INTERCONNECTION SYSTEM IMPACT STUDY REPORT

GENERATOR INTERCONNECTION REQUEST
GI-2017-12

170 MW Wind Generating Facility
Interconnecting at
Keenesburg 230kV Substation

XCEL ENERGY – Public Service Company of Colorado (PSCo)
October 16, 2018

Executive Summary

GI-2017-12 ("GI") is a wind generation facility rated at 170 MW gross electrical output that will be located in Weld County, Colorado. The GI Customer designated the 230kV bus at PSCo's Keenesburg Substation as the Point of Interconnection (POI) – no alternative POI was specified. The GI-2017-12 facility will connect to the POI via the existing Cedar Creek wind generating facility's 230kV gen-tie line. The Commercial Operation Date (COD) requested by the GI Customer is November 30, 2019.

In accordance with the signed Interconnection Request, GI-2017-12 was evaluated for both Energy Resource Interconnection Service (ERIS)[1] and Network Resource Interconnection Service (NRIS)[2] in the Feasibility Study stage and the final report was posted on October 27, 2017. For both ERIS and NRIS evaluation, the 170 MW rated output of GI-2017-12 is assumed to be delivered to PSCo native load. This System Impact Study provides the results and conclusions for the GI-2017-12 interconnection evaluated as ERIS in accordance with the GI Customer's decision on October 12, 2018 to modify this GI request to ERIS only.

The GI-2017-12 interconnection request was studied in queue order and, based on engineering judgment, it was determined that no higher-queued interconnection requests have an impact on the results of this study.

The power flow analysis indicated no thermal constraints in the PSCo transmission system for the 170 MW injection from GI-2017-12 – therefore, no network upgrades are identified. The transient stability analysis determined that all generating units remain stable (in synchronism), have positive damping and satisfy acceptable dynamic performance criteria after the GI-2017-12 interconnection. The short-circuit and breaker duty analysis did not identify any over-dutied circuit breakers due to GI-2017-12.

The estimated cost of the recommended system improvements to interconnect the GI-2017-12 project is $0.080 million and includes:

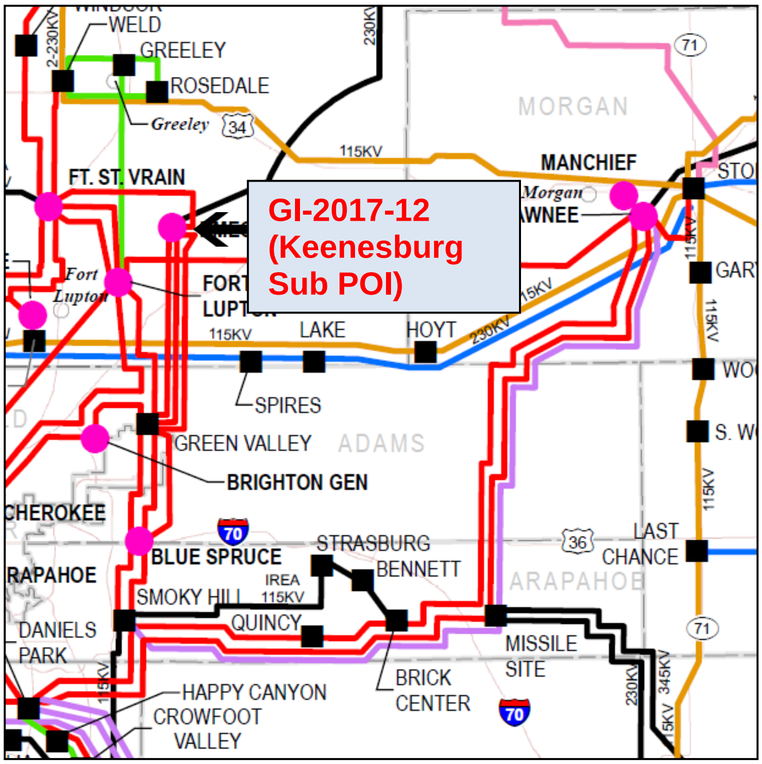
- $ 0.080 million for Transmission Provider's Interconnection Facilities (Table 1)
- $ 0.000 million for Network Upgrades for Interconnection for ERISor NRIS (Table 2)

[1] **Energy Resource Interconnection Service (ERIS)** allows Interconnection Customer to connect the Large Generating Facility to the Transmission System and be eligible to deliver the Large Generating Facility's output using the existing firm or non-firm capacity of the Transmission System on an "as available" basis. Energy Resource Interconnection Service does not in and of itself convey any right to deliver electricity to any specific customer or Point of Delivery. (*section 3.2.1 of Attachment N in Xcel Energy OATT*)

[2] **Network Resource Interconnection Service (NRIS)** 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*)

Introduction

GI-2017-12 ("GI") is a wind generation facility rated at 170 MW gross electrical output that will be located in Weld County, Colorado. The proposed 170 MW generating facility is expected to consist of approximately sixty-eight (68) GE 2.5 wind turbines and one 34.5/230kV, 200 MVA step-up transformer. The GI Customer designated the 230kV bus at PSCo's Keenesburg Substation as the Point of Interconnection (POI) – no alternative POI was specified. The GI-2017-12 facility will connect to the POI via the existing Cedar Creek wind generating facility's 230kV gen-tie line. The Commercial Operation Date (COD) requested by the GI Customer is November 30, 2019.



