Generator Interconnection Request # GI-2014-6
Feasibility Study

100 MW Solar Photo-Voltaic (PV) Generation
Pueblo County, Colorado

Public Service Company of Colorado
Transmission Planning
January 22, 2015

A. Executive Summary

On May 22, 2014, Public Service Company of Colorado (PSCo) received an interconnection request (GI-2014-6) for a 100 MWac solar photovoltaic (PV) generation facility in Pueblo County, Colorado. The proposed Point of Interconnection (POI) is the PSCo-owned Midway 115 kV bus within the Midway 345/230/115 kV transmission substation (see Figure 1). The Commercial Operation Date (COD) requested by the Interconnection Customer is July 1, 2016, and accordingly the approximate target Backfeed Date is assumed to be April 1, 2016.

The solar photovoltaic generating facility will consist of 60 Eaton Power Xpert dc/ac inverters, each rated 1835 kVAac, 1670 kWac, 355 Vac, 0.91 lead – 0.91 lag adjustable power factor. Each inverter will be connected to a pad-mounted step-up transformer (SUT) which provides voltage transformation for integration of the inverter and its associated PV source circuits with the medium voltage (15, 25 or 35 kV class) power collection system within the generating plant. One main GSUT will provide the final transformation to allow the generating facility to interconnect to the Midway 115 kV bus POI via an overhead 115kV transmission line owned by the Interconnection Customer.

Based on the inverter's technical specifications provided by the Interconnection Customer, it is expected that the 0.91 lead – 0.91 lag adjustable power factor capability of the inverters will enable the GI-2014-6 generating plant to be operated in either the voltage control mode or the power factor control mode to follow the voltage schedule at the POI (Midway 115 kV bus) specified by the Transmission Operator.

The Feasibility Study consists of the power flow (steady-state) contingency analysis and the short-circuit analysis. These analyses did not identify any thermal or voltage violations, nor any over-dutied circuit breakers, that may be attributed to the GI-2014-6 interconnection. However, the power flow analysis did identify some pre-existing thermal overloads that must be mitigated. PSCo Transmission Planning has identified a transmission reinforcement solution for mitigating these thermal overloads – the planned transmission upgrade project consists of installing a series reactor in the Palmer Lake--Monument 115 kV line. The transmission capacity provided by this

planned system upgrade is sufficient to accommodate the 100 MW rated output of GI-2014-6 (see Table 5 in the Appendix).

Based on the Feasibility Study results, it is concluded that the 100 MW rated output of the GI-2014-6 interconnection qualifies for both Network Resource Interconnection Service (NRIS)[1], as well as Energy Resource Interconnection Service (ERIS)[2] without requiring any Network Upgrades for Delivery. However, until the planned Palmer Lake 115 kV series reactor project is placed in-service, the GI-2014-6 generation output would be deliverable only as Energy Resource Interconnection Service (ERIS) using the existing firm/non-firm transmission capacity on as-available basis.

Cost Estimates

The total estimated cost of the required interconnection facilities at the Comanche Station (in 2014 dollars) is **$3.675 million** and includes:

- $ 1.362 million for PSCo-Owned, Customer-Funded Interconnection Facilities
- $ 2.313 million for PSCo-Owned, PSCo-Funded Network Upgrades for Interconnection

PSCo Engineering estimates that it will need 18 months to complete the Customer-Funded Interconnection Facilities and PSCo-Funded Network Upgrades for Interconnection in the Comanche 230 kV switchyard.

