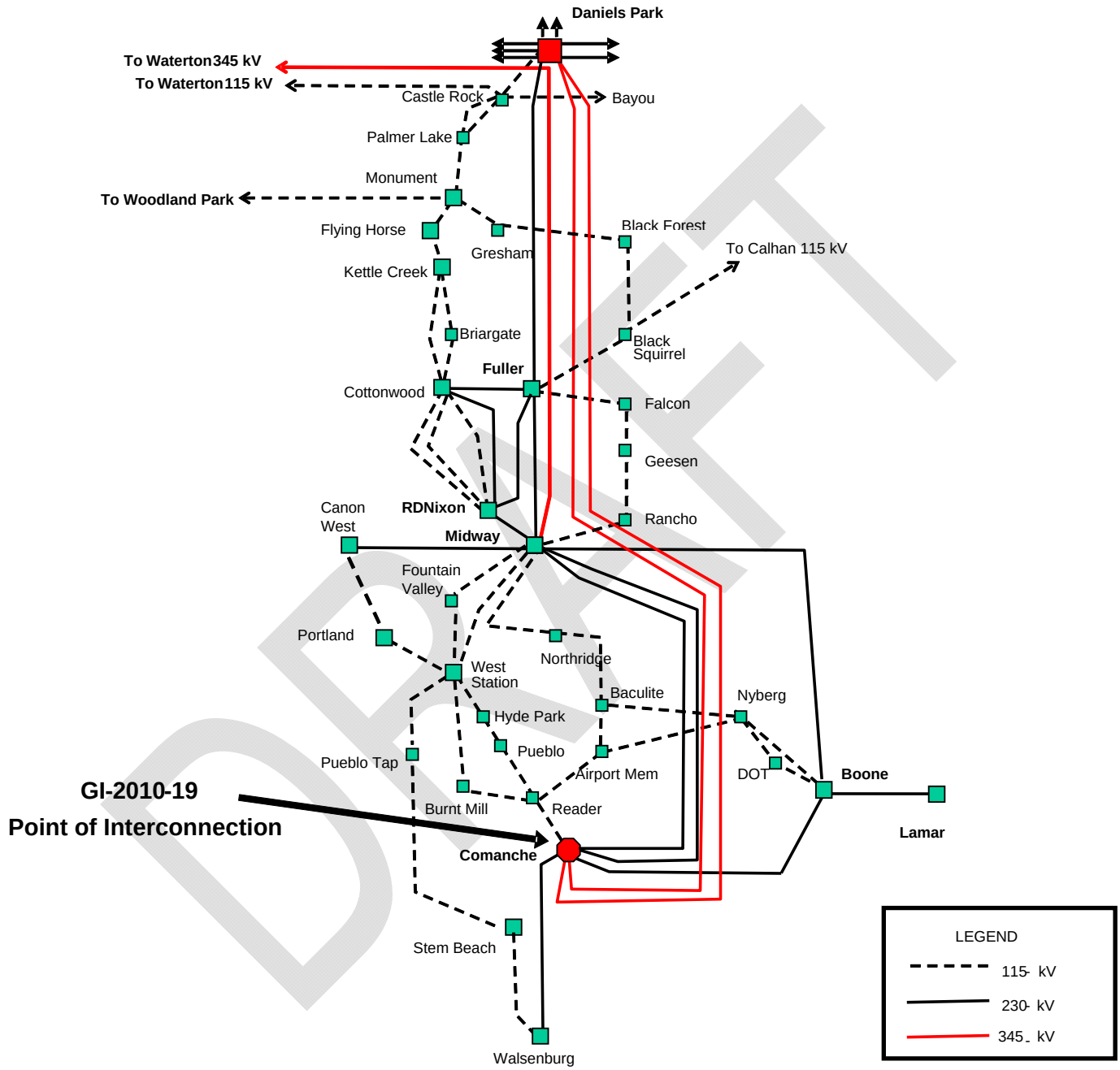
Generator Interconnection
System Impact Study
Request # GI-2010-19

120 MW Photo-Voltaic Solar Generation
Pueblo County, Colorado

Public Service Company of Colorado
Transmission Planning
May 12, 2014

A. Executive Summary

Figure 1 Comanche Station and Surrounding Transmission System (2016)