GI-2017-12 Point of Interconnection and Surrounding Area

In accordance with the signed Interconnection Request, GI-2017-12 was evaluated for both Energy Resource Interconnection Service (ERIS) and Network Resource Interconnection Service (NRIS) in the Feasibility Study stage and the final report was posted on October 27, 2017. For both ERIS and NRIS evaluation, the 170 MW rated output of GI-2017-12 is assumed to be delivered to PSCo native load. This System Impact Study provides the results and conclusions for the GI-2017-12 interconnection evaluated as ERIS only, in accordance with the customer decision on October 12, 2018 to modify this request to ERIS only.

The GI-2017-12 interconnection request was studied in queue order and based on engineering judgment it was determined that no higher-queued interconnection requests have an impact on the results of this study.

Study Scope and Analysis Criteria

The scope of this report includes steady state (power flow) analysis, transient stability analysis, short circuit analysis and scoping level cost estimates. The power flow analysis identifies thermal and voltage violations in the PSCo transmission system and the Affected Systems as a result of the GI-2017-12 interconnection. The transient stability analysis verifies that all generating units within PSCo transmission system and the Affected Systems remain stable (in synchronism), have positive damping and satisfy acceptable dynamic performance criteria. The short circuit analysis determines the maximum available fault current at the POI and identifies the circuit-breaker(s) within PSCo station(s) that would exceed their breaker duty rating and hence need to be replaced.

PSCo adheres to applicable NERC Reliability Standards & Western Electricity Coordinating Council (WECC) Reliability Criteria, as well as its internal transmission planning criteria for studies. The steady state analysis criteria are as follows:

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

P1-P2 – Single Contingencies:
Thermal Loading: <=100% Normal facility rating
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

Transient stability criteria require that all generating machines remain in synchronism and all power swings should be well damped following a contingency event. Also, transient voltage performance should meet the following WECC Disturbance-Performance criteria:

- Following fault clearing, the voltage shall recover to 80% of the pre-contingency voltage within 20 seconds for all contingencies
- For all contingencies, following fault clearing and voltage recovery above 80%, voltage at each applicable BES bus serving load shall neither dip below 70% of pre-contingency voltage for more than 30 cycles nor remain below 80% of pre-contingency voltage for more than two seconds.
- For contingencies without a fault, voltage dips at each applicable BES bus serving load shall neither dip below 70% of pre-contingency voltage for more than 30 cycles nor remain below 80% of pre-contingency voltage for more than two seconds

Power Flow Study Models

The study was performed using the Western Electricity Coordinating Council (WECC) 2022HS2 power flow case released on 07/19/2017. The WECC base case was adjusted by adopting the generation dispatch noted in Appendix C to create the Benchmark case (without GI-2017-12) and Study case (with GI-2017-12). GI-2017-12 was modeled using the modeling data provided by the GI Customer and dispatched at 170 MW (100% of nameplate rating). The existing Cedar Creek wind generation dispatch was increased from 21% to 80% of nameplate rating. PSCo's Comanche units were used as the sink for GI-2017-12 and for the increased injection from Cedar Creek units.

Voltage Regulation and Reactive Power Capability

Interconnection Customer is 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* (available at: http://www.transmission.xcelenergy.com/staticfiles/microsites/Transmission/Files/PDF/Interconnection/Interconnections-POL-TransmissionInterconnectionGuidelineGreat20MW.pdf).
In addition, wind generating plant interconnections must also fulfill the performance requirements specified 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 are expected to adhere to the *Rocky Mountain Area Voltage Coordination Guidelines (RMAVCG)*. Accordingly, since the POI for this interconnection request is located within Southeast Colorado - Region 4 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 non-synchronous 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 (34.5kV or 230kV 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 POI. Further, for wind generating plants to meet the LVRT (Low Voltage Ride Through) performance requirements specified in FERC Order 661-A, an appropriately sized and located dynamic reactive power device (DVAR, SVC, etc.) may also need to be installed within the generating plant. Finally, it is the responsibility of the Interconnection Customer to compensate their generation tie-line to ensure minimal reactive power flow under no load conditions.
- 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).

Power Flow Study Results

The power flow analysis simulated single contingencies within the transmission system surrounding the POI for GI-2017-12. The results of the single contingency analysis (P1 and P2 events) are given in Appendix A.

Several pre-existing thermal overloads are identified; but since these thermal overloads show net zero incremental change with the addition of GI-2017-12, none of them can be attributed to GI-2017-12. All pre-existing thermal overloads shall be mitigated by implementing corrective action plans.

The single contingency analysis did not show any voltage limit violations due to the addition of the GI-2017-12.

Transient Stability Study Results

Transient stability analysis was performed using General Electric's PSLF ver.21.0_02 program. A dynamics study case was created by modeling GI-2017-12 in the 2023HS2 base case and the existing Cedar Creek wind generation was dispatched at 80% of nameplate rating. The five disturbances noted below were simulated using the PSLF's DYTOOLS EPCL feature. Bus voltage, bus frequency and generator angle were recorded and analyzed. Also, any generators that went out of synchronism were recorded.