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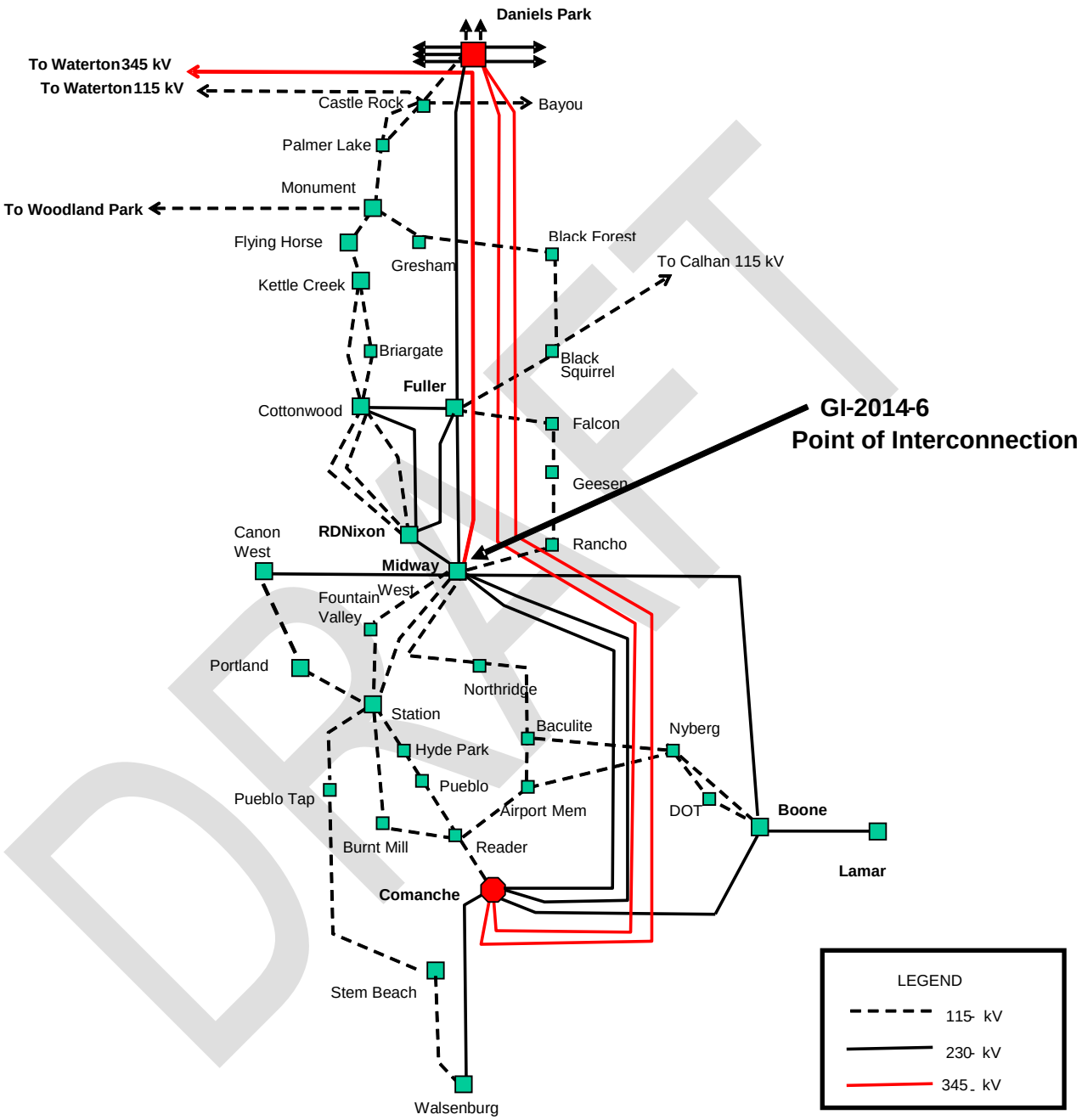
Figure 1 Midway Station and Surrounding Transmission System (2016)



B. Introduction

On May 22, 2014, Public Service Company of Colorado (PSCo) received an interconnection request (GI-2014-6) for a 100 MWac solar photovoltaic (PV) generation facility in Pueblo County, Colorado. The proposed Point of Interconnection (POI) is the PSCo-owned Midway 115 kV bus within the Midway 345/230/115 kV transmission substation (see Figure 1). The Commercial Operation Date (COD) requested by the Interconnection Customer is July 1, 2016, and accordingly the approximate target Backfeed Date is assumed to be April 1, 2016.

The solar photovoltaic generating facility will consist of 60 Eaton Power Xpert dc/ac inverters, each rated 1835 kVAac, 1670 kWac, 355 Vac, 0.91 lead – 0.91 lag adjustable power factor. Each inverter will be connected to a pad-mounted step-up transformer (SUT) which provides voltage transformation for integration of the inverter and its associated PV source circuits with the medium voltage (15, 25 or 35 kV class) power collection system within the generating plant. One main GSU transformer will provide the final transformation to allow the generating facility to interconnect to the Midway 115 kV bus POI via an overhead 115kV transmission line owned by the Interconnection Customer.

