Interconnection System Impact Study Report
Request # GI-2016-23

150 MW Solar Generating Facility
Green Valley 230 kV Substation, Colorado

Public Service Company of Colorado
Transmission Planning
November 27, 2017

Executive Summary

Public Service Company of Colorado (PSCo) received an Interconnection Request (IR) on October 3, 2016 which was assigned GI-2016-23 queue position. GI-2016-23 is a solar photovoltaic generating facility rated at 150 MW gross electrical output that will be located in Adams County Colorado. The Point of Interconnection (POI) requested for GI-2016-23 is the 230 kV bus within PSCo's Green Valley 230 kV Switching Station.

The proposed 150 MW generating facility is expected to consist of approximately 75 inverters rated at 2.0 MW each. Preliminary information on the generating facility's layout suggests that the 75 inverters will be grouped in branches into five 34.5 kV collector systems, and each 34.5 kV collector system will connect to one 34.5/230 kV main step-up transformer. The generating facility will interconnect to the POI via an approximately one mile 230 kV transmission line.

The Commercial Operation Date (COD) requested for the generating facility is December 31, 2019. The assumed back-feed date for the facility is June 30, 2019 which is approximately six months prior to the COD.

Figure 1 below is a conceptual one-line diagram of the proposed physical connection location for GI-2016-23 the POI and the surrounding transmission system.

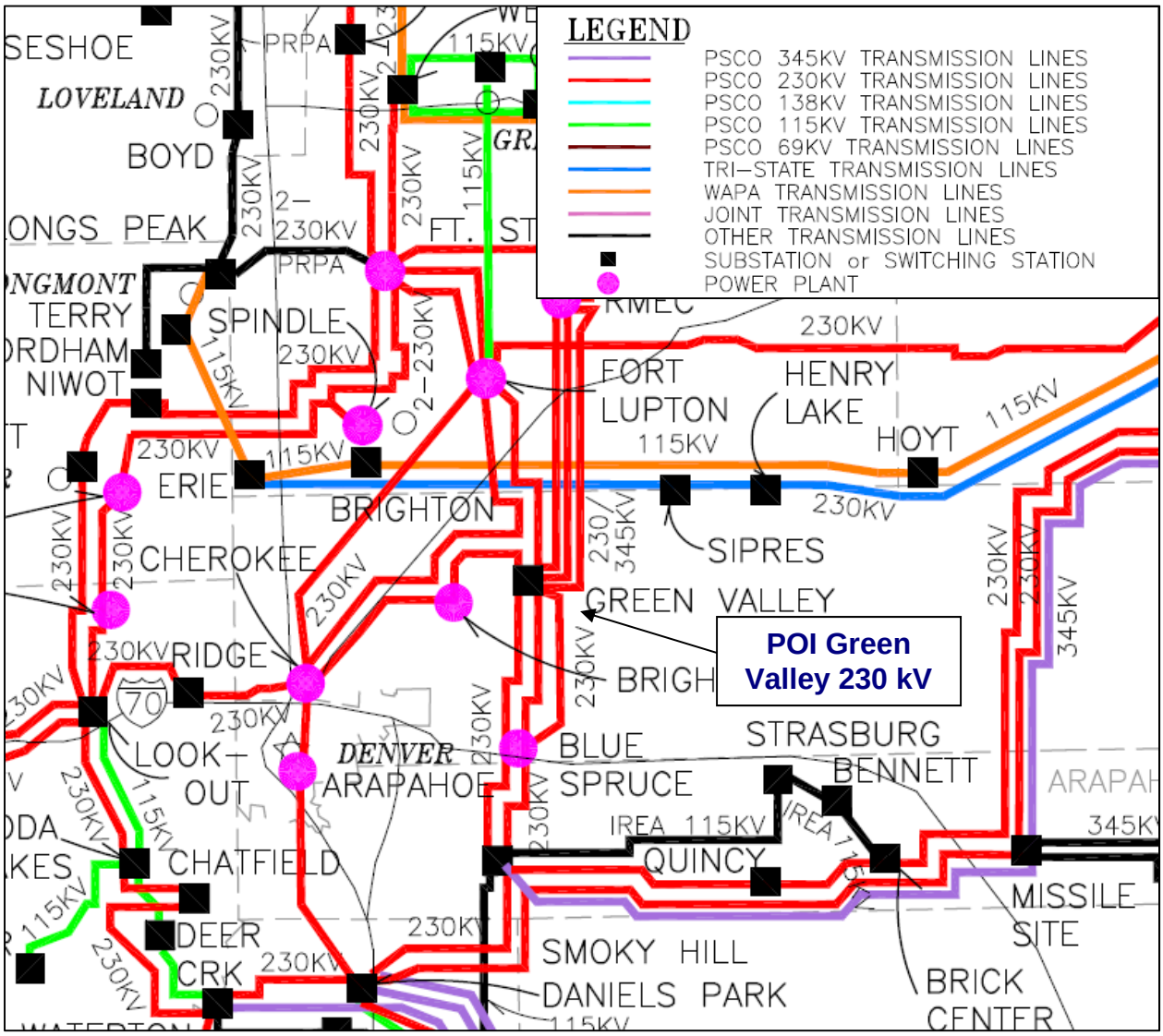


Figure 1: Conceptual one-line of proposed physical connection, the POI and surrounding Transmission System