NERC Category P1 (single contingency) Disturbances

Three-phase, close-in fault at bus designate by asterisk (*) with normal clearing of 5 cycles

1. Keenesburg* – Green Valley 230kV Ckt. #1
2. Keenesburg* – Green Valley 230kV Ckt. #2
3. Keenesburg* – Ft. St. Vrain 230kV
4. Keenesburg* – RMEC 230kV

NERC Category P7 (common structure double contingency) Disturbances

Three-phase, close-in fault at bus designate by asterisk (*) with normal clearing of 5 cycles

1. Keenesburg* – Green Valley 230kV Ckt. #1 and #2, double circuit tower line (DCTL)

The transient stability results indicated that unacceptable/degraded stability performance did not occur due to the proposed GI-2017-12 interconnection. The following results were obtained for every disturbance analyzed:

- ✓ No machines lost synchronism with the system
- ✓ No transient voltage drop violations were observed
- ✓ Machine rotor angles displayed positive damping

Transient stability plots showing surrounding bus voltages, bus frequencies, generator terminal voltages, generator relative angles, generator speeds, and generator power output for each of the disturbances run for each study scenario have been created and documented in Appendix B. Furthermore, 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 the NERC Reliability Standard PRC-024-1.

Short Circuit and Breaker Duty Analysis

The calculated short circuit levels and Thevenin system equivalent impedances at the POI are tabulated below.

Short Circuit Parameters at the GI-2017-12 Keenesburg 230kV Switching Station POI

	Without Proposed Generation	With Proposed Generation
Three Phase Current	31557 A	31689 A
Single Line to Ground Current	26104 A	26173 A
Positive Sequence Impedance	0.33160+J4.19470 ohms	0.33116+J4.17722 ohms
Negative Sequence Impedance	0.38970+J4.19188 ohms	0.38877+J4.17440 ohms
Zero Sequence Impedance	1.41690+J6.72316 ohms	1.41647+J6.71817 ohms

A preliminary breaker duty study found that no circuit breakers in the Keenesburg Substation (or in PSCo's remaining system) are over-dutied due to the proposed GI-2017-12 interconnection.

Costs Estimates and Assumptions

Figure 1 below shows the one-line diagram of the proposed GI-2017-12 interconnection to the PSCo Transmission System.

Transmission Provider has estimated the cost of the equipment, engineering, procurement and construction work needed to interconnect GI-2017-12. Tables 1 and 2 below summarize the transmission system improvements required to accommodate the interconnection of GI-2017-12.

The estimated cost of the recommended system improvements to interconnect the GI-2017-12 project is $0.080 million.

Table 1 – Transmission Provider's Interconnection Facilities

Element	Description	Cost Est. (Millions)
PSCo's Keenesburg 230kV Substation	Interconnect via the existing Cedar Creek Wind Farm Transmission Line 5967. • Associated transmission line communications, relaying and testing	**$0.080**
	Total Cost Estimate for Transmission Provider's Interconnection Facilities	**$0.080**
Time Frame	**Site, design, procure and construct**	**18 months**

Table 2 – Network Upgrades required for Interconnection (for ERIS or NRIS)

Element	Description	Cost Est. (Millions)
PSCo's Keenesburg 230kV Substation	Interconnect Customer via the existing Cedar Creek Wind Farm Transmission Line 5967. The new equipment includes; • None identified	**$0.000**
	Siting and Land Rights support for substation CPCN, land acquisition, and construction.	**$0.000**
	Total Cost Estimate for Network Upgrades ERIS	**$0.000**
Time Frame	**Site, design, procure and construct**	**N/A**

The cost responsibilities associated with these transmission system improvements shall be handled as per current FERC guidelines.

Cost Estimate Assumptions

- Scoping level (+/-30% accuracy) cost estimates for Interconnection Facilities were developed by PSCo Engineering.
- Estimates are based on 2018 dollars (appropriate contingency and escalation applied).
- Allowance for Funds Used During Construction (AFUDC) has been excluded.
- Labor is estimated for straight time only with no overtime included.
- Lead times for materials were considered for the schedule.
- PSCo (or its 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 Facilities construction.
- The estimated time to design, procure and construct the Interconnection Facilities is approximately 18 months.
- Line and substation bus outages will be necessary during the construction period. Outage availability could potentially be problematic and extend requested backfeed date due.
- 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.
- Power Quality Metering (PQM) will be required on the Customer’s 230kV line terminating into Transmission Provider’s Substation.
- The Customer’s Generation Facility is not in PSCo’s retail service territory. Therefore, no costs for retail load metering are included in these estimates.