A Feasibility Study (FeS) Agreement was executed on July 8, 2014 and was subsequently revised in October, 2014 to reduce the study scope.

For this interconnection request, the potential Affected Parties are Black Hills Colorado Electric (BHCE) and Colorado Springs Utilities (CSU).

C. Study Scope and Analysis

This interconnection request was studied both as a Network Resource Interconnection Service (NRIS)[3] and Energy Resource Interconnection Service (ERIS)[4].

The Feasibility Study (FeS) scope consisted of performing power flow analysis to evaluate the steady-state thermal and/or voltage limit violations in the transmission system resulting from the proposed generator interconnection, as well as to determine the adequacy of the generating plant's power factor range (reactive power capability) at the POI. For evaluating NRIS feasibility, the entire 100 MW output of GI-2014-6 was assumed deliverable to PSCo loads. Whereas for evaluating ERIS feasibility, half of GI-2014-6 output (50 MW) was assumed

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deliverable to PSCo loads and the other half (50 MW) was assumed deliverable to BHCE loads. Note that this approach is in accordance with the mutually agreed study assumptions.

The Feasibility Study scope also consists of short-circuit analysis to determine any over-dutied circuit breakers due to the proposed generator interconnection. Together these analyses help identify the network upgrades required to deliver the 100 MW rated output of the proposed generation to load, for both NRIS and ERIS.

PSCo adheres to NERC & WECC System Performance Criteria, as well as internal system performance criteria for transmission system planning studies. Operationally, PSCo attempts to maintain a transmission system voltage profile ranging from ≥1.02 per unit at regulating (generation) buses to ≥1.0 per unit at transmission load buses.

D. Power Flow Study Models

The power flow studies were based on the WECC approved 17HS1AP_r32 case that was modified to reflect 2016 summer peak system conditions. PSCo loads in the case were adjusted to reflect the most recent PSCo load forecast for 2016. IREA load was also adjusted to reflect IREA's load forecast (November 2013). The transmission system topology was also updated to reflect current project plans. Updates were included for the PSCo, IREA, CSU, TSG&T, WAPA, PRPA and BHCE systems.

The PSCo updates included the addition of the new Cherokee combined cycle plant and associated transmission upgrades. The new IREA Happy Canyon distribution substation connected to the Crowfoot Valley – Daniels Park 115 kV circuit was also included. A significant CSU case update was the re-termination of the Nixon end of the Kelker – Nixon 230 kV line to Front Range.

Three power flow cases were created for evaluating the system impact of the proposed generator interconnection – a Reference Case (without GI-2014-6) and two Study Cases (with GI-2014-6). Both study cases include the 100 MW generator connected at Midway 115 kV bus – they differ only with respect to the sink location for this generation. In the NRIS study case the entire 100 MW output is sunk at PSCo's Ft St Vrain generating plant, whereas in the ERIS study case 50 MW is sunk at PSCo's Ft St Vrain generating plant and 50 MW is sunk at BHCE's Baculite generating plant.

To assess the impact of the proposed generation on the interconnected transmission system, the generation dispatch in the reference case was adjusted to create a south to north power flow stress on the Comanche – Midway - Jackson Fuller – Daniels Park transmission path. This was accomplished by adopting the generation dispatch described below that reflects the resource acquisitions approved in PSCo's 2013 Energy Resource Plan (ERP) for which Power Purchase Agreements (PPA's) have been signed. The six combustion turbines in Fountain Valley generating plant were dispatched at 242 MW rated output, the GI-2007-12 wind generation at Jackson Fuller was dispatched at 250 MW rated output, and the GI-2010-19 solar generation at

Comanche was dispatched at 120 MW. The Lamar dc tie was dispatched at 101 MW import into PSCo and the Colorado Green / Twin Buttes wind generation (interconnected at Lamar) was dispatched to 97.3 MW, the generation level at which loss of one of the two 230/115 kV transformers at Lamar resulted in a 100% of normal rating loading level on the other 230/115 kV transformer at Lamar. Other PSCo thermal generating units were dispatched according to their relative production costs (merit-order). It should be noted that the Area 70 (Area PSCOLORADO) swing machine in the WECC load flow case was moved to Fort Saint Vrain (FSV) Unit #1. The resulting PSCo (Area 70) generation dispatch can be found in Appendix B.