B. Introduction

On November 16, 2010, Public Service Company of Colorado (PSCo) received an interconnection request (GI-2010-19) for a 120 MW solar photovoltaic generation facility in Pueblo County, Colorado. The proposed point of interconnection (POI) is the Comanche 230 kV bus within the Comanche 345/230/115 kV transmission substation (see Figure 1 above). The solar generating facility will be located at the northeast corner of the Lime road and St. Charles road, immediately east of PSCo's Comanche generating plant, and will be connected to the PoI via an approximately 0.5 miles long radial 230 kV overhead transmission line owned by the interconnection customer.

A System Impact Study (SIS) Agreement was executed on January 17, 2014. The System Impact Study consists of steady-state power flow analyses to evaluate the thermal and voltage impact of the proposed generating plant on the transmission system, as well as determine the adequacy of the generating plant's power factor range (reactive power capability) at the POI. Based on information provided by the Interconnection Customer, it is expected that the dc/ac inverters will have +/- 0.90 power factor capability and will be capable of being operated in either voltage control or power factor control modes.

The dc/ac inverter forms an asynchronous interface of the PV solar generating plant to the transmission system and is expected to provide dynamic voltage control capability within the +/- 0.90 power factor range. This, along with the Voltage Ride Through (VRT) capability information for the inverters provided by the Interconnection Customer, a transient stability study to assess the interconnecting generating facility's impact on system stability was not deemed necessary.

C. Study Scope and Analysis

The System Impact Study evaluated the transmission impacts associated with the proposed wind farm. It consisted of power flow and short circuit analyses.

The power flow analysis identified any steady-state thermal or voltage limit violations resulting from the installation of the proposed wind farm and an identification of network upgrades required to deliver the proposed generation to PSCo loads.

PSCo adheres to NERC & WECC Reliability Criteria, as well as internal Company criteria for planning studies. During system intact conditions, criteria are to maintain transmission system bus voltages between 0.95 and 1.05 per unit of nominal, and steady-state power flows below the thermal ratings of all facilities. Operationally, PSCo tries to maintain a transmission system voltage profile ranging from 1.02 per unit or higher at regulating (generation) buses to 1.0 per unit or higher at transmission load buses. Following a single contingency, transmission system steady state bus voltages must remain within 0.90 per unit to 1.05 per unit, and power flows within 100% of the facilities' continuous thermal ratings.

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

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.

Energy Resource Interconnection Service shall mean an Interconnection Service that allows the Interconnection Customer to connect its Generating Facility to the Transmission Provider's Transmission System to be eligible to deliver the Generating Facility's electric output using the existing firm or non-firm capacity of the Transmission Provider's Transmission System on an as available basis. Energy Resource Interconnection Service in and of itself does not convey transmission service.

For this project, potential Affected Parties are Colorado Springs Utilities (CSU(, Tri-State Gas & Electric Transmission (TSGT) and the Intermountain Rural Electric Association (IREA).

D. Power Flow Study Models

The power flow studies were based on the WECC approved 17HS1AP_r32 case. PSCo loads in the case were adjusted to reflect the most recent (April 2013) PSCo load forecast. IREA load was also adjusted to reflect IREA's latest load forecast (November 2013). The topology was also updated to reflect current project plans. Updates were included for the PSCo, IREA, CSU, TSG&T, WAPA, PRPA, BHE, and BEPC 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.

Two main power flow generation dispatch scenarios were evaluated. One was created as a reference scenario and the other was created with the proposed generation connected to Jackson Fuller 230 kV.

To assess the impact of the proposed generation on the transmission system, the generation dispatch was adjusted to create a south to north flow stress through the Jackson Fuller area. This was accomplished by increasing the Colorado Green / Twin Buttes wind generation to 97.3 MW, the level at which loss of one of the 230/115 kV transformers at Lamar resulted in a 100% of

normal rating loading level on the other 230/115 kV transformer at Lamar. The combustion turbines at Fountain Valley were also dispatched at 242 MW, due to the Colorado PUC's recent decision regarding Xcel Energy's Energy Resource Plan filing. PSCo signed a PPA for generation from this plant on January 27, 2014. Other PSCo thermal units were dispatched according to their relative generation costs. It should be noted that the Area 70 (Area PSCOLORADO) swing machine in the WECC load flow case was moved to Fort Saint Vrain Unit 1. The resulting PSCo 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 Thermal Results

Network Resource Interconnection Service

The results of the Network Resource contingency analysis are summarized in the tables in the Appendix. The results of the Category B contingency analyses (see Table 1) show two transmission facilities with overloads, none of which can be attributed to the proposed PV solar generating plant. Both transmission facilities are owned by Colorado Springs Utilities.