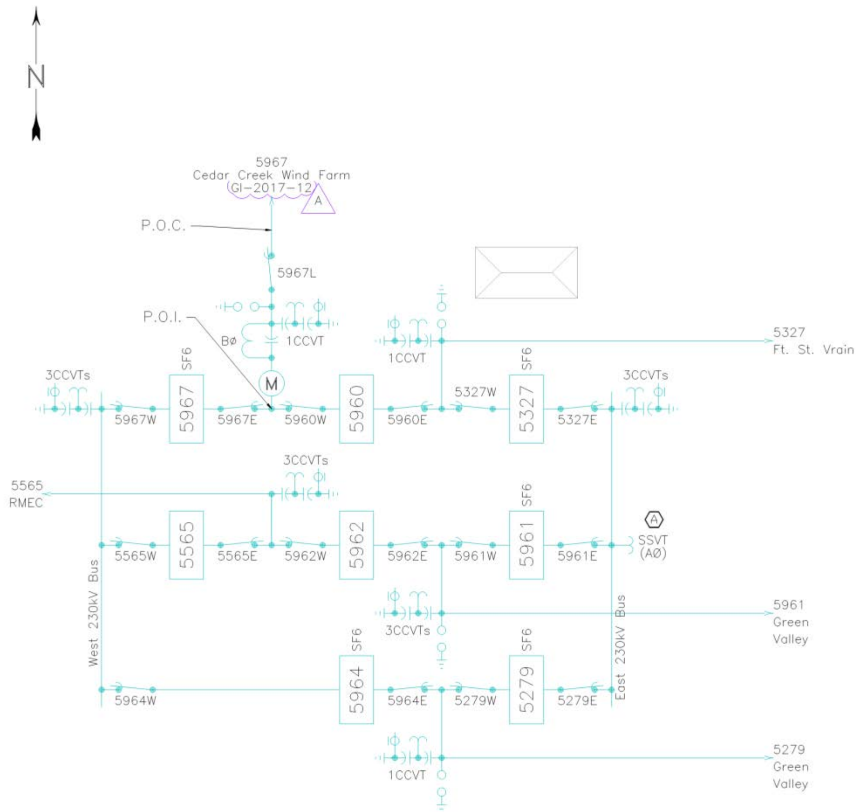


Figure 1 – GI-2017-12 Interconnection to Keenesburg 230kV Substation via the existing Cedar Creek Wind Generating Facility's Gen-Tie (Transmission Line 5967)

Appendix - A

A. Power Flow Analysis Results

1. No new thermal violations occurred with GI-2017-12.
2. Thermal overloads are calculated using the Normal Rating of the Facility.
3. Below are samples of pre-existing thermal violations (that is, without GI-2017-12). The comprehensive list of pre-existing thermal violations is available upon request.

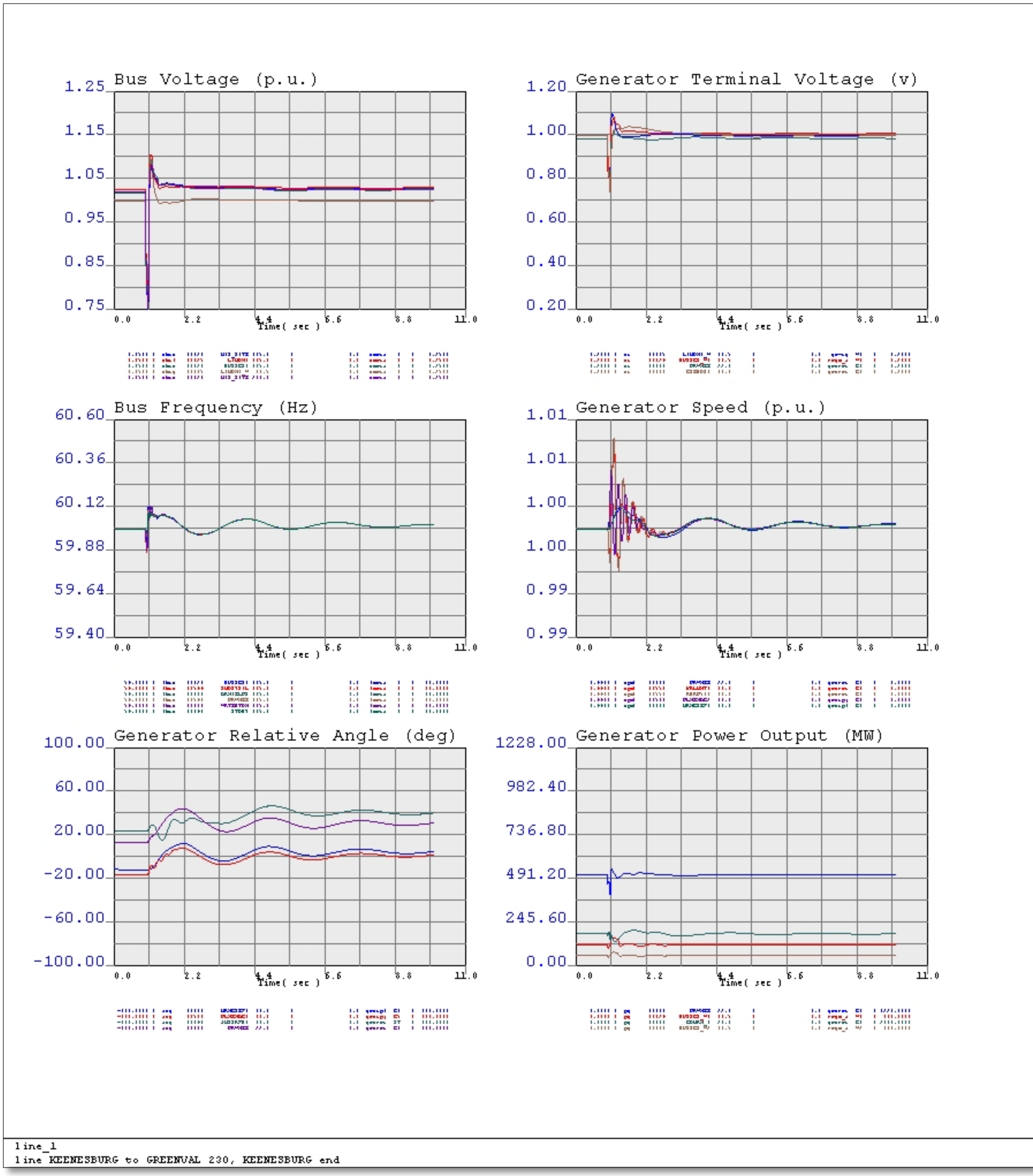
Summary of thermal violations from Single Contingency Analysis									
				Facility Loading Without GI-2017-12		Facility Loading With GI-2017-12			
Monitored Facility (Line or Transformer)	**Type**	**Owner**	**Branch Rating MVA (Norm/Emer)**	**N-1 Flow MVA**	**N-1 Flow % of Rating (Norm/Emer)**	**N-1 Flow MVA**	**N-1 Flow % of Rating (Norm/Emer)**	**% Change**	**NERC Single Contingency**
Allison – Soda Lake 115kV	Line	PSCo	153/174	159	104%/91%	159	104%/91%	0.0%	Bancroft – Kendrick 115kV
Bancroft – Kendrick 115kV	Line	PSCo	158/174	159	101%/91%	159	101%/91%	0.0%	Allison – Soda Lake 115kV
Cherokee_S – Mapleton2 115kV	Line	PSCo	159/175	165	104%/95%	165	104%/95%	0.0%	Cherokee_S – North 115kV

