Rating	Differential % Impact	N-1 Contingency Outage
Smoky Hill 230/345 kV # T4	Xfmr	PSCo	560	607.9	108.6%	701.1	125.2%	16.6%	Smoky Hill 230/345 kV # T5
Smoky Hill 230/345 kV # T5	Xfmr	PSCo	560	607.9	108.6%	701.1	125.2%	16.6%	Smoky Hill 230/345 kV # T4
Clark – Jordan 230 kV	Line	PSCo	331	324.7	98.1%	343.9	103.9%	5.8%	Smoky Hill -- Leetsdale 230 kV

Table A.2 – After Addition of 345/230 kV Auto at Harvest Mile

				Branch N-1 Loading After 300 MW GI			
Monitored Facility (Line or Transformer)	Type	Owner	Summer Normal (Continuous) Facility Rating MVA	Flow in MVA	Flow in % of Summer Normal Rating	% Mitigation	N-1 Contingency Outage
Smoky Hill 230/345 kV # T4	Xfmr	PSCo	560	402.1	71.8%	–53.4%	Smoky Hill 230/345 kV # T5
Smoky Hill 230/345 kV # T5	Xfmr	PSCo	560	402.1	71.8%	–53.4%	Smoky Hill 230/345 kV # T4
Clark – Jordan 230 kV	Line	PSCo	331	349.9	105.7%	+1.8%	Smoky Hill -- Leetsdale 230 kV

[1] **Due to proposed 300 MW generation increase at Missile Site 230 kV Station**

Table A.3 – After Addition of Smoky Hill (Harvest Mile) – Daniels Park 345 kV Line

				Branch N-1 Loading After 300 MW GI			
Monitored Facility (Line or Transformer)	**Type**	**Owner**	**Summer Normal (Continuous) Facility Rating MVA**	**Flow in MVA**	**Flow in % of Summer Normal Rating**	**% Mitigation**	**N-1 Contingency Outage**
Smoky Hill 230/345 kV # T4	Xfmr	PSCo	560	485.3	86.7%	–38.5%	Smoky Hill 230/345 kV # T5
Smoky Hill 230/345 kV # T5	Xfmr	PSCo	560	485.3	86.7%	–38.5%	Smoky Hill 230/345 kV # T4
Clark – Jordan 230 kV	Line	PSCo	331	281.7	85.1%	–18.8%	Smoky Hill -- Leetsdale 230 kV

Table A.4 – After Addition of 345/230 kV Auto at Harvest Mile plus Smoky Hill (Harvest Mile) – Daniels Park 345 kV Line

				Branch N-1 Loading After 300 MW GI			
Monitored Facility (Line or Transformer)	**Type**	**Owner**	**Summer Normal (Continuous) Facility Rating MVA**	**Flow in MVA**	**Flow in % of Summer Normal Rating**	**% Mitigation**	**N-1 Contingency Outage**
Smoky Hill 230/345 kV # T4	Xfmr	PSCo	560	318.8	56.9%	–68.3%	Smoky Hill 230/345 kV # T5
Smoky Hill 230/345 kV # T5	Xfmr	PSCo	560	318.8	56.9%	–68.3%	Smoky Hill 230/345 kV # T4
Clark – Jordan 230 kV	Line	PSCo	331	297.9	90.0%	–13.9%	Smoky Hill -- Leetsdale 230 kV