DRAFT

GENERATION INTERCONECTION
REQUEST # GI-2016-9

SYSTEM IMPACT STUDY REPORT
480 MW PV SOLAR, ALAMOSA COUNTY, COLORADO

XCEL ENERGY – PSCO TRANSMISSION PLANNING WEST

November 14, 2017

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I. Executive Summary

On June 14, 2016, Public Service Company of Colorado (PSCo) Transmission Planning received an Interconnection Request (IR) for a 480 MW photovoltaic solar generation facility at the San Luis Valley Substation, which was assigned queue number GI-2016-9. The 230kV bus at San Luis Valley Substation was specified as the Point of Interconnection (POI). The Interconnection Customer requested a commercial operation date of December, 2018.

In accordance with the Interconnection Request, GI-2016-9 was studied for both Energy Resource Interconnection Service (ERIS)[1] and Network Resource Interconnection Service (NRIS)[2]. The main purpose of this System Impact Study (SIS) is to evaluate the potential system impact of GI-2016-9 on the PSCo transmission infrastructure, as well as that of neighboring entities, due to its rated 480 MW output injected at San Luis Valley 230kV bus for delivery to PSCo loads in the Denver metro area. The scope of this SIS included power flow analysis, transient stability analysis and short circuit analysis.

The 480 MW electrical output of GI-2016-9 IR was 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.

For power flow and short circuit analyses, the SIS verified the prior results and conclusions of the Feasibility Study. The transient stability analysis indicated there was no unacceptable stability performance due to the GI-2016-9 interconnection. The system remained stable for all five dynamic simulations corresponding to normal clearing of three phase fault on a transmission facility near the POI, which included the most severe N−1 contingency (i.e. loss of Poncha – SLV 230kV #1 line)

Based on the power flow contingency analysis results provided in Appendix A, the following Network Upgrades are identified for GI-2016-9 to deliver its rated 480 MW output to the PSCo loads:

1) A new 230kV transmission line between Poncha and San Luis Valley Substation and
2) A new 230kV transmission line between Poncha and Midway Substation.

[1] **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.

[2] **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.

As noted in Tables 2, 3 & 4, the total estimated cost for the transmission improvements needed for interconnection and delivery of the 480 MW rated output of GI-2016-9 as NRIS is $229.5M.

Therefore, for GI-2016-9 it is concluded that:

NRIS = 0 MW without Network Upgrades
NRIS = 480 MW with Network Upgrades
ERIS = 0–166 MW on an as-available basis

However, based on the 60 months construction timeframe for Network Upgrades noted in Table 4, the earliest feasible COD for GI-2016-9 to interconnect as NRIS is expected to be in 2023. And based on the 18 months construction timeframe for Interconnection Facilities in Tables 2 & 3, the requested December, 2018 COD is not feasible even for GI-2016-9 to interconnect as ERIS only.

II. Introduction

On June 14, 2016, Public Service Company of Colorado (PSCo) Transmission Planning received an Interconnection Request for a 480 MW photovoltaic solar generation facility at the San Luis Valley Substation, which was assigned queue number GI-2016-9. The 230kV bus at San Luis Valley Substation was specified as the Point of Interconnection (POI). The Interconnection Customer requested a commercial operation date of December, 2018.

III. Power flow and Transient Analyses

A. Power Flow N-1 Contingency Analysis

This is a recap of the power flow single contingency analysis that was done in the Feasibility Study for GI-2016-9. The GI-2016-9 benchmark case was derived from the 2018HS3 base case by changing the generation dispatch in the San Luis Valley. 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 around San Luis Valley area were dispatched as noted below.

San Luis Valley "generation pocket" for Solar

San Luis Valley 230kV Solar = 85% of rated capacity = 44.2 MW (52)
San Luis Valley 115kV Solar = 85% of rated capacity = 25.5 MW (30)
Blanca Peak 115kV Solar = 85% of rated capacity = 25.5 MW (30)
Greater Sand Hill 69kV Solar = 85% of rated capacity = 13.6 MW (16)
Mosca Distribution Solar = 85% of rated capacity =6.8 MW (8)

Aggregate generation dispatched in the San Luis Valley area in study cases = 115.6 MW. The GI-2016-9 study case was created by adding the GI-2016-9 generation to the benchmark case and dispatching it at 480 MW rated output.