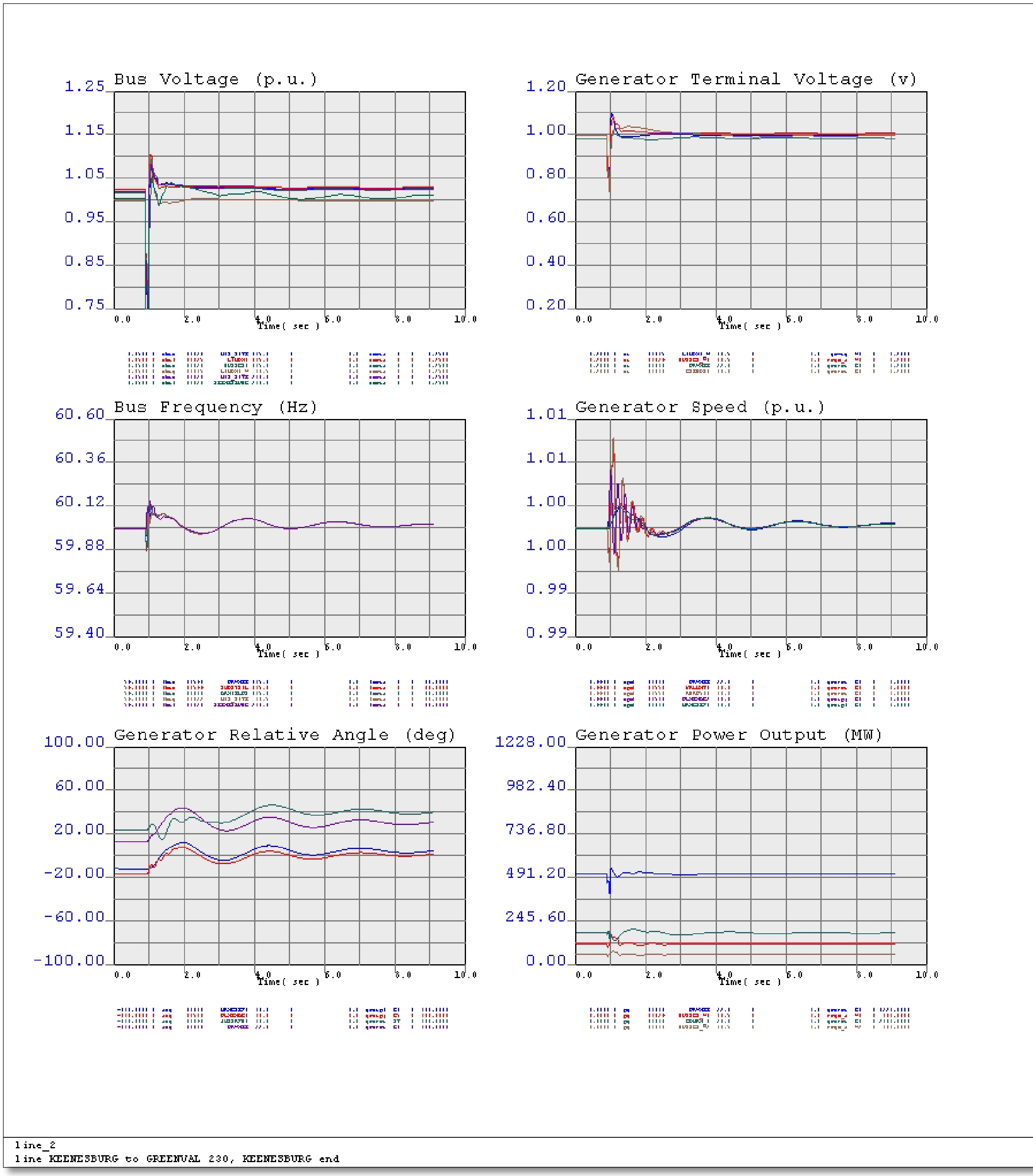
Appendix - B

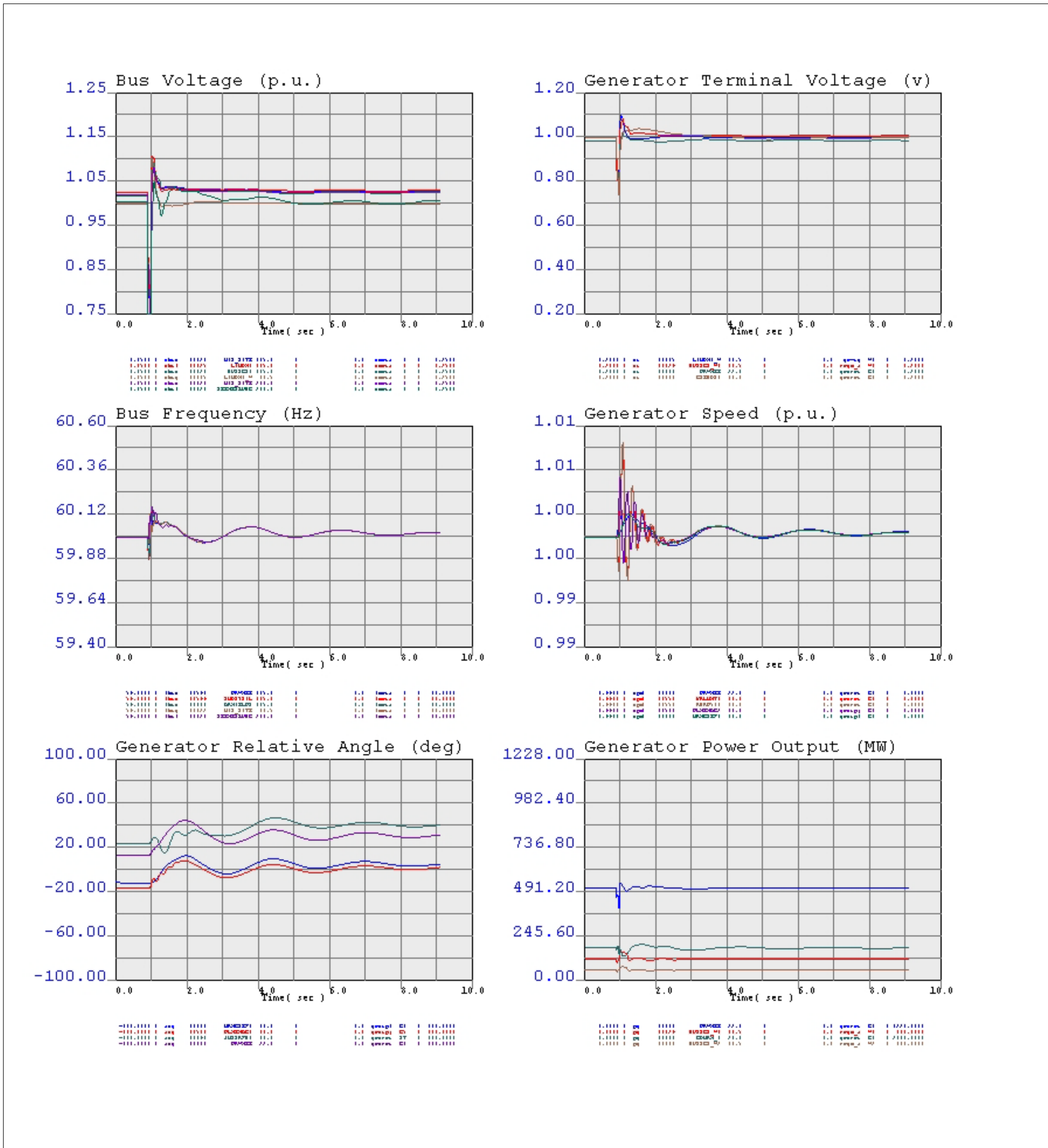
B. Transient Stability Analysis Results

1. No transient instability occurred with GI-2017-12.
2. Transient stability examined faults in the vicinity of the proposed generation.
3. Stability Plots are available upon request.

