Interconnection System Impact Study Report
Request # GI-2010-09

30 MW Solar Photovoltaic Generation
Pueblo County, Colorado

Public Service Company of Colorado
Transmission Asset Management
July 11, 2012

A. Executive Summary

Public Service Company of Colorado (PSCo) received an interconnection request (GI-2010-09) for a 30 MW solar photovoltaic generation facility in Pueblo County, Colorado. The interconnection request was received June 22, 2010. The solar generation facility is planned to consist of 60 Advanced Energy Solaron 500 kW inverters connected to photovoltaic panels. The draft of the Feasibility Study for this project was completed and posted on OASIS August 30, 2011 and the System Impact Study Agreement was executed October 3, 2011. Based on the results of the Feasibility Study, the Boone 115 kV substation was selected for study in the System Impact Study. The Customer's solar facility is currently planned to be located in the proximity of the Boone 115 kV substation and the electrical connection between these facilities would consist of a radial 115 kV line. For the SIS, the requested in service date was changed to December 31, 2013 with a backfeed date of October 1, 2013.

This request was studied as a Network Resource and an Energy Resource. These investigations included steady-state power flow and short circuit analyses. The request was studied as a stand-alone project only, with no evaluations made of other potential new generation requests that may exist in the Large Generator Interconnection Request (LGIR) queue, other than the generation projects that are already approved and planned to be in service by June 2014. The main purpose of this SIS was to evaluate the potential impact on the PSCo transmission infrastructure as well as that of neighboring utilities when injecting the additional 30 MW of solar photovoltaic generation at the existing Boone 115 kV substation, and delivering the additional generation to native PSCo loads.

Please note that due to the solid-state nature of the solar photovoltaic inverters, and because PSCo does not require solar PV facilities to include low voltage ride through or dynamic reactive power control for automatic voltage regulation, no transient stability analysis was necessary. However, the thermal and voltage analyses of the Feasibility Study were repeated in the System Impact Study for the new requested in-service date.

The results of the Category B & C contingency analyses can be found in Tables 5 & 6 in the Appendix. There were no Category B overloads that could be attributed to the

proposed generation. All of the Category C overloads in Table 6 are also overloaded in the Benchmark Case. The overloaded facilities are owned by BHE, PSCo, TSGT, and WAPA. The PSCo overloaded facility is the Midway 230/115 kV T1 transformer. PSCo PSCo plans to include the upgrade of this transformer in next year's 2014-2018 budget.. . For the remaining overloads, the Customer will need to work with BHE, TSGT, and WAPA to address their facilities.

Network Resource Interconnection Service (NRIS)

The analyses did not find thermal problems that could be solely attributed to the proposed PV solar generation. Therefore, the Network Resource Interconnection Service was found to be:

NRIS = 30 MW

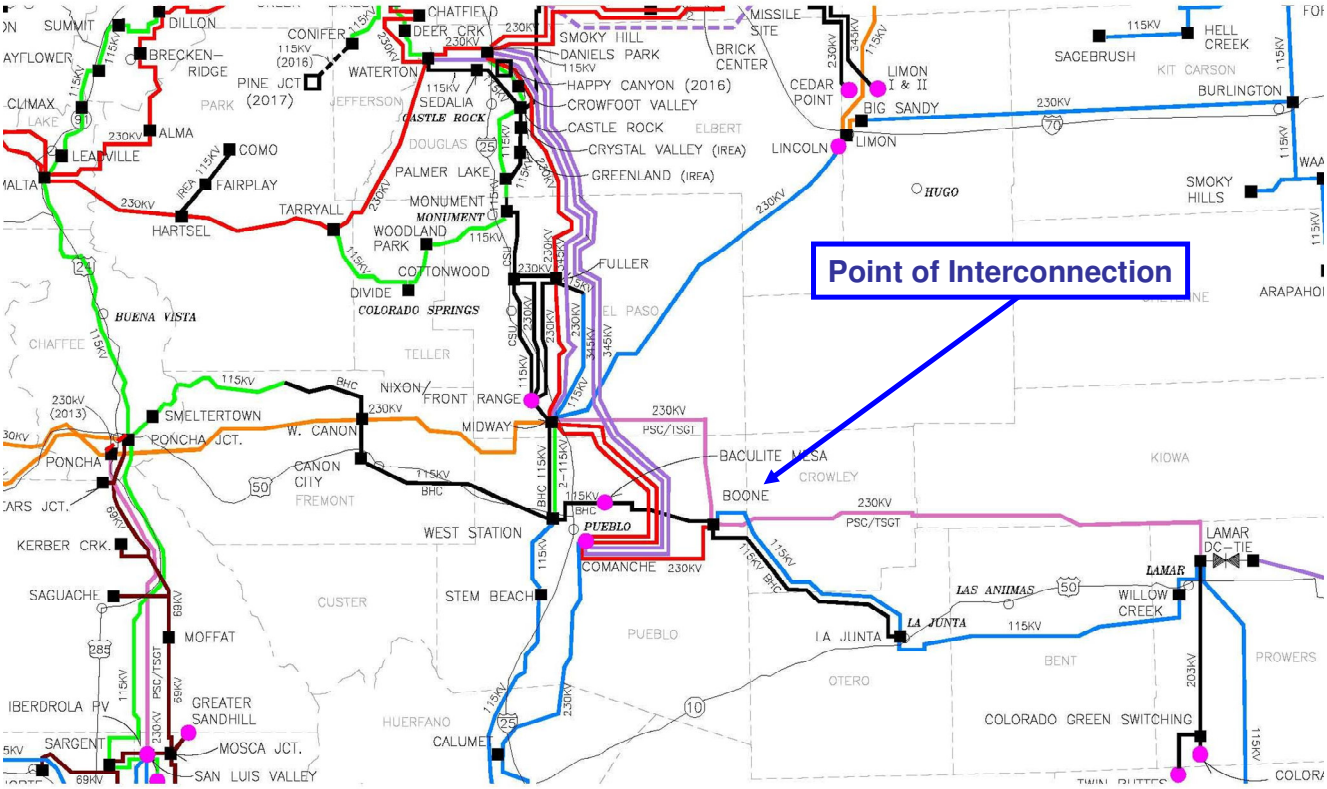
Energy Resource Interconnection Service (ERIS)

The analyses found facilities in the area that were overloaded due to Category C contingencies in both the benchmark case and the case with the proposed generation. This was for peak summer conditions. The studies found that the proposed generation caused significant increases in those pre-existing overloads (greater than 1%). Therefore, up to 30 MW of firm or non-firm transmission capability may be available depending upon generation dispatch levels, demand levels, WECC Major Path import levels (TOT 2A, TOT 3, TOT 7, etc.), and the operational status of transmission facilities.

Please note that upgrade of the PSCo Midway 230/115 kV T1 transformer is planned for inclusion in next year's 2014-2018 budget. The generation developer will need to work with WAPA, BHE, and TSGT to address the need to upgrade their facilities.

As indicated, the estimated time to design, procure and construct the interconnection facilities is approximately 18 months after authorization to proceed has been obtained. An Engineering & Procurement Agreement may be required to complete the interconnection facilities before December 31, 2013.

Figure 1 Comanche, Midway, Boone and Surrounding Transmission System



B. Introduction

Public Service Company of Colorado (PSCo) received an interconnection request (GI-2010-09) for a 30 MW solar photovoltaic generation facility in Pueblo County, Colorado. The interconnection request was received June 22, 2010. The solar generation facility is planned to consist of 60 Advanced Energy Solaron 500 kW inverters connected to photovoltaic panels.

The draft of the Feasibility Study for this project was completed and posted on OASIS August 30, 2011 and the System Impact Study Agreement was executed October 3, 2011. Based on the results of the Feasibility Study, the Boone 115 kV substation was selected for study in the System Impact Study. The Customer's solar facility is currently planned to be located in the proximity of the Boone 115 kV substation and the electrical connection between these facilities would consist of a radial 115 kV line. For the SIS, the requested in service date was changed to December 31, 2013 with a backfeed date of October 1, 2013.

This request was studied as a Network Resource and an Energy Resource. These investigations included steady-state power flow and short circuit analyses. The request was studied as a stand-alone project only, with no evaluations made of other potential new generation requests that may exist in the Large Generator Interconnection Request (LGIR) queue, other than the generation projects that are already approved and planned to be in service by June 2014.

The main purpose of this SIS was to evaluate the potential impact on the PSCo transmission infrastructure as well as that of neighboring utilities when injecting the additional 30 MW of generation at the existing Boone 115 kV substation, and delivering the additional generation to native PSCo loads. Please note that due to the solid-state nature of the solar photovoltaic inverters, no transient stability analysis was necessary. However, the thermal and voltage analyses of the Feasibility Study were repeated in the System Impact Study for the new requested in-service date.