As per the IR, GI-2016-23 is studied for both Network Resource Interconnection Service (NRIS) and Energy Resource Interconnection Service (ERIS). The 150 MW electrical output of GI-2016-23 is studied as a stand-alone project. That is, the study did not include any prior-queued IR's existing in PSCo's or any affected party's Generation Interconnection queue except those IR's which are:

a) considered to be PSCo planned resources in recognition of their signed Power Purchase Agreements, or
b) assumed in-service as per the agreed-upon study assumptions with the Interconnection Customer.

Accordingly, this System Impact Study determined the steady state and dynamic system impacts of the aggregate injection at the Green Valley 230 kV POI resulting from

the proposed 150 MW output of GI-2016-23 and the concurrent rated MW outputs of the existing Rocky Mountain, Blue Spruce Energy Centers, and Frank R. Knutson generation facilities. Further, this study also identifies the transmission improvements (i.e. Network Upgrades) needed to enable delivery of the proposed 150 MW electrical output of GI-2016-23 to PSCo network loads – that is, for GI-2016-23 to qualify for NRIS.

The System Impact Study consisted of steady state (power flow), short-circuit and transient stability analyses. The power flow analyses were performed using 2021 heavy summer (2021HS) base case. Two power flow models were created from the 2021HS case – a Benchmark Case which models the planned transmission system topology before the proposed GI-2016-23 interconnection (i.e. Before GI-2016-23 case) and a Study Case that includes the 150 MW generation under study (i.e. After GI-2016-23 case).

Power flow analysis performed for this study shows that the additional 150 MW generation injection into Green Valley Switching Station causes no significant differential impact (i.e. greater than 2 percent power flow change) on the transmission system, and thus GI-2016-23 is not considered to cause any adverse system impact. Therefore, no Network Upgrade is required for the proposed GI-2016-23 interconnection to meet the steady-state performance criteria.

The short circuit analysis results based on the 2019 transmission topology did not identify the need for any Network Upgrade for the proposed GI-2016-23 interconnection.

The transient stability analysis was performed using a 2021 heavy summer (2021HS) case and did not identify any unacceptable/degraded stability performance due to the proposed GI-2016-23 interconnection. Both angular stability as well as LVRT (Low Voltage Ride-Through) performance was acceptable for all normally cleared three-phase fault disturbances at the Green Valley 230 kV bus. Therefore, no additional Network Upgrades are required based on the transient stability analysis.

Based on the power flow analysis, Network Upgrades are not required for the proposed GI-2016-23 interconnection to achieve 150 MW NRIS[1].

Therefore, for GI-2016-23 interconnection:

NRIS = 150 MW

ERIS = 150 MW

As shown in **Tables 1–2**, (see pages 10-11) the cost for the Interconnection Facilities is **$3.570 million** and includes:

[1] Network Resource Interconnection Service allows Interconnection Customer 's Large Generating Facility to be designated as a Network Resource, up to the Large Generating Facility's full output, on the same basis as existing Network Resources interconnected to Transmission Provider's Transmission System, and to be studied as a Network Resource on the assumption that such a designation will occur. (*section 3.2.2 of Attachment N in Xcel Energy OATT*)

- $0.77 million for PSCo-Owned, Interconnection Customer Funded Interconnection Facilities
- $2.80 million for PSCo-Owned, PSCo Funded Interconnection Facilities

It is estimated that this work can be completed in approximately 18 months, following receipt of authorization to proceed.

No adverse impacts on the transmission systems of other entities are identified in the System Impact Study. Therefore, there is no affected party for GI-2016-23.

Power Flow N-1 Contingency Analysis

The 2021HS base case was updated to dispatch the existing and planned generation within the Green Valley area at their respective highest coincident output deemed appropriate for the planning of adequate transmission capacity. This was done in accordance with the generation dispatch assumptions practiced by PSCo Transmission Planning function to study the feasibility and system impact of generator interconnection requests as a Transmission Provider. Accordingly, the existing, planned and proposed generating plants near Green Valley Switching Station were dispatched as noted below.

- ✓ Rocky Mountain Energy Center gas generation = 586 MW
- ✓ Blue Spruce Energy Center gas generation = 268 MW
- ✓ Frank R. Knutson gas generation = 132 MW
- ✓ GI-2016-23 solar generation (Green Valley 230 kV) = 150 MW

Aggregate Area Generation Dispatched in Benchmark Case = 986 MW

Aggregate Area Generation Dispatched in Study Case = 1,136 MW

The GI-2016-23 *Benchmark Case* was derived from the 2021HS base case by changing the aggregate area generation dispatch near Green Valley Switching Station to 986 MW, as noted above. The GI-2016-23 *Study Case* was created by adding the proposed GI-2016-23 generating plant in the Benchmark Case and dispatching it at 150 MW rated output, thus resulting in 1,136 MW aggregate area generation dispatch near Green Valley Switching Station.