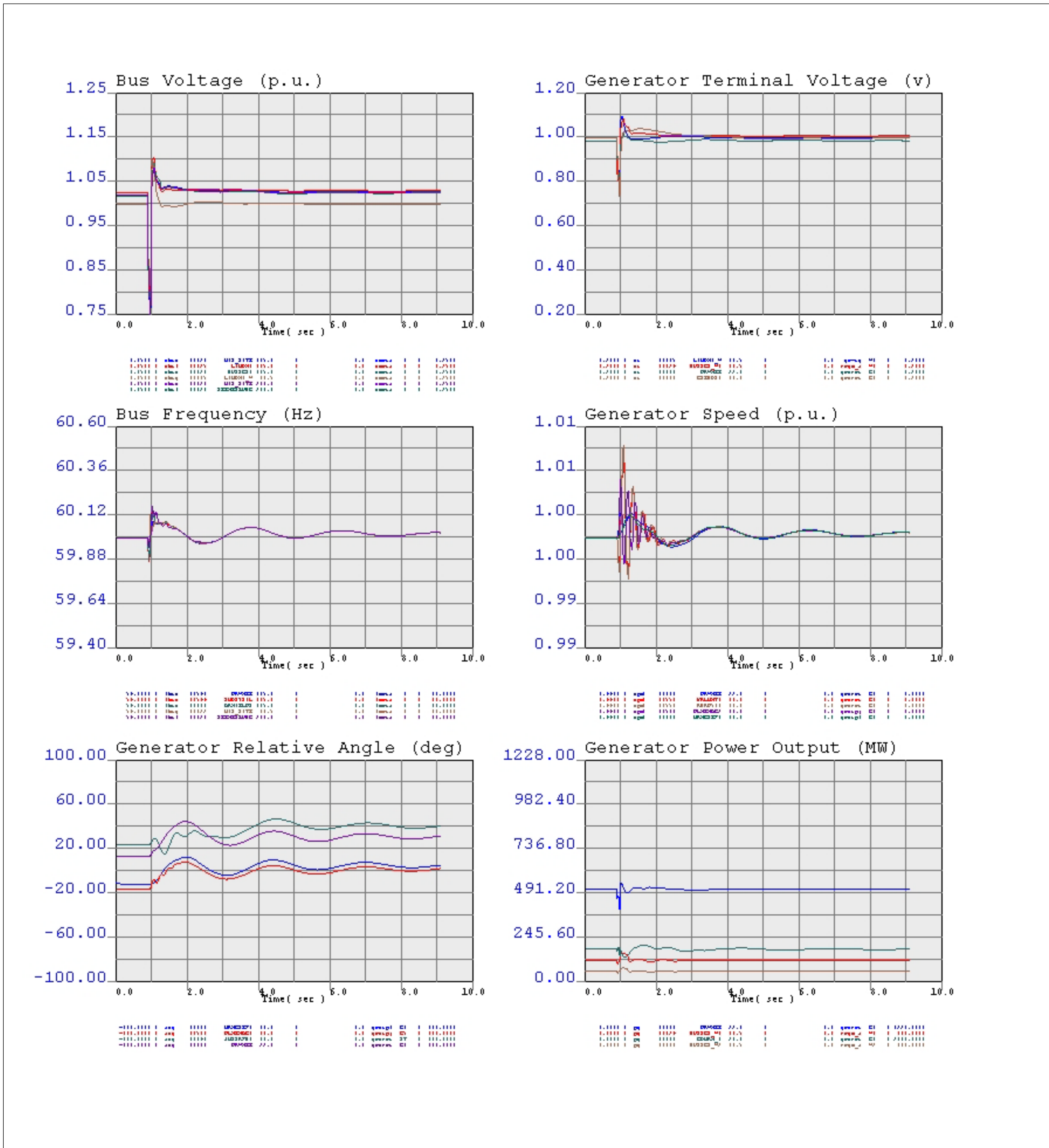
Stability Scenarios						
#	**Fault Location**	**Fault Type**	**Facility Tripped**	**Clearing Time (cycles)**	**Post-Fault Voltage Recovery**	**Angular Stability**
1	Keenesburg 230kV	3ph	Keenesburg-Green Valley #1 230kV Line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
2	Keenesburg 230kV	3ph	Keenesburg-Green Valley #2 230kV Line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
3	Keenesburg 230kV	3ph	Keenesburg-St.Vrain 230kV Line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
4	Keenesburg 230kV	3ph	Keenesburg-RMEC 230kV Line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
5	Keenesburg 230kV	3ph	Keenesburg-Green Valley #1, #2 230kV double circuit tower lines (DCTL)	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping


Bus Voltage (p.u.)
1.25
1.15
1.05
0.95
0.85
0.75
Generator Terminal Voltage (v)
1.20
1.00
0.80
0.60
0.40
0.20
Bus Frequency (Hz)
60.60
60.36
60.12
59.88
59.64
59.40
Generator Speed (p.u.)
1.01
1.01
1.00
1.00
0.99
0.99
Generator Relative Angle (deg)
100.00
60.00
20.00
-20.00
-60.00
-100.00
Generator Power Output (MW)
1228.00
982.40
736.80
491.20
245.60
0.00
0.0
2.2
4.4
6.6
8.8
11.0
Time(sec)
line_1
line KEENESBURG to GREENVAL 230, KEENESBURG end