E. Power Flow Study Process

Contingency power flow studies were completed on the reference model and the model with the proposed new generation using PTI's PSSE Ver. 32.1.0 & 33.4.0 program. Results from the two cases were compared and new overloads or overloads that increased significantly in the new generation case were noted. Voltage criteria violations were also recorded. The PSSE Ver. 33.4.0 ACCC contingency analysis activity was used to perform the load flow contingency analysis. The PSCo Category B & C analysis was performed using contingency definitions that reflect breaker to breaker outages. Single branch switching was also performed for branches in Zones 700, 704, 705, 709, 712, 752, 757, and 791. Single unit outages were also modeled for generators in Zones 700, 704, 705, 709, 712, 752, 757, 790, and 791. The facilities in Zones 700, 704, 705, 709, 712, 752, 757, and 791 were monitored for overloads and voltage problems.

F. Power Flow Contingency Analysis Results

Network Resource Interconnection Service

The results of the Network Resource contingency analysis are summarized in Table 5 in the Appendix. The results of the Category B contingency analysis performed before modeling the planned Palmer Lake – Monument 115 kV series reactor transmission reinforcement show several 115 kV transmission facilities with thermal overloads – two of these 115 kV facilities are wholly-owned by CSU and the third 115 kV facility (Monument – Palmer Lake) is a tie-line between CSU and PSCo. Since these transmission facilities are also overloaded prior to the GI-2014-6 interconnection (that is, in the benchmark case), none of these thermal overloads may be attributed to the proposed 100 MW injection at Midway from GI-2014-6.

The effectiveness of the planned Palmer Lake series reactor project in mitigating these pre-existing thermal overloads is evident from the Category B contingency analysis results for the GI-2014-6 NRIS study case given in Table 5 in the Appendix. These results also demonstrate that no new thermal overloads occur after the entire 100 MW output of GI-2014-6 as NRIS is delivered to PSCo loads. Consequently, no network upgrades for delivery are needed.

Energy Resource Interconnection Service

As defined in Section C above, Energy Resource Interconnection Service allows the Customer to deliver a Generating Facility's electric output using the existing firm or non-firm capacity of the Transmission Provider's Transmission System on an as available basis. Therefore, until the planned Palmer Lake – Monument 115 kV series reactor transmission reinforcement needed to mitigate the pre-existing thermal overloads is placed in-service, the GI-2014-6 output would be deliverable as Energy Resource Interconnection Service (ERIS) using the existing firm/non-firm transmission capacity on an as available basis. This also applies to delivery of half the GI-2014-6 output (50 MW) to Black Hills Colorado Electric (BHCE) loads and the remaining 50 MW to PSCo loads. After the planned project is placed in service, the power flow analysis did not identify any thermal constraints for the deliverability of GI-2014-6 output as ERIS.

G. Voltage Regulation and Reactive Power Capability

Interconnection Customers are required to interconnect their Large Generating Facilities with Public Service of Colorado's (PSCo) Transmission System in conformance to the *Xcel Energy Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater Than 20 MW* (available at http://www.xcelenergy.com/staticfiles/xe/Regulatory/Transmission-Interconnection-Guidelines-Great-20MW.pdf). Wind and Solar generating plant interconnections (Variable Energy Resources) must also conform to the performance requirements in FERC Order 661-A. Accordingly, the following voltage regulation and reactive power capability requirements (at the POI) are applicable to this interconnection request:

- To ensure reliable operation, all Generating Facilities interconnected to the PSCo transmission system must adhere to the Rocky Mountain Area Voltage Coordination Guidelines. Accordingly, since the POI for this request is located within Southeast Colorado Region 4; the applicable ideal transmission system voltage profile range is 1.02 – 1.03 per unit at regulated buses and 1.0 – 1.03 per unit at non-regulated buses.
- Xcel Energy's OATT requires all Interconnection Customers to have the reactive capability to achieve +/– 0.95 power factor at the POI, with the maximum "full output" reactive capability available at all output levels. Furthermore, Xcel Energy requires all Interconnection Customers to have dynamic voltage control and maintain the voltage specified by the Transmission Operator within the limitation of +/– 0.95 power factor at the POI, as long as the generating plant is on-line and producing power.
- It is the responsibility of the Interconnection Customer to determine the type (switched shunt capacitors and/or switched shunt reactors, etc.), the size (MVAR), and the locations (690 V, 34.5 kV or 230 kV bus) of any additional static reactive power equipment needed within the generating plant in order to have the reactive capability to meet the +/– 0.95 power factor and the 1.02 – 1.03 per unit voltage range standards at the POI. The Interconnection Customer may need to perform additional studies for this purpose.

- It is the responsibility of the Interconnection Customer to ensure that its generating facility is capable of meeting the voltage ride-through and frequency ride-through (VRT and FRT) performance specified in NERC Reliability Standard PRC-024-1.
- The Interconnection Customer is required to demonstrate to the satisfaction of PSCo Transmission Operations prior to the commercial in-service date of the generating plant that it can safely and reliably operate within the required power factor and voltage ranges noted above.

H. Short Circuit Analysis Results

The calculated short circuit levels and Thevenin system equivalent impedances for the POI at the Midway 115kV bus are tabulated below. No circuit-breakers at Midway 115kV bus or at the neighboring buses were found to be over-dutied due to the proposed interconnection.

Table 1 – Short Circuit Levels at the Midway 115 kV POI

System Condition	Three-Phase Fault Level (Amps)	Single-Line-to-Ground Fault Level (Amps)	Thevenin System Equivalent Impedance R +j X (ohms)
Before GI-2004-6 Interconnection	11,902	10,998	Z1(pos) = 0.75129 + j5.52766 Z2(neg) = 0.77768 + j5.52607 Z0(zero) = 0.34656 + j6.95926
After GI-2004-6 Interconnection	11,902	11,538	Z1(pos) = 0.75129 + j5.52766 Z2(neg) = 0.77768 + j5.52607 Z0(zero) = 0.29216 + j6.11294

I. Study Conclusion

Based on the Feasibility Study results, it is concluded that the 100 MW rated output of the GI-2014-6 interconnection qualifies for both Network Resource Interconnection Service (NRIS)[5], as well as Energy Resource Interconnection Service (ERIS)[6] without requiring any Network Upgrades for Delivery attributed to GI-2014-6.

However, until the planned Palmer Lake 115 kV series reactor project is placed in-service, the GI-2014-6 generation output would be deliverable only as Energy Resource Interconnection Service (ERIS) using the existing firm/non-firm transmission capacity on as-available basis.

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Costs Estimates and Assumptions

Scoping level cost estimates for Interconnection Facilities and Network/Infrastructure Upgrades for Delivery (+/- 30% accuracy) were developed by PSCo Engineering. The cost estimates are in 2014 dollars with escalation and contingencies applied (AFUDC is not 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, and construction of these new PSCo facilities. These cost estimates do not include the cost for any other Customer owned equipment and associated design and engineering.

The following tables list the improvements required to accommodate the interconnection and the delivery of the Project. The cost responsibilities associated with these facilities shall be handled as per current FERC guidelines. System improvements are subject to change upon more detailed analysis.

Table 2 – PSCo Owned; Customer Funded Interconnection Facilities

Element	Description	Cost Est. (Millions)
PSCo's Midway 115 kV Transmission Substation	Interconnect Customer to the 115 kV bus at the Midway 115 kV Substation. The new equipment includes: • Install one 115kV line position • Three 115 kV line arresters • Three 115kV Metering Units • One 115kV line switch • One 115kV deadend structure • New relaying for the new transmission line. • One relay panel • Associated communications, supervisory and SCADA equipment • Associated line relaying and testing • Associated bus, wiring and equipment • Associated foundations and structures • Associated transmission line communications, relaying and testing	**$0.446**
Customer's 115 kV Substation	Load Frequency/Automated Generation Control (LF/AGC) RTU and associated equipment. Install a new relay panel at the customer generation site. Connect SCADA from the site to the Lookout Control Center.	**$0.205**
	Total Cost Estimate for PSCo-Owned, Customer-Funded Interconnection Facilities	**$0.651**
Time Frame	**Site, design, procure and construct**	**12 Months**