C. Study Scope and Analysis

The System Impact Study evaluated the transmission impacts associated with the proposed 30 MW solar plant. It consisted of power flow and short circuit analyses. A transient stability analysis was not performed.

The power flow analysis was performed to identify any steady-state thermal or voltage limit violations resulting from the installation of the proposed generation and identify network upgrades required to deliver the proposed generation to PSCo loads. The short circuit analysis identified short circuit levels and determined short circuit impacts on area circuit breakers due to the installation of the proposed generation. Transient stability analyses were not performed because the proposed PV solar facility will be connected through

power electronic inverters which are not subject to inertial oscillations as are conventional rotating machines.

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 as a Network Resource Interconnection Service (NRIS). 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.

The project's Energy Resource Capability was also evaluated. 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 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, Affected Parties include Black Hills Energy (BHE), Tri-State Generation & Transmission (TSG&T) and Western Area Power Administration (WAPA).

D. Power Flow Study Models

The power flow studies were based on the WECC approved 12HS3SAP case. PSCo loads in the case were adjusted to reflect the most recent (September 2011) PSCo load forecast. IREA load was also adjusted to reflect IREA's latest load forecast. 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. Of note, a second 230/115 kV 150 MVA transformer is now planned for the Boone Substation and was included in the load flow models. TSG&T has requested this transformer be placed in service in 2014.

Two main power flow generation dispatch scenarios were evaluated. One was created as a reference benchmark scenario and the other was created with the proposed generation.

As part of the transmission system load flow model preparation, most of the existing and planned PSCo-connected wind turbine generation levels were increased to a level (21% of max) that represents the approximate average output of these wind plants. These wind plants include Peetz Logan, Cedar Creek, and Missile Site. However, the Colorado Green and Twin Buttes wind plant, coupled with the Lamar DC Tie, were dispatched to produce the 248 MW maximum flow on the Boone-Lamar 230 kV circuit. The PSCo thermal units were dispatched according to their relative generation costs. The resulting PSCo generation dispatch can be found in Appendix B. Please note that Cherokee Unit 2 was recently converted into a synchronous condenser.

The Area 70 (Area PSCOLORADO) swing machine in the WECC load flow case was moved to Fort St. Vrain Unit 1.

In the case with the proposed generation, the 30 MW of new PV solar was added to the Boone 115 kV bus using modeling information provided by the customer. The generator modeling settings for the System Impact Study are as follows:

	MW	Mvar Limits
60 x 0.5 MW Solaron 500E PV Inverters	30.0	+0 to -0

The generation dispatch with the proposed generation can also be found in Appendix A.

E. Power Flow Study Process

Contingency power flow studies were completed on the benchmark model and the model with the proposed new generation using PTI's PSSE Ver. 32.1.0 and MUST Ver. 10.2 programs. Results from the two cases were compared and new overloads in the new generation case were noted. Voltage criteria violations were also recorded. MUST's contingency analysis activities were 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 the south and southeast of the Denver Metro area, as well as the Denver Metro area itself (Zones 700, 704, 712, & 757). This area includes transmission owned by CSU, TSGT, and BHE. Single generating unit outages were also modeled for generators south and southeast of the Denver Metro area. The transmission facilities south and southeast of the Denver Metro area, along with the Denver Metro area itself, were monitored for overloads and voltage problems.

F. Power Flow Thermal Results

There were no Category B overloads that could be attributed to the new generation.

The results of the Category C contingency analyses can be found in Table 6 in the Appendix. These overloaded facilities are also overloaded in the Benchmark Case. The overloaded facilities are owned by BHE, PSCo, TSGT, and WAPA. The PSCo overloaded facility is the Midway 230/115 kV T1 transformer. PSCo plans to include the upgrade of this transformer in next year's 2014-2018 budget. For the remaining overloads, the Customer will need to work with WAPA, BHE, and TSGT to address their facilities.

In the Feasibility Study, BHE's Portland – West Station 115 kV circuit was found to be overloaded for both the Category B and C contingency analyses. However, BHE plans to complete construction of a second Portland – West Station 115 kV circuit by December 2012. The second circuit relieves that overload.

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).