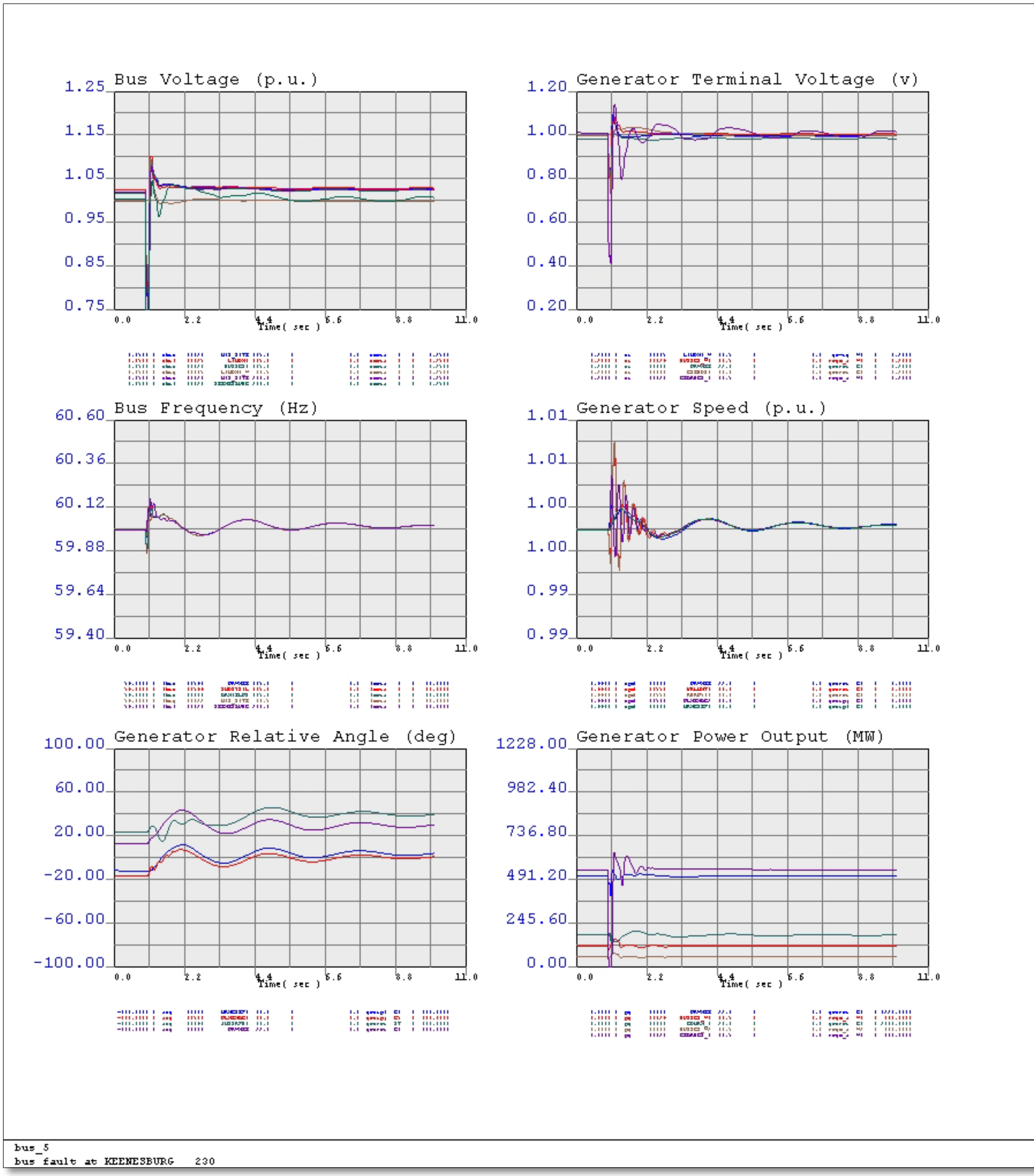

Bus Voltage (p.u.)
Generator Terminal Voltage (v)
Bus Frequency (Hz)
Generator Speed (p.u.)
Generator Relative Angle (deg)
Generator Power Output (MW)
Time(sec)
line_2
line KEENESBURG to GREENVAL 230, KEENESBURG end



line_3
line KEENESBURG to ST.VRAIN 230, KEENESBURG end



line_4
line KEENESBURG to PMEC 230, KEENESBURG end


Bus Voltage (p.u.)
1.25
1.15
1.05
0.95
0.85
0.75
Generator Terminal Voltage (v)
1.20
1.00
0.80
0.60
0.40
0.20
Bus Frequency (Hz)
60.60
60.36
60.12
59.88
59.64
59.40
Generator Speed (p.u.)
1.01
1.01
1.00
1.00
0.99
0.99
Generator Relative Angle (deg)
100.00
60.00
20.00
-20.00
-60.00
-100.00
Generator Power Output (MW)
1228.00
982.40
736.80
491.20
245.60
0.00
0.0
2.2
4.4
6.6
8.8
11.0
Time(sec)
bus_5
bus fault at KEENESBURG 230

Appendix - C

C. Generation Dispatch in the Study area (MW is Gross Capacity)

PSCo:

BUS	Gen ID	MW (Pgen)	MW (Pmax)
Comanche 1	C1	360	360
Comanche 2	C1	327	365
Comanche 3	C1	350	780
Pawnee	C1	515	536
RMEC 1	G1	147	147
RMEC 2	G2	147	147
RMEC 3	G3	292	292
Spruce 1	G1	132	132
Spruce 2	G2	136	136
Cedar Creek 1A	W1	176	220
Cedar Creek 1B	W1	64	80
Cedar Creek 2A	W1	120	150
Cedar Creek 2B	W1	40	50
Cedar Creek 2B	W2	40	50
GI-2017-12	W1	170	170
Cedar Point	W1	52.5	250
RushCrk_W1	W1	84	400
RushCrk_W2	W2	42	200
Limon1_W	W1	42.2	201
Limon2_W	W2	42.2	201
Limon3_W	W3	42.2	201