PSCo adheres to applicable NERC Reliability Standards & WECC Reliability Criteria for Bulk Electric System (BES) acceptable performance, as well as its internal performance criteria for planning studies. For steady state analysis, the performance criteria are as follows:

P0 - System Intact conditions:
Thermal Loading: <=100% Normal facility rating
Voltage range: 0.95 to 1.05 per unit

P1-P2 – Single Contingencies:
Thermal Loading: <=100% Normal facility rating[2]
Voltage range: 0.90 to 1.10 per unit
Voltage deviation: <=5% of pre-contingency voltage

P3-P7– Multiple Contingencies:
Thermal Loading: <=100% Emergency facility rating
Voltage range: 0.90 to 1.10 per unit
Voltage deviation: <=5% of pre-contingency voltage

[2] PSCo allows use of eight-hour facility rating for transformers for which it is available.

As is evident from the power flow analysis results performed for this study, the additional 150 MW generation injection into Green Valley Switching Station causes no significant differential impact (greater than 2 percent power flow change) on the transmission system, and thus GI-2016-23 is not considered to cause any adverse system impact. Therefore, no Network Upgrade is required for the proposed GI-2016-23 interconnection to meet the steady-state performance criteria.

Voltage Regulation and Reactive Power Capability

Interconnection Customers are required to interconnect its Large Generating Facility with Public Service of Colorado's (PSCo) Transmission System in accordance with the *Xcel Energy Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater Than 20 MW.* The guidelines are available at:

http://www.transmission.xcelenergy.com/staticfiles/microsites/Transmission/Files/PDF/Interconnection/Interconnections-POL-TransmissionInterconnectionGuidelineGreat20MW.pdf.

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 are expected to adhere to the *Rocky Mountain Area Voltage Coordination Guidelines (RMAVCG)*. Accordingly, since the POI for this interconnection request is located within Northeast Colorado - Region 7 defined in the *RMAVCG*; 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 (Attachment N effective 10/14/2016) requires all nonsynchronous Generator Interconnection (GI) Customers to provide dynamic reactive power within the power factor range of 0.95 leading to 0.95 lagging at the high side of the generator substation. Furthermore, Xcel Energy requires every Generating Facility to have dynamic voltage control capability to assist in maintaining the POI voltage schedule specified by the Transmission Operator as long as the Generating Facility does not have to operate outside its 0.95 lag – 0.95 lead dynamic power factor range capability.
- 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 (34.5 kV or 230 kV bus) of any additional static reactive power compensation needed within the generating plant in order to have adequate reactive capability to meet the +/– 0.95 power factor and the 1.02 – 1.03 per unit voltage range standards at the high side of the generator substation. Further, it is the responsibility of the Interconnection Customer to compensate their generation tie-line to ensure zero reactive power flow under no load conditions (i.e. all or most generators off-line).
- 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 Interconnection Customer has the responsibility 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-024-2.

Transient Stability Analysis

The transient stability analysis was performed using a benchmark and study case derived from the WECC 2021 Heavy Summer (2021HS) dynamics case created for use with the General Electric PSLF software program. The benchmark case was updated to match the generation dispatch in the Green Valley area similar to the power flow cases discussed previously. The generation facility was modeled using the PV solar dynamic model supplied by the Interconnection Customer.

The transient stability analysis simulated normal clearing of three-phase faults in the immediate study area. The following seven disturbances were simulated for the benchmark and/or study cases:

A. NERC/WECC Category P1 (single contingency) Disturbances
(Three-phase, close-in faults at Green Valley with normal clearing of 6 cycles)

1. Green Valley – Rocky Mountain Energy Center 230 kV Line
2. Green Valley – Spruce 230 kV Line
3. Green Valley – Imboden 230 kV Line
4. Green Valley – Sky Ranch 230 kV Line
5. Green Valley – Fort Lupton 230 kV Line
6. Green Valley – Barr Lake 230 kV Line

B. NERC/WECC Category P7 (common structure) Disturbances
(Three-phase, close-in faults at Green Valley with normal clearing of 6 cycles)

7. Green Valley – Keenesburg #1 & #2 230 kV double circuit tower line

The results noted in Appendix B demonstrate that no unacceptable/degraded stability performance occurs due to the proposed GI-2016-23 interconnection. Since none of the normally cleared three-phase fault disturbances at Green Valley resulted in tripping of the solar generators proposed for the GI-2016-23 generating facility, it is concluded that angular stability as well as LVRT (Low Voltage Ride-Through) performance of GI-2016-23 is acceptable. Select stability plots are provided in Appendix C. A complete set of stability plots are available on request.

Short Circuit Analysis

The short circuit study results show that no circuit breakers in the Green Valley Switching Station (or in PSCo's transmission system in proximity of the POI) will be over-dutied by interconnecting the proposed GI-2016-23 solar generation facility. The base case scenario before GI-2016-23 included preliminary models for all planned transmission system improvements and planned generating plants projected to be in-service through the end of 2019.

GI-2016-23 Impact on Short Circuit Levels and Breaker Duty Margins at Green Valley 230 kV POI

System Condition	Three-Phase (3-Ph) Fault Level (Amps)	Single-Line-to-Ground (SLG) Fault Level (Amps)	Thevenin System Equivalent Impedance (R + jX) (Ohms)
Before GI-2016-23 Y2019	31,609	21,893	Z1(pos)= 0.354 +j 4.186 Z2(neg)= 0.396 +j 4.179 Z0(zero)= 2.765 +j 9.489
After GI-2016-23 Y2019	31,752	24,569	Z1(pos)= 0.354 +j 4.186 Z2(neg)= 0.396 +j 4.179 Z0(zero)= 1.827 +j 7.743

Costs Estimates and Assumptions

Scoping level cost estimates for Interconnection Facilities and Network/Infrastructure Upgrades for Delivery were developed by Public Service Company of Colorado (PSCo) / Xcel Energy (Xcel) Engineering. The cost estimates are in 2017 dollars with escalation and contingency factors included. AFUDC is not included. Estimates are developed assuming typical construction costs for previous completed projects. These estimates include all applicable labor and overheads associated with the siting support, engineering, design, material/equipment procurement, construction, testing 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 upgrades is $3.570 million.

Figure 2 below represents a preliminary one-line of the proposed GI-2016-23 interconnection within the Green Valley Station. The following tables list the improvements required to accommodate the interconnection and the delivery of the GI-2016-23 generation output. The cost responsibilities associated with these facilities shall be handled as per current FERC guidelines. Cost estimates and system improvements are subject to change upon a more detailed and refined design, which will occur in the facilities study.

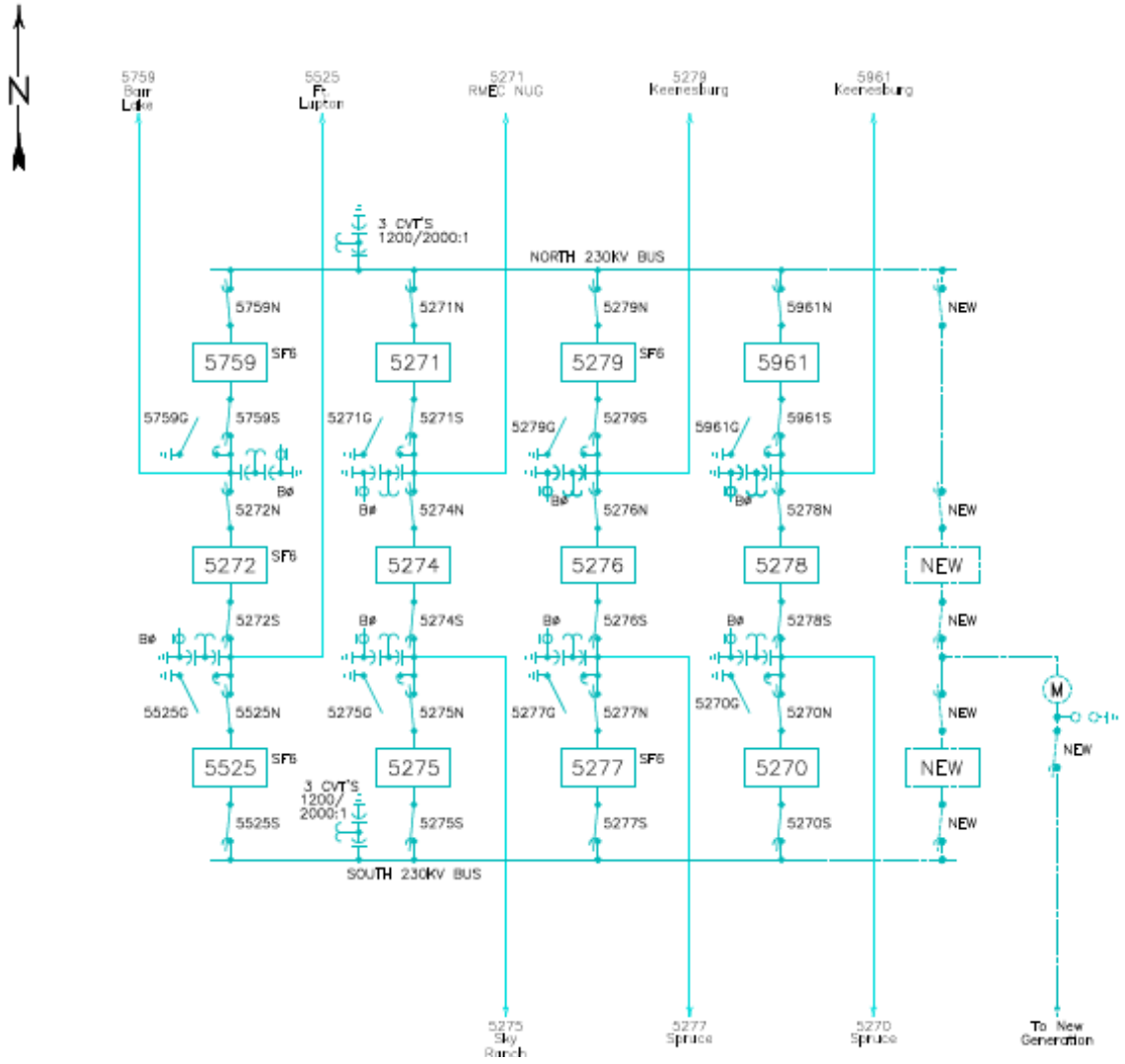


Figure 2: GI-2016-23 Interconnection to the 230 kV Bus in Green Valley Station

Table 1 – PSCo Owned; Customer Funded Interconnection Facilities

Element	Description	Cost Est. (Millions)
PSCo's Green Valley Transmission Switching Station	Interconnect the Customer's generating facility to the Green Valley 230kV Transmission Station The new equipment includes: • 230kV disconnect switch • 230kV arresters • 230kV CT/PT metering units • Station controls • Instrument transformers • Associated bus, wiring and equipment • Associated site development, grounding, foundations and structures • Associated transmission line communications, relaying and testing	**$0.700**
	230kV transmission line tap/upgrades into the station. Last span to station on Customer's T-line.	**$0.050**
	Siting and Land Rights support for permitting, ROW, and construction.	**$0.020**
	Total Cost Estimate for PSCo-Owned, Customer-Funded Interconnection Facilities	**$0.770**
Time Frame	**Site, design, procure and construct**	**18 Months**

Table 2 – PSCo Owned; PSCo Funded Interconnection Facilities

Element	Description	Cost Estimate (Millions)
PSCo's Green Valley Transmission Switching Station	Interconnect the Customer's generating facility to the Green Valley 230kV Transmission Station The new equipment includes: • Two 230kV circuit breaker • Five 230kV disconnect switches • Associated communications, supervisory and SCADA equipment • Associated line relaying and testing • Associated bus, miscellaneous electrical equipment, cabling and wiring • Associated foundations and structures • Associated road and site development, fencing and grounding	**$2.750**
	Siting and Land Rights support for siting studies, land and ROW acquisition and construction.	**$0.050**
	Total Cost Estimate for PSCo-Owned, PSCo-Funded Interconnection Facilities	**$2.800**
Time Frame	**Regulatory, site, design, procure and construct**	**18 Months**

Table 3 – PSCo Network Upgrades for Delivery

Element	Description	Cost Est. (Millions)
	None identified	**N/A**
	Total Cost Estimate for PSCo Network Upgrades for Delivery	**$0.000**
Time Frame	**Design, procure and construct**	**N/A**
	Total Project Estimate	**$3.570**

Cost Estimate Assumptions:

- Scoping level project cost estimates for Interconnection Facilities and Network Upgrades for Delivery have an assumed +/- 30% accuracy.
- Estimates are based on 2017 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 Customer's Generation Facility may not be located 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.
- No additional land is required.
- PSCo (or our Contractor) crews will perform all construction, wiring, testing and commissioning for PSCo owned and maintained facilities.
- A CPCN will not be required for the interconnection at the Green Valley Station.
- The Customer will be required to design, procure, install, own, operate and maintain a Load Frequency/Automated Generation Control (LF/AGC) RTU at their Customer Substation. PSCo / Xcel will need indications, readings and data from the LFAGC RTU.
- Customer will string OPGW fiber into the substation as part of the transmission line construction scope.

Conclusion

The power flow, transient stability, and short circuit analyses performed for this System Impact Study shows that the additional 150 MW generation injection into Green Valley Switching Station has no unacceptable impacts on the transmission system.

Therefore, for GI-2016-23 interconnection:

NRIS = 150 MW

ERIS = 150 MW

The estimated total cost for the transmission improvements required for GI-2016-23 interconnection is $3.570 million. They are expected to take approximately 18 months to construct, following receipt of authorization to proceed.

Appendix A – Power Flow N-1 Contingency Analysis Results

High Coincidence Generation Dispatch Near Green Valley:

Rocky Mountain Energy Center Gas 230kV = 586 MW;
Blue Spruce Energy Center Gas 230kV = 268 MW;
Frank R. Knutson Gas 230kV = 132 MW;
150 MW output from GI-2016-23 is dispatched to sink at Fort Lupton and Comanche

Table A.1 – Differential Impact[3] of GI-2016-23 on Facility Loadings

				Branch N-1 Loading Before 150 MW GI		Branch N-1 Loading After 150 MW GI			
Monitored Facility (Line or Transformer)	Type	Owner	Summer Normal (Continuous) Facility Rating in MVA	Flow in MVA	Flow in % of Summer Normal Rating	Flow in MVA	Flow in % of Summer Normal Rating	Differential Impact of GI-2016-23	N-1 Contingency Outage
Cherokee – California 115 kV	Line	PSCo	137	140	100.9%	141	101.4%	0.5%	Cherokee – Mapleton 115 kV
Arapahoe – Englewood 115 kV	Line	PSCo	120	139	116.8%	139	117.0%	0.2%	Waterton – Littleton 115 kV
Allison – Soda Lake 115 kV	Line	PSCo	152	157	101.6%	156	101.4%	-0.2%	Bancroft – Gray Street 115 kV
Fort Lupton – Coors Rec 115 kV	Line	PSCo	120	134	114.0%	136	115.3%	1.3%	Valmont – Lafayette 115 kV

[3] **Due to proposed 150 MW generation increase at Green Valley 230 kV Switching Station**

Appendix B – Transient Stability Analysis Results

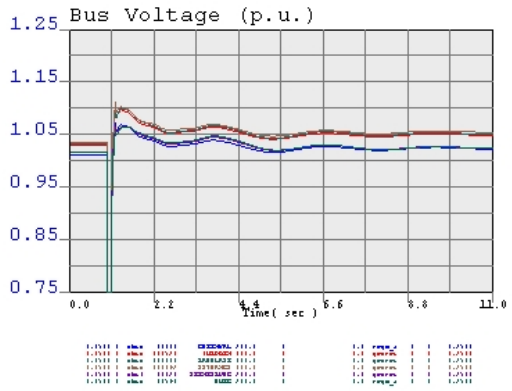
Stability Disturbances							
#	Fault Location	Fault Type	Facility Tripped	Clearing Time (cycles)	Stability Performance	Post-Fault Voltage Recovery	Angular Stability
1	Green Valley 230 kV	3ph	Green Valley – Rocky Mountain Energy Center 230 kV	Primary (6.0)	Acceptable	Maximum transient voltage dips within WECC criteria	No generator tripped & positive damping
2	Green Valley 230 kV	3ph	Green Valley – Spruce 230 kV	Primary (6.0)	Acceptable	Maximum transient voltage dips within WECC criteria	No generator tripped & positive damping
3	Green Valley 230 kV	3ph	Green Valley – Imboden 230 kV	Primary (6.0)	Acceptable	Maximum transient voltage dips within WECC criteria	No generator tripped & positive damping
4	Green Valley 230 kV	3ph	Green Valley – Sky Ranch 230 kV	Primary (6.0)	Acceptable	Maximum transient voltage dips within WECC criteria	No generator tripped & positive damping
5	Green Valley 230 kV	3ph	Green Valley – Fort Lupton 230 kV	Primary (6.0)	Acceptable	Maximum transient voltage dips within WECC criteria	No generator tripped & positive damping
6	Green Valley 230 kV	3ph	Green Valley – Barr Lake 230 kV	Primary (6.0)	Acceptable	Maximum transient voltage dips within WECC criteria	No generator tripped & positive damping
7	Green Valley 230 kV	3ph	Green Valley – Keenesburg 230 kV	Primary (6.0)	Acceptable	Maximum transient voltage dips within WECC criteria	No generator tripped & positive damping

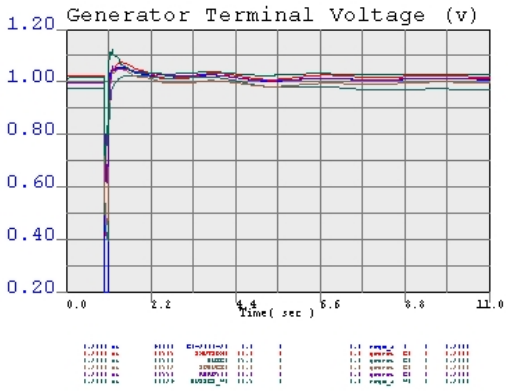
Appendix C – Transient Stability Analysis Plots

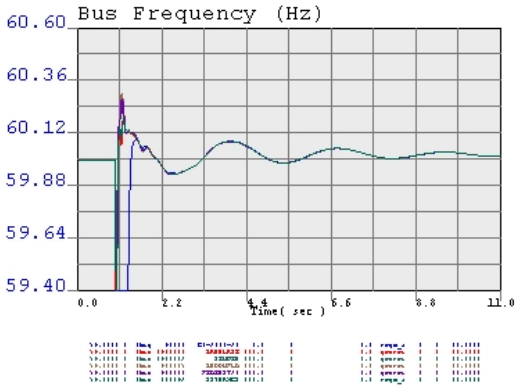
Plots shown below various recordings of bus voltage, bus frequency, generator angle, generator terminal voltage, generator speed, and generator power output for the following outages performed on the study case:

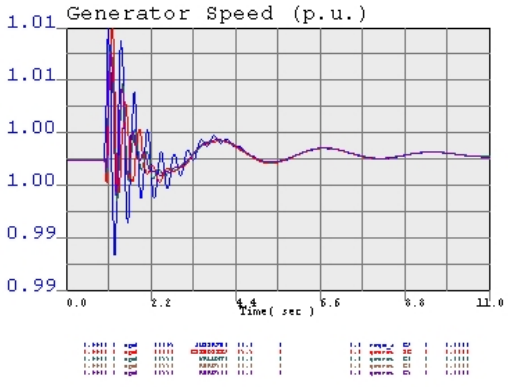
#1 – Green Valley – Rocky Mountain Energy Center 230 kV line
#5 – Green Valley – Spruce 230 kV line
#7 – Green Valley – Keenesburg 230 kV Double Circuit Tower line

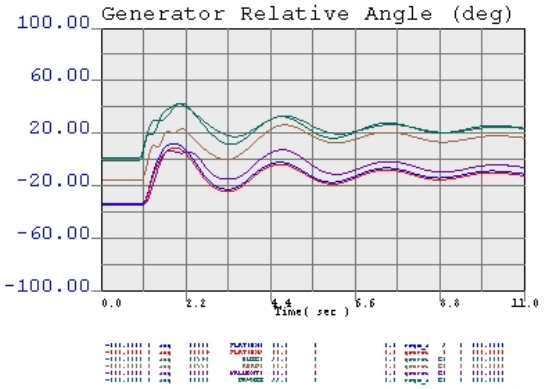
Other plots are available upon request.

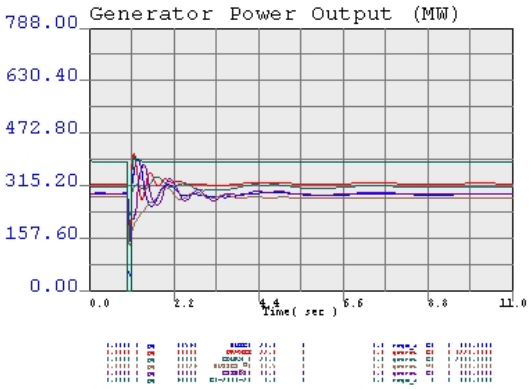




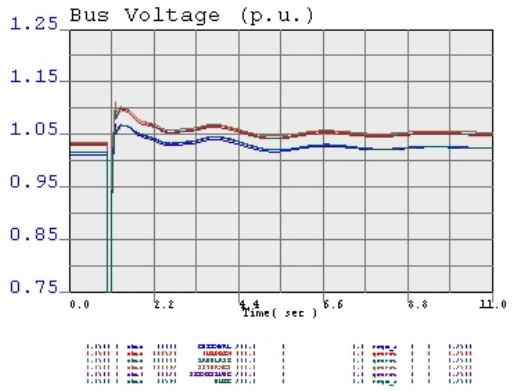


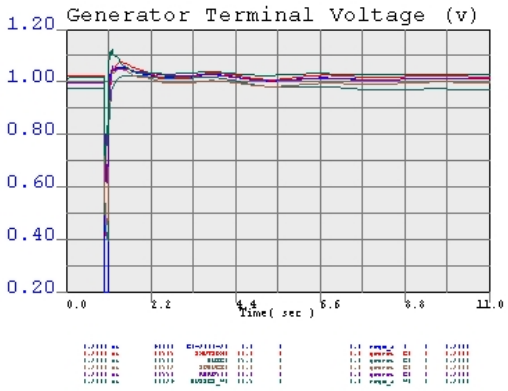


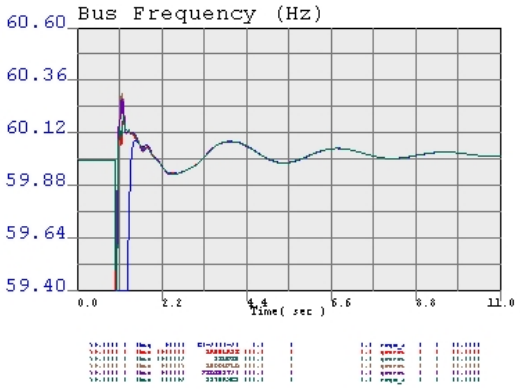


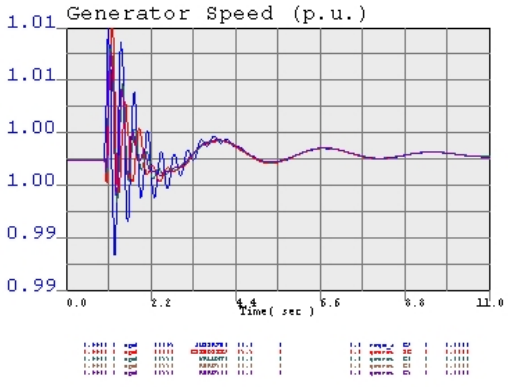


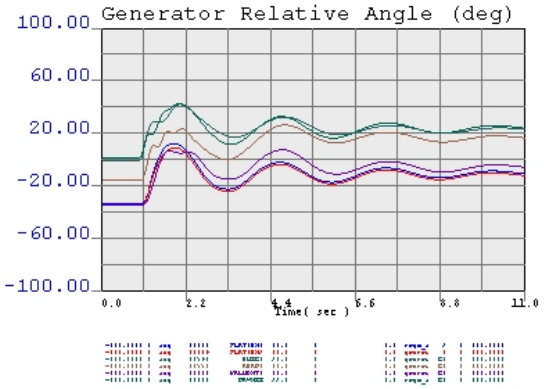
1
Green Valley fault, lose GV-RMEC

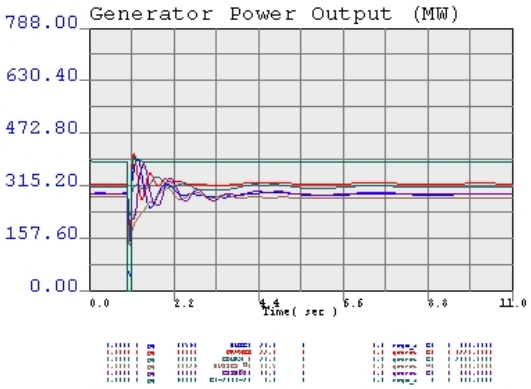




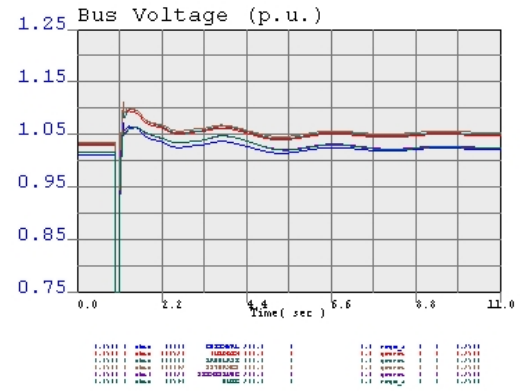


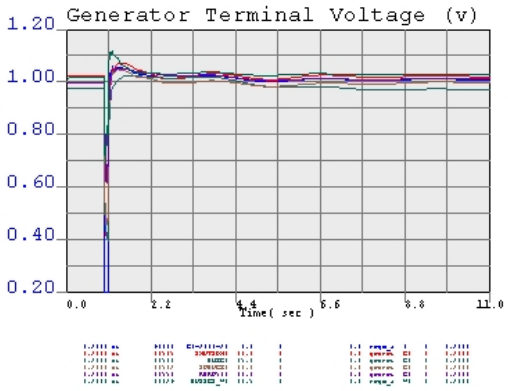


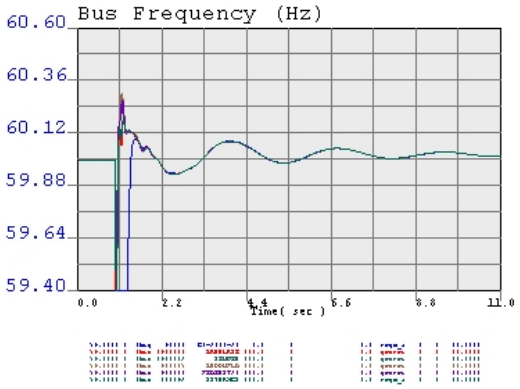


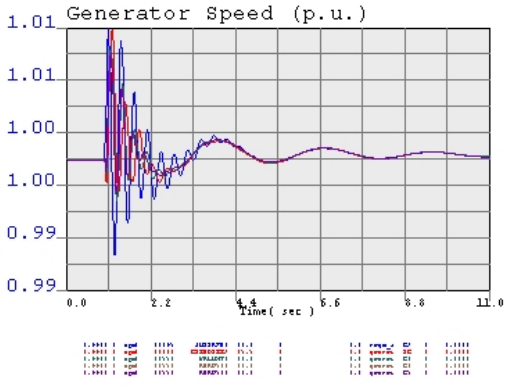


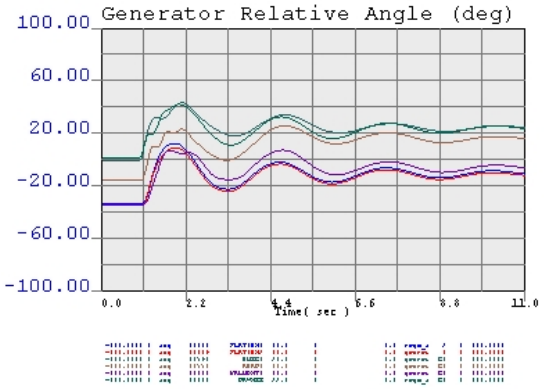
2
Green Valley fault, lose GV-Spruce

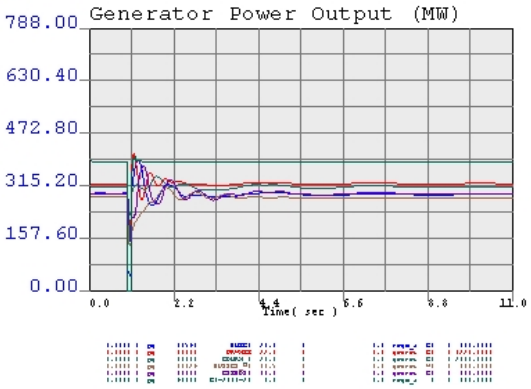












7
Green Valley fault, lose GV-Keenesburg DCTL