PSCo adheres to all applicable NERC Standards & WECC Criteria for Bulk Electric System (BES) acceptable performance, as well as its internal transmission planning criteria for all studies. During system intact (N-0) conditions, PSCo's steady-state performance criteria require the transmission bus voltages remain within 0.95 – 1.05 per unit of nominal and the power flows stay below the applicable normal ratings of the transmission facilities. Following a single contingency, the steady state bus voltages must remain within 0.90 – 1.05 per unit of nominal, and the power flows must continue to stay below the applicable normal facility ratings. For N-1 post-contingency system conditions, the applicable normal rating is the seasonal continuous rating of the transmission facility – but PSCo allows use of eight-hour facility rating for transformers for which it is available. Further, PSCo does not rely on 30-minute emergency ratings of transmission facilities for meeting N-1 system performance in planning studies.

Based on the results of the steady-state power flow analyses provided in Table 1 of the Feasibility Study Report, and also provided in Appendix A of this report, it is evident that the GI-2016-9 generation will result in steady-state and post contingency overloads at various facilities in and around the SLV area. Therefore, the Network Upgrades required for GI-2016-9 to achieve NRIS for its rated 480 MW output are:

1) A new 230kV transmission line between Poncha and San Luis Valley Substation, and
2) A new 230kV transmission line between Poncha and Midway Substation.

B. 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 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/Interconn ection/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 request is located within South Central Colorado Region 5; 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 requires all Interconnection Customers to have the reactive capability to achieve +/− 0.95 power factor at the POI, with the maximum reactive capability (corresponding to rated output) available at all output levels. Furthermore, Xcel Energy requires all Generating Facilities to have dynamic voltage control capability and maintain the POI voltage specified by the Transmission Operator as long as the generating plant is on-line, producing power and it is not called upon to operate outside its 0.95 lag – 0.95 lead power factor range capability at the POI.

- 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.

➢ 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.

C. Short Circuit Analysis

The short circuit study results show that no circuit breakers in the San Luis Valley station (or any adjoining station) will be over-dutied by interconnecting the proposed GI-2016-9 solar generation facility.

Table 1 – GI-2016-9 Impact on Short Circuit Levels at SLV 230kV POI

Conditions	Fault Currents	Thevenin Impedances
Without GI-2016-9	Three-Phase: 3079A Single-Line: 3791A	Z1 = 6.583+j49.343 ohms Z2 = 6.589+j49.346 ohms Z0 = 1.345+j21.494 ohms
With GI-2016-9	Three-Phase: 3079A Single-Line: 4251A	Z1 = 6.583+j49.345 ohms Z2 = 6.589+j49.349 ohms Z0 = 0.617+j8.502 ohms

D. Transient Stability Analysis

The purpose of this analysis is to evaluate the transient stability impact of adding six 80 MW photovoltaic solar units (480 MW total) interconnected at the SLV 230kV station. The study area is the south-central Colorado transmission system centered on the San Luis Valley substation. The study area is impacted by generation dispatch, load levels, and system topology.

1. Methodology

Transient stability analysis determines the response of the transmission system to system disturbances such as the occurrences of faults, tripping of generator units, tripping of transmission lines or tripping of loads in the area around the POI. These studies evaluate generator frequency, generator rotor angles, bus voltages and power flows before, during and after a disturbance to determine if the system would remain stable after the disturbance.

A transient stability analysis was performed for several three-phase faults in San Luis Valley area. Some of these faults will consist of 3-phase faults occurring near the end of the transmission lines as well as at nearby power transformers and with normal clearing of the facility involved in five cycles for 230kV breakers and four cycles for 345kV breakers.

2. Computer Software

Analysis was performed using Positive Sequence Load Flow (GE-PSLF version 19).