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Table 3 – PSCo Owned; PSCo Funded Interconnection Facilities

Element	Description	Cost Estimate (Millions)
PSCo's Comanche 230kV Transmission Substation	Interconnect Customer to the 115 kV bus at the Midway 115 kV Substation. The new equipment includes: • Three 115kV disconnect Switches • One 115kV circuit breaker • One power quality panel • Associated communications, supervisory and SCADA equipment • Associated bus, wiring and equipment • Associated foundations and structures	**$0.564**
	Total Cost Estimate for PSCo-Owned, PSCo-Funded Interconnection Facilities	**$0.564**
Time Frame	**Site, design, procure and construct**	**12 Months**

Table 4 – PSCo Network Upgrades for Delivery - PSCo Funded

Element	Description	Cost Est. (Millions)
	Not Required	
	Total Cost Estimate for PSCo Network Upgrades for Delivery	**N/A**
Time Frame	**Site, design, procure and construct**	**N/A**
	Total Project Estimate	**$1.215**

Assumptions

- Scoping level cost estimates for Interconnection Facilities and Network Upgrades for Delivery (+/- 30% accuracy) were developed by PSCo Engineering.
- Estimates are based on 2014 dollars (appropriate contingency and escalation applied).
- AFUDC has been excluded.
- Labor is estimated for straight time only – no overtime included.
- Installation contingency of 20%
- Equipment contingency of 10%
- Internal construction labor will be used
- Standard Hard Dollar labor and material prices will be used.
- PSCo (or it's Contractor) crews will perform all construction, wiring, testing and commissioning for PSCo owned and maintained facilities.

- The estimated time to design, procure and construct the interconnection facilities is approximately 12 months after authorization to proceed has been obtained.
- This project is completely independent of other queued projects and their respective ISD's.
- A CPCN will not be required for the Interconnection Facilities construction.
- Line and substation bus outages will be authorized during the construction period to meet the backfeed date.
- The Interconnection Customer will string OPGW fiber into the substation as part of their 115 kV transmission line construction scope.
- The Interconnection Customer will only pay for equipment directly related to their 115 kV transmission line connection.
- Power Quality Metering (PQM) will be required on the Interconnection Customer's 115 kV transmission line terminating into Midway Substation.
- Soil conditions are suitable for typical foundation installations
- Soil parameters allow for typical ground grid installation
- There are only two 115kV Black Hills owned Transmission Lines currently at Midway substation.
- No new substation land required. Substation work to be completed within existing property boundaries.
- The GI-2014-6 Generation Facility is not in PSCo's retail service territory. Therefore, no costs for retail load metering are included in these estimates.

Appendix

GI-2014-6 (100 MW) Interconnection at Midway 115 kV POI

A. Power Flow Thermal Results – 2016 Summer Heavy Load (16HS) – Colorado South-North Flow Stress

Lamar DC Tie = 101 MW Import Colorado Green + Twin Buttes Wind Gen = 97.3 MW
PSCo 2013 Electric Resource Plan (ERP) Generation:
Gas Gen: Fountain Valley CTs = 242 MW (dispatched @ 100% of Installed Capacity)
Wind Gen: Jackson Fuller = 250 MW (dispatched @ 100% of Installed Capacity)
Solar PV Gen: Comanche = 120 MW, San Luis Valley = 50 MW (dispatched @100% of Installed Capacity)

Includes Planned Project – Series Reactor (X = 20.0%) in the Monument – Palmer Lake 115 kV Line – with 2016 target ISD

Table 5 – GI-2014-6 Summary Listing of Post-Contingency Loadings on Facilities[1] with Highest Impact (Category B Contingencies)