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. The ER analyses were performed using the same 2016 peak summer load flow cases as were used for the Network Resource contingency analyses.

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 should adhere to the Rocky Mountain Area Voltage Coordination Guidelines. Accordingly, since the POI for this interconnection 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. Further, for wind generating plants to meet the LVRT performance requirements specified in FERC Order 661-A, appropriately sized and located reactive power compensation devices (capacitor, DVAR, SVC, etc.) may need to be installed within the generating plant.
- 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).

The Customer will need to perform additional studies to determine the capabilities, optimum location(s) and configuration(s) for the reactive compensation required to meet the +/– 0.95 power factor standard at the POI.

H. Dynamic Stability Analysis – Results

The dc/ac inverter forms an asynchronous interface of the PV solar generating plant to the transmission system and is expected to provide dynamic voltage control capability within the +/-

0.90 power factor range. This, along with the Voltage Ride Through (VRT) capability information for the inverters provided by the Interconnection Customer, a transient stability study to assess the interconnecting generating facility's impact on system stability was not deemed necessary.

I. Short Circuit

The calculated short circuit levels and Thevenin system equivalent impedances for the POI at the Comanche 230kV bus are shown in Table below. No PSCo breakers were found to be overdutied due to the proposed interconnection .

Table – Short Circuit Parameters at the Comanche 230 kV POI

System Condition	Three-Phase Fault Level (Amps)	Single-Line-to-Ground Fault Level (Amps)	Thevenin System Equivalent Impedance (R +j X) (ohms)
System Intact	17306.8	13712.7	Zpos = 0.77698 +j .63328 Zneg = 0.78659 +j 7.63233 Z0 = 2.90694 +j 13.4397
Fountain Valley Units Off	16704.1	13379.1	Zpos = 0.80791 +j 7.90844 Zneg = 0.81947 +j 7.90728 Z0 = 2.93934 +j 13.6754
Strongest Line Out - Jackson Fuller – Midway 230 kV Out	13707.0	11050.4	Zpos = 1.16312 +j 9.61772 Zneg = 1.17237 +j 9.61635 Z0 = 3.23950 +j 16.3825
Fountain Valley Units and Jackson Fuller – Midway 230 kV Out	13474.4	10912.7	Zpos = 1.17314 +j 9.78565 Zneg = 1.18383 +j 9.78417 Z0 = 3.25830 +j 16.5011

Costs Estimates and Assumptions
GI-2010-19 (System Impact Study Report)
Revised ????

The estimated costs shown are (+/-30%) estimates in 2013 dollars and are based upon typical construction costs for previously performed similar construction. These estimated costs include all applicable labor and overheads associated with the engineering, design, procurement and construction of these new PSCo facilities. This estimate does 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 1 – PSCo Owned; Customer Funded Interconnection Facilities

Element	Description	Cost Est. (Millions)
PSCo's Comanche 230kV Transmission Substation	Interconnect Customer to the 230kV bus at the Comanche 230kV Substation. The new equipment includes: • Extend the 230kV Bus at to a new bay location • One new underground transmission line transition structure • One 230 kV gang switch and one grounding switch • Three 230 kV line arresters • Connect the new 230kV position to the bus • New relaying for the new transmission line. • Power Quality Metering (230kV line from Customer) • Three 230kV lightning arresters • One relay panel (transformer breaker panel) • One new underground transmission line transition structure • 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	**$0.930**

Customer's 230kV 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.	**$0.228**
	Total Cost Estimate for PSCo-Owned, Customer-Funded Interconnection Facilities	**$1.158**
Time Frame	**Design, procure and construct**	**18 Months**

Table 2: PSCo Owned; PSCo Funded Interconnection Facilities

Element	Description	Cost Estimate (Millions)
PSCo's Comanche 230kV Transmission Substation	Interconnect Customer to the 230kV bus at the Comanche 230kV Substation. The new equipment includes: • Three 230 kV gang switches • Install a new 230 kV bay by extending the busses to the east • Five 230 kV gang switches • Two 230 kV breakers • Modify the relaying for the new bay position	**$1.589**
		$0.0
	Total Cost Estimate for PSCo-Owned, PSCo-Funded Interconnection Facilities	**$1.589**
Time Frame	**Site, design, procure and construct**	**18 Months**

Table 3 – PSCo Network Upgrades for Delivery - PSCo Funded

Element	Description	Cost Est. Millions
	Not Applicable	
	Total Estimated Cost for PSCo Network Upgrades for Delivery	**N/A**
Time Frame	Site, design, procure and construct	**N/A**

Assumptions

- The cost estimates provided are “scoping estimates” with an accuracy of +/- 30%.
- Estimates are based on 2014 dollars.
- There is contingency and escalation included in the estimates. AFUDC is not included.
- Labor is estimated for straight time only – no overtime included.
- The Generator is not in PSCo’s retail service territory. Therefore no costs for retail load metering are included in these estimates.
- PSCo (or its Contractor) crews will perform all construction and wiring associated with PSCo owned and maintained facilities.
- The estimated time to site, design, procure (long lead time materials) and construct the interconnection facilities is at least 18 months, and is completely independent of other queued projects and their respective ISDs.
- A CPCN will not be required for interconnection facility construction.
- Customer will string OPGW fiber into substation as part of the transmission line construction scope.
- PSCo crews to perform checkout, relay panel construction and final commissioning.
- No new substation land required. Substation work to be completed within existing property boundaries.

Appendix

GI-2010-19
Comanche 230 kV – 120 MW

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 – 97.3 MW
PSCo 2013 Electric Resource Plan Generation - Fountain Valley CTs – 242 MW
Jackson Fuller Wind – 250 MW & SLV PV Solar – 50 MW

Table 5 – GI-2010-19 Summary Listing of Worst Case Overloaded Facilities[1] (Category B Contingencies)

				Branch Contingency Loading Without GI-2010-19		Branch Contingency Loading With GI-2010-19			
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	168.6	112.4% / 87.8%	177.0	116.6% / 92.2%	4.2% / 4.4%	Cottonwood N – Kettle Creek 115 kV
Cottonwood N – Kettle Creek 115 kV	LN	CSU	162 / 180	181.0	111.7% / 100.5%	188.5	116.1% / 104.5%	4.4% / 4.0%	Briar Gate – Cottonwood S 115 kV

*Current-corrected flows for transmission lines only.

[1] Includes facilities with an Impact Factor of 2% or more of the proposed 120 MW generation.

Xcel Energy

Table 6 – GI-2010-19 Summary Listing of Worst Case Overloaded Facilities[1] (Category C Contingencies)