3. Model Development

The study cases that were prepared for the power flow studies were used for the transient stability analysis. The cases used for the power flow studies assumed summer peak load assumptions and expected dispatch levels. Generation was dispatched as required to maintain a high north-to-south transfer level on TOT3.

The study base case reflected the system topology and load forecast for the 2021 summer peak demand period. The 2021 HS2 Approved Operating Case in GE PSLF Version 19.0 format (approved on January 5, 2016) was used for the study.

The following modeling and dispatch updates were done in the study cases.

- The Poncha – San Luis Valley #2 230kV and Poncha – W.Canon – Midway 230kV are modeled in-service.
- The solar generation was left at the dispatch level in the 2021HS case.
- The wind generation was left at the dispatch level in the 2021HS case.
- The Cherokee 5 and 7 outputs were reduced by 100 MW each.
- Fort St. Vrain Unit 1 output was reduced by 200 MW
- Ft. St. Vrain Unit 2 output was reduced by 80 MW
- The proposed generating facility was modeled as one single generation unit of 480 MW at +/- 0.95 power factor. The project's output was connected to the bulk electric system via a 34.5 kV collector system consisting of six 100 MVA 34.5/230kV transformers and a short gen-tie.
- The same dispatch assumptions for GI-2016-9 in the steady state analysis were used for the stability analysis.

a. Assumptions

1. Loads are represented at the high-voltage busses.
2. The power factor of loads is adjusted as necessary for the bus on which the load is represented and is based on historical power factor data where this information is available.
3. Voltage criteria violations on the transmission system are of more concern at load busses than at non-load busses.

b. Contingency Criteria

The transient stability analysis consisted of verifying the stability performance for the following five normally cleared three-phase fault disturbances.

NERC Category P1 (single contingency) Disturbances
Three-phase, close-in fault at bus designated by asterisk (*) with normal clearing of 5 cycles

1. PonchaBR* - San Luis Valley 230kV ckt. #2 line
2. PonchaBR - San Luis Valley* 230kV ckt. #2 line
3. Poncha* – Sargent 115kV line
4. Sargent – San Luis Valley*115kV line

NERC Category P2 (single contingency) Disturbances
Three-phase bus fault with normal clearing of 5 cycles

1. Poncha_PS 230kV bus fault

IV. Cost Estimates and Assumptions

Scoping level cost estimates (+/- 30% accuracy) for the Interconnection Facilities and Network Upgrades for Delivery were developed by Public Service Company of Colorado (PSCo)/Xcel Energy (Xcel) Engineering. These cost estimates are in 2017 dollars with escalation and contingency factors included. These cost estimates are developed assuming typical construction costs for previous completed projects and do not include the cost for any other Customer owned equipment and associated design and engineering.

Figure 1 below is the conceptual one-line of the GI-2016-9 interconnection to the San Luis Valley 230kV bus.

Figure 2 below is the one-line drawing that depicts the actual interconnection into the San Luis Valley 230kV bus.

Tables 2, 3, and 4 below list the transmission improvements needed to accommodate the interconnection and delivery of GI-2016-9 generation output as NRIS. The estimated total cost for the needed transmission improvements is **$229.3 million** dollars.