				Branch Contingency Loading Without GI-2014-6		Branch Contingency Loading With GI-2014-6			
Monitored Facility (Line or Transformer)	Type	Line Owner	Branch Rating MVA (Norm/Emer)	Cat B Flow in MVA (Current Equiv)	Cat B Flow in % Current Equiv of Normal/Emer Rating	Cat B Flow in MVA (Current Equiv)	Cat B Flow in % Current Equiv of Normal/Emer Rating	% Change	NERC Category B Contingency Outage
Briar Gate – Cottonwood S 115 kV	LN	CSU	150 / 192	156.7	103.1% / 80.5%	161.7	107.8% / 84.2%	4.7% / 3.7%	Cottonwood N – Kettle Creek 115 kV
Cottonwood N – Kettle Creek 115 kV	LN	CSU	162 / 180	164.4	101.1% / 91.0%	169.4	104.6% / 94.1%	3.5% / 3.1%	Briar Gate – Cottonwood S 115 kV
Jackson Fuller – Daniels Park 230 kV	LN	PSCo	478 / 478	366.3	76.6% / 76.6%	401.0	84.0% / 84.0%	7.4% / 7.4%	Midway – Waterton 345 kV or Midway 345/230 kV Xfmr

Note: Emergency Ratings are the Applicable Facility Ratings to determine acceptable post-contingency loading on CSU facilities.

[1] Includes facilities with an Impact Factor of 2% or more of the proposed 100 MW generation.

B. Generation Dispatch

Case Description: 2016 HS, Colorado South to North Generation Flow Bias, based on WECC 17hs1ap.sav with updates from CCPG companies plus PSCo Existing/Planned Generation as per 2013 ERP.

Benchmark Case – Before GI-2014-06

Arapahoe Unit 3 & 4	0 MW
Arapahoe Units 5-7	118 MW
Cabin Creek Units	210 MW
Cherokee Units 1–3	0 MW
Cherokee Unit 4	383 MW
Cherokee Units 5–7	603.8 MW
Fountain Valley Units 1–4	242 MW
Comanche Unit 1	360 MW
Comanche Unit 2	365 MW
Comanche Unit 3	804 MW
Valmont Unit 5	196 MW
Valmont Unit 6	0 MW
Spindle Units 1 & 2	0 MW
Ft St Vrain Units 1-4	700 MW
Ft St Vrain Units 5 & 6	0 MW
Pawnee Unit 1	536 MW
Manchief Units 1 & 2	0 MW
Alamosa Units 1 & 2	27 MW
Ft Lupton Units 1 & 2	0 MW
QF Thermo – Ft Lupton	266 MW
Brush Units 1, 3, & 4	0 MW
Brush Unit 2	0 MW
QF UNC	0 MW
Plains End Units	0 MW
RMEC Units 1-3	586 MW
Spruce Units 1 & 2	0 MW
Brighton Units 1 & 2	85 MW
Lamar DC Tie	101 MW Import from SPS
Colorado Grn/Twin Buttes Wind	97.3 MW
Peetz Logan Wind	132.4 MW (23%)
Cedar Point Wind	57.5 MW (23%)
Limon I, II & III Wind	138.1 MW (23%)
Cedar Creek I & II Wind	126.8 MW (23%)
San Luis Valley area Solar	85.2 MW
Golden West (GI-2007-9) Wind	249.9 MW (100%)
SunEdison (GI-2010-19) Solar	120 MW (100%)

Lamar Units	0 MW (ARPA)
Baculite Mesa Plant	382 MW (BHE)
Busch Ranch Wind	28.8 MW (BHE)
Remaining BHE Gens	0 MW (BHE)
Birdsall	0 MW (CSU)
Nixon	224.8 MW (CSU)
Nixon CTs	0 MW (CSU)
Tesla	24.8 MW (CSU)
Drake	265.4 MW (CSU)
Front Range CC	404 MW (CSU)

GI-2014-6 **NRIS** Study Case Adjustments

Ft St Vrain Units 1-4	600 MW

GI-2014-6 **ERIS** Study Case Adjustments

Ft St Vrain Units 1-4	650 MW
Baculite Mesa Plant	332 MW (BHE)

C. One-Line of Proposed GI-2014-6 Interconnection at Midway 115kV Station