				Branch Contingency Loading Without GI-2010-19		Branch Contingency Loading With GI-2010-19			
Monitored Facility (Line or Transformer)	**Type**	**Line Owner**	**Branch Rating MVA (Norm/Emer)**	**Cat C Flow in MVA (Current Equiv*)**	**Cat C Flow in % Current Equiv of Normal/Emer Rating**	**Cat C Flow in MVA (Current Equiv*)**	**Cat C Flow in % Current Equiv of Normal/Emer Rating**	**% Change**	**NERC Category C Contingency Outage**
Daniels Park – Jackson Fuller 230 kV	LN	PSCo	478 / 478	498.1	104.2% / 104.2%	542.4	113.5% / 113.5%	9.3% / 9.3%	Double-Circuit Tower Comanche – Daniels Park 345 kV 1 & 2
Monument – Palmer Lake 115 kV	LN	PSCo / CSU	120 / 120	162.0	135.0% / 135.0%	176.4	148.5% / 148.5%	13.5% / 13.5%	Double-Circuit Tower Midway – Waterton 345 kV Daniels Park – Jackson Fuller 230 kV
Monument – Palmer Lake 115 kV	LN	PSCo / CSU	120 / 120	146.3	121.9% / 121.9%	159.1	132.6% / 132.6%	10.7% 10.7%	Double-Circuit Tower Comanche – Daniels Park 345 kV 1 & 2
Monument – Flying Horse 115 kV	LN	CSU	142 / 156	173.4	122.1% / 111.2%	189.6	133.8% / 121.5%	11.7% / 10.3%	Double-Circuit Tower Midway – Waterton 345 kV Daniels Park – Jackson Fuller 230 kV
Monument – Flying Horse 115 kV	LN	CSU	142 / 156			166.5	117.3% / 106.7%		Double-Circuit Tower Comanche – Daniels Park 345 kV 1 & 2
Kettle Creek – Flying Horse 115 kV	LN	CSU	162 / 180	183.4	113.2% / 101.9%	201.2	123.4% / 111.1%	10.2% / 9.2%	Double-Circuit Tower Midway – Waterton 345 kV Daniels Park – Jackson Fuller 230 kV
Kettle Creek – Flying Horse 115 kV	LN	CSU	162 / 180	163.5	100.9% / 90.8%	176.7	109.1% / 98.2%	9.2% / 7.4%	Double-Circuit Tower Comanche – Daniels Park 345 kV 1 & 2
Cottonwood N – Kettle Creek 115 kV	LN	CSU	162 / 180			177.6	107.9% / 97.1%		Double-Circuit Tower Midway – Waterton 345 kV Daniels Park – Jackson Fuller 230 kV
Cottonwood N – Kettle Creek 115 kV	LN	CSU	162 / 180	165.3	102.1% / 91.9%	173.0	106.7% / 96.1%	4.6% / 4.2%	Bus Fault Cottonwood 115 kV S bus
Briar Gate – Cottonwood S 115 kV (For Information Only)	LN	CSU	150 / 192	170.0	112.2% / 87.6%	170.0	112.2% / 87.6%	0% / 0%	Bus Fault Cottonwood 115 kV N bus

*Current-corrected flows for transmission lines only.

[1] Includes facilities with an Impact Factor of 2% or more of the proposed 120 MW generation.

B. Generation Dispatch

Case Description: 2016 HS, Colorado South to North Generation Flow Bias, Fountain Valley Units On at Maximum, based on WECC 17hs1ap.sav with updates from CCPG companies.

Benchmark Case – GI-2007-12

Arapahoe Unit 3 & 4	0 MW
Cabin Creek Units	210 MW
Cherokee Units 1 – 3	0 MW
Cherokee Unit 4	383 MW
Cherokee Unit 5-7	603.8 MW
Comanche Unit 1	360 MW
Comanche Unit 2	365 MW
Ft Lupton Units 1 & 2	0 MW
Pawnee Unit 1	536 MW
Manchief Units 1 & 2	0 MW
Ft St Vrain Units 1-4	700 MW
Valmont Unit 5	196 MW
Valmont Unit 6	0 MW
Alamosa Units 1 & 2	27 MW
QF Thermo – Ft Lup	266 MW
Brush Units 1, 3, & 4	0 MW
Brush Unit 2	0 MW
QF UNC	0 MW
Arapahoe Units 5-7	118 MW
Lamar DC Tie	101 MW Import from SPS
Spruce Units 1 & 2	0 MW
Brighton Units 1 & 2	85 MW
Fountain Valley Units	242 MW
Plains End Units	0 MW
RMEC Units 1-3	586 MW
Spindle Units 1 & 2	0 MW
Cedar Point Wind (MS 230 kV)	57.5 MW (23%)
Limon Wind (MS 345 kV)	138.1 MW (23%)
Peetz Logan 230 kV	132.4 MW (23%)
Comanche Unit 3	804 MW
Cedar Creek Wind	126.8 MW (23%)
San Luis Valley Solar	85.2 MW
Colorado Grn/Twin Buttes	97.3 MW
Ft St Vrain Units 5 & 6	134.5 MW
GI-2007-12 (J. Fuller 230kV)	249.9 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-2010-19 Case Adjustments

Ft St Vrain Units 5 & 6	0 MW

C. Proposed Project Schedule

D. Proposed Cherokee 230kV Station One-Line