Xcel Energy

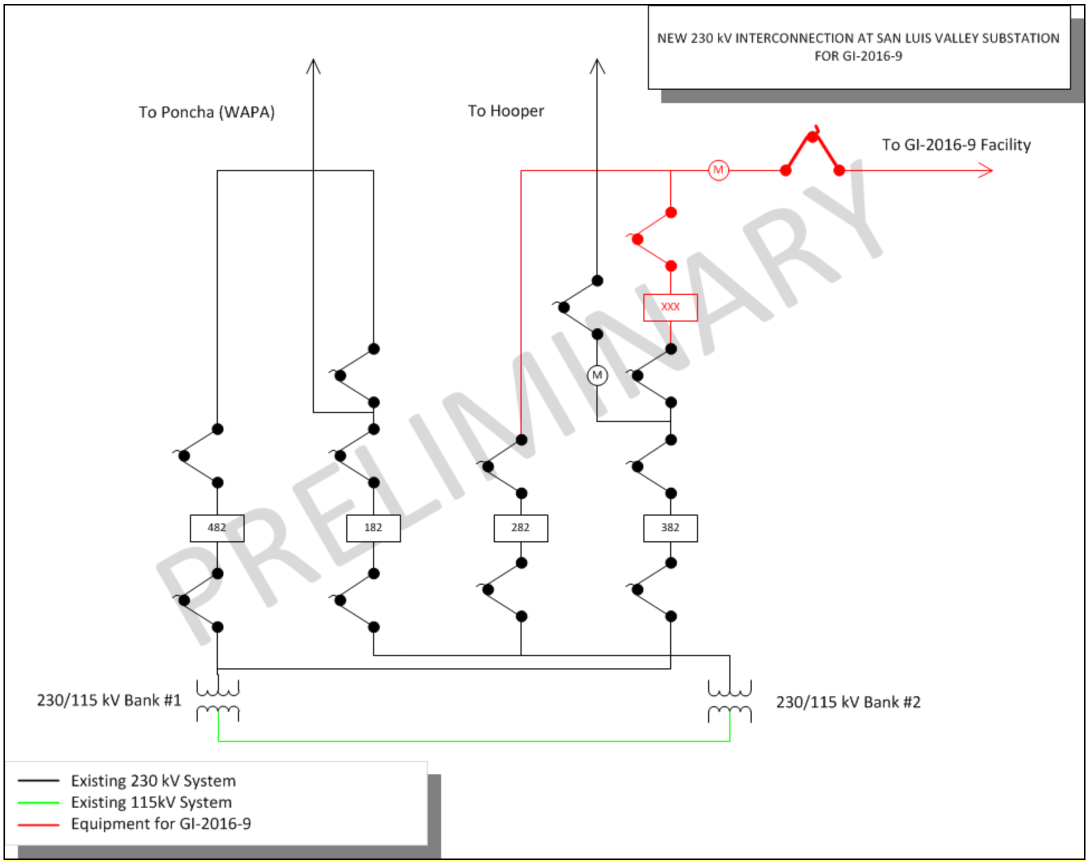


Figure 1 Conceptual one-line of the GI-2016-9 interconnection to the San Luis Valley 230kV bus.

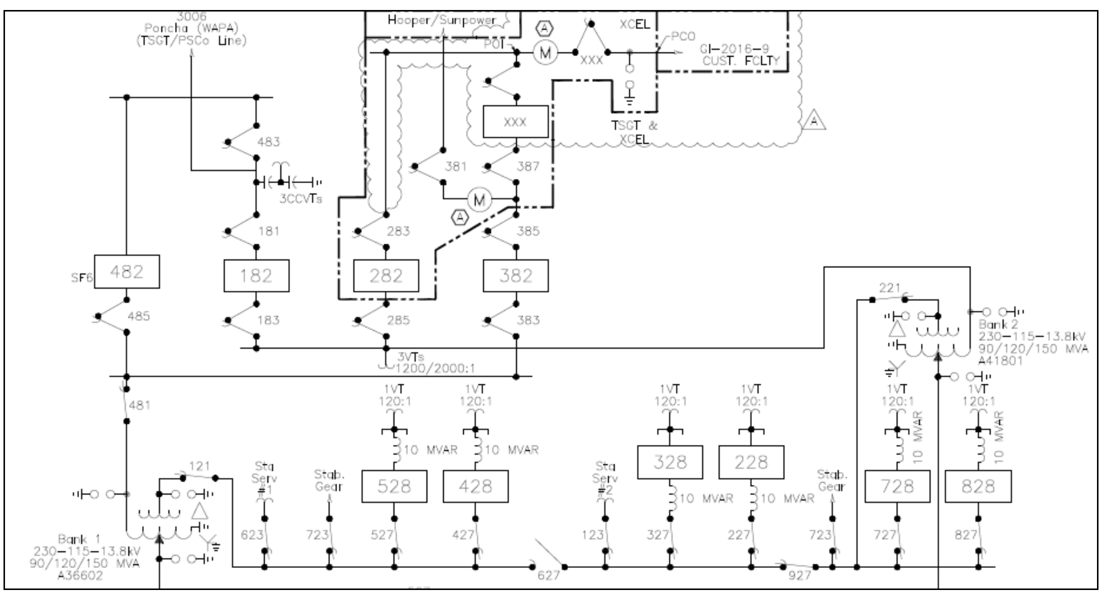


Figure 2 Preliminary one-line of the actual GI-2016-9 Interconnection Facilities at the San Luis Valley 230kV bus.

Table 2 – Interconnection Customer Funded, PSCo Owned Interconnection Facilities

Element	Description	Cost Est. (Millions)
San Luis Valley 230kV Transmission Substation	Interconnect Customer to tap at the San Luis Valley 230kV Transmission Substation (into the 230kV bus). The new equipment includes: • One 230kV gang switch • Three 230kV arresters • One set 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	**$1.230**
	Transmission line tap into substation. Three spans, structures, conductor, insulators, hardware and labor.	**$0.074**
	Siting and Land Rights support for siting studies, land and ROW acquisition and construction.	**$0.020**
	Total Cost Estimate for Interconnection Customer-Funded, PSCo-Owned Interconnection Facilities	**$1.324**
Time Frame	**Site, design, procure and construct**	**18 Months**

Table 3: PSCo Funded, PSCo Owned Interconnection Facilities

Element	Description	Cost Estimate (Millions)
San Luis Valley 230kV Transmission Substation	Interconnect Customer to tap at San Luis Valley 115kV Transmission Substation (into the 230kV bus). The new equipment includes: • One 230kV circuit breaker • Three 230kV gang switches • Three 230kV arresters • Control Building (Electric Equipment Enclosure) • Station battery system upgrades • Station controls • 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	**$2.914**
	Siting and Land Rights support for substation construction.	**$0.020**
	Total Cost Estimate for PSCo-Funded, PSCo-Owned Interconnection Facilities	**$2.934**
Time Frame	**Site, design, procure and construct**	**18 Months**

Table 4 – PSCo Funded Network Upgrades for Delivery

Element	Description	Cost Est. (Millions)
San Luis Valley - Poncha 230kV OH Transmission Line	Construct approximately 62 miles of new single circuit 230kV OH transmission line. Will require new easements/ROW. New line terminations and associated equipment at San Luis and Poncha Substations.	**$58.0**
Poncha - West Canon - Midway 230kV OH Transmission Line	Construct approximately 88 miles of new single circuit 230kV OH transmission line. Will require new easements/ROW. New line terminations and associated equipment at Poncha, West Canon and Midway Substations.	**$167.0**
	Total Cost Estimate for PSCo Funded Network Upgrades for Delivery	**$225.0**
Time Frame	**Regulatory (CPCN), site, design, procure and construct**	**60 months**

Cost Estimate Assumptions:

- Scoping level project cost estimates for Interconnection Facilities and Infrastructure Upgrades for Delivery (+/- 30% accuracy) were developed by PSCo Engineering.
- Indicative level project estimates for PSCo funded Network Upgrades for Delivery (no level of accuracy) were developed by PSCo Engineering
- Estimates are based on 2017 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 (distribution) facilities and metering required for station service are included in these estimates.
- PSCo (or our Contractor) crews will perform all construction, wiring, testing and commissioning for PSCo owned and maintained facilities.
- The estimated time frame for regulatory activities (CPCN) and to site, design, procure and construct the interconnection and network delivery facilities (entire Project) is approximately 48 months after authorization to proceed has been obtained.
- A CPCN will not be required for the Interconnection Facilities construction.
- A CPCN will be required for the PSCo funded Network Upgrades for Delivery.
- 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 substation as part of the transmission line construction scope.
- No new substation land will need to be required.
- Breaker duty study determined that no breaker replacements are needed in neighboring substations.

Appendix A – Power Flow N-1 Contingency Analysis Results

From Bus	To Bus	Voltage Class (kV)	Ckt	Branch Rating (MVA))	Branch Loading - % of Branch Rating			Contingency	Limiting Element
					Base Case	No Upgrades	Additional 230 kV Line		
70056 BNVSTATP	70312 RAY LEWI	115	1	91*	10.6	106.3	104.5	70327 PONCHA - 70394 SMELTER	T-Line Conductor
70056 BNVSTATP	70312 RAY LEWI	115	1	91*	9.7	133.9	139.0	73551 W CANON - 79054 PONCHABR	T-Line Conductor
70312 RAY LEWI	70327 PONCHA	115	1	124*	5.4	101.1	103.8	73551 W CANON - 79054 PONCHABR	T-Line Conductor / Switch
70327 PONCHA	70394 SMELTER	115	1	60	50.0	148.8	151.0	73551 W CANON - 79054 PONCHABR	Breaker CT and Secondary Elements
70374 SANLSVLY	70379 SARGENT	115	1	100	29.5	109.4	86.9	PONCHA 3 WINDING XFMR	Breaker CT and Secondary Elements

From Bus	To Bus	Voltage Class (kV)	Ckt	Branch Rating (MVA))	Branch Loading - % of Branch Rating			Contingency	Limiting Element
					Base Case	No Upgrades	Additional 230 kV Line		
70312 RAY LEWI	70327 PONCHA	115	1	120	5.6	104.5	107.3	73551 W CANON - 79054 PONCHABR	T-Line Conductor / Switch
70374 SANLSVLY	70379 SARGENT	115	1	105	28.1	104.2	82.8	PONCHA 3 WINDING XFMR	Breaker CT and Secondary Elements

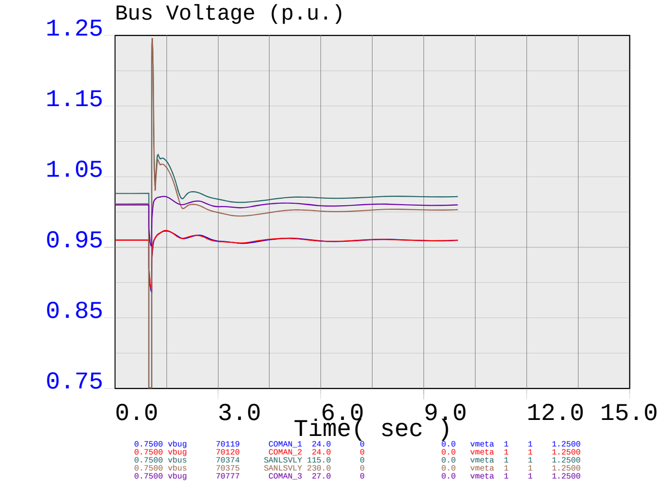
Appendix B – Transient Stability Analysis Results

GI-2016-9 System Impact Stability Scenarios						
#	Fault Location	Fault Type	Facility Tripped	Clearing Time (cycles)	Post-Fault Voltage Recovery	Post Angular Stability
1	PonchaBR 230kV	3ph	PonchaBR – SLV 230kV #1	Primary (5.0)	Acceptable*	Acceptable*
2	SLV 230kV	3ph	PonchaBR – SLV 230kV #1	Primary (5.0)	Acceptable*	Acceptable*
3	Poncha 115kV	3ph	Poncha – Sargent 115kV & Sargent – SLV 115kV	Primary (5.0)	Acceptable*	Acceptable*
4	SLV 115kV	3ph	Poncha – Sargent 115kV & Sargent – SLV 115kV	Primary (5.0)	Acceptable*	Acceptable*
5	Poncha_PS 230kV	3ph	Poncha_PS T1 230/115kV & Poncha_PS – PonchaBR 230kV	Primary (5.0)	Acceptable*	Acceptable*