Also, to ensure reliable operation, all Generating Facilities interconnected to the PSCo transmission system should adhere to the Rocky Mountain Area Voltage Coordination Guidelines. 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 for both the 115kV and 230 kV systems.

This study examined the impact of the proposed 30 MW PV solar generation connecting at the Boone 115 kV station on area transmission system voltages. No problems were found that could be attributed to the proposed generation.

H. Transient and Dynamic Stability Analysis

This project consists of 30 MW of PV solar generation and interfaces with the grid through 60 500 kW inverters. As a result, the proposed generation project will not exhibit any inertial or oscillatory characteristics as would a conventional synchronous machine. Also, PSCo does not require solar PV facilities to include low voltage ride through or dynamic reactive power control for automatic voltage regulation. Therefore, transient and dynamic stability analysis was excluded from this study.

I. Short Circuit

For the Customer proposed interconnection at the Boone 115 kV primary POI, no new circuit breakers are expected to exceed their capabilities following installation of the new generation. The calculated short circuit parameters for the POI at the Boone 115 kV substation are shown in Table 1 below. These results include the impact of the planned second 230/115 kV transformer at Boone.

.

Table 1 – Short Circuit Parameters at the Boone 115 kV Station POI

System Condition	Three-Phase Fault Level (Amps)	Single-Line-to-Ground Fault Level (Amps)	Thevenin System Equivalent Impedance (R +j X) (ohms)
All Facilities in Service w/o GI-2010-09	14,430	13,935	Z1(pos)= 0.56551 +j 4.56621 Z2(neg)= 0.58299 +j 4.56470 Z0(zero)= 0.61328 +j 5.05405

J. Costs Estimates and Assumptions

GI-2010-9 (System Impact Study Report)
May 22, 2012

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 2012 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. 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 upgrades is **$2,084,000.** The diagram in Appendix C below represents a conceptual one-line of the proposed interconnection at the Boone 115kV Substation. These estimates do not include costs 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 Armadillo Flats Project 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

Table 2 – PSCo Owned; Customer Funded Transmission Provider Interconnection Facilities

Element	Description	Cost Est. (Millions)
PSCo's Boone 115kV Transmission Substation	Interconnect Customer to the 115kV bus at the Boone 115kV Substation. The new equipment includes: • Three 115kV gang switches • One 115kV circuit breaker • Two 115V combination CT/PT metering units • Power Quality Metering (115kV line from Customer) • Three 115kV lightning arresters • One relay panel (transformer breaker 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	**$1.909**
Element Power's Armadillo flats 115kV Substation	Load Frequency/Automated Generation Control (LF/AGC) RTU and associated equipment.	**$0.175**
	Total Cost Estimate for PSCo-Owned, Customer-Funded Interconnection Facilities	**$2.084**
Time Frame	**Design, procure and construct**	**18 Months**

Table 3: PSCo Owned; PSCo Funded Interconnection Network Facilities

Element	Description	Cost Estimate (Millions)
PSCo's Boone 115kV Transmission Substation	N/A	**$0.0**
		$0.0
	Total Cost Estimate for PSCo-Owned, PSCo-Funded Interconnection Facilities	**$0.0**
Time Frame	**Site, design, procure and construct**	**N/A**

Table 4 – PSCo Network Upgrades for Delivery

Element	Description	Cost Est. (Millions)
	Not Applicable	
	Total Cost Estimate for PSCo Network Upgrades for Delivery	**$0.0**
	Design, procure and construct	**N/A**
	Total Project Estimate	**$2.084**

Cost Estimate Assumptions

- Scoping level cost estimates for Interconnection Facilities and Network/Infrastructure Upgrades for Delivery (+/- 30% accuracy) were developed by PSCo Engineering.
- Estimates are based on 2012 dollars (appropriate contingency and escalation applied).
- 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 metering are included in these estimates.
- 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 18 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.
- Customer will string OPGW fiber into substation as part of the transmission line construction scope.
- Breaker duty study determined that no breaker replacements are needed in neighboring substations.
- Line and substation bus outages will be authorized during the construction period to meet backfeed. Could potentially be problematic and extend requested backfeed date due to summer construction window.
- Power Quality Metering (PQM) will be required on the Customer's 115 kV line terminating into Boone Substation.

Appendix

GI-2010-09
Boone 115 kV – 30 MW

A. Load Flow Thermal Results (2014HS) –

Table 5 – Summary Listing of Differentially Overloaded Facilities (Category B Contingencies)[1]

					Benchmark Case Branch Contingency Loading Without GI-2010-09		Proposed Gen Case Branch Contingency Loading With GI-2010-09				
Overloaded Monitored Facility (Line or Transformer)	Type	Line Owner	FAC 009 Branch Rating MVA	Line Cond Rating MVA	N-1 Flow in MVA	N-1 Flow in % of Rating	N-1 Flow in MVA	N-1 Flow in % of Rating	% Change	Total # Overloads	Worst NERC Category B Contingency Outage
NONE											

[1] **Newly overloaded elements, or delta overloads > 1.0% of rating, due to proposed 30 MW generation increase at POI.**

Xcel Energy

Table 6 – Summary Listing of Differentially Overloaded Facilities (Category C Contingencies)[2]

					Benchmark Case Branch Contingency Loading Without GI-2010-09		Proposed Gen Case Branch Contingency Loading With GI-2010-09				
Overloaded Monitored Facility (Line or Transformer)	**Type**	**Line Owner**	**FAC 009 Branch Rating MVA**	**Line Cond Rating MVA**	**N-1 Flow in MVA**	**N-1 Flow in % of Rating**	**N-1 Flow in MVA**	**N-1 Flow in % of Rating**	**% Change**	**Total # Overloads**	**Worst NERC Category C Contingency Outage BF = Breaker Failure DCT = Double Circuit Tower**
Midway PS 230/115 kV T1	TR	PSCo	97	97	115.4	119.0	118.0	121.6	2.6	1	DCT Comanche – Daniels Park 345 kV #1 Comanche – Daniels Park 345 kV #1 #7015 & #7017
Midway PS – Midway BR 230 kV Bus Tie	TIE	PSCo/ WAPA	429	429	440.5	102.7	451.3	105.2	2.5	1	DCT Comanche – Daniels Park 345 kV #1 Comanche – Daniels Park 345 kV #1 #7015 & #7017
Desert Cove – West Station 115 kV	LN	BHE	120	122	137.6	114.6	140.5	117.1	2.5	2	BF Midway BR 230 kV Sub and Midway PS – Jackson Fuller 230 kV #1 #5129
Midway BR – Rancho 115 kV	LN	TSGT	80	N/A	80.0	99.9	81.0	101.3	1.4	1	DCT Comanche – Daniels Park 345 kV #1 Comanche – Daniels Park 345 kV #1 #7015 & #7017

[2] **Newly overloaded elements, or delta overloads > 1.0% of rating, due to proposed 30 MW generation increase at POI.**

B. Generation Dispatch

Case: 2014 HS; based on WECC 12HS3SAP including updates from CCPG companies.

Gross MW Dispatch of Major Generating Units in the Vicinity of GI-2010-09:

PSCo:

Bus	LF ID	MW
Comanche	C1	360
Comanche	C2	365
Comanche	C3	804.0
Lamar DC Tie	DC	210.0 Import
Fountain Valley	G1	0.0
Fountain Valley	G2	0.0
Fountain Valley	G3	0.0
Fountain Valley	G4	0.0
Fountain Valley	G5	0.0
Fountain Valley	G6	0.0
Colorado Green	1	44.7
Colorado Green	1	44.7
Twin Butte	1	41.3

ARPA:

Bus	LF ID	MW
City of Lamar	G1	24.8
City of Lamar	G2	10.3

BHE:

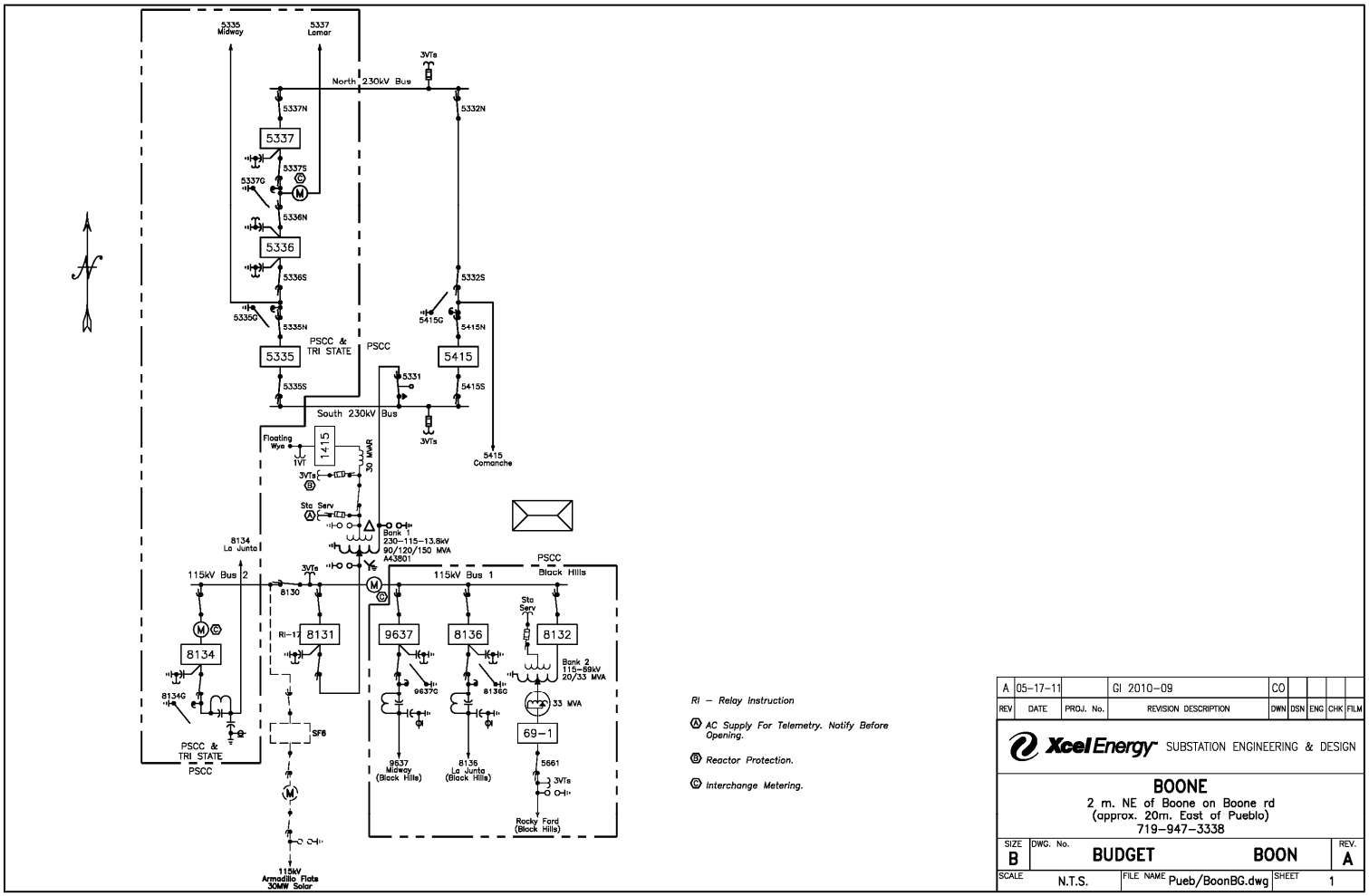
Bus	LF ID	MW
Canon City 55	C1	0.0
Canon City 59	C1	0.0
E Canon	G1	0.0
PP_MINE	G1	0.0
Pueblo Diesels	G1	0.0
Pueblo Plant	G1	0.0
Pueblo Plant	G2	0.0
R.F. Diesels	G1	8.6
Airport Diesels	G1	0.0
Baculite 1	G1	90.0
Baculite 2	G1	90.0
Baculite 3	G1	40.0
Baculite 3	G2	40.0

Baculite 3	S1	24.0
Baculite 4	G1	40.0
Baculite 4	G2	40.0
Baculite 4	S1	24.0
Baculite 5	G1	90.0

CSU:

Bus	LF ID	MW
Birdsale 1	1	0.0
Birdsale 2	1	0.0
Birdsale 3	1	0.0
Nixon	1	224.8
Tesla	1	28.0
Drake 5	1	49.0
Drake 6	1	82.3
Drake 7	1	139.1
Nixon CT 1	1	0.0
Nixon CT 2	1	0.0
Front Range CC 1	1	112.0
Front Range CC 2	1	112.0
Front Range CC 3	1	127.2

C. Boone Substation One-Line with GI-2010-09



D. GI-2010-09 Project Schedule

GI-2010-9 Feasibility & System Impact Study Report
30 MW Solar Interconnection, Boone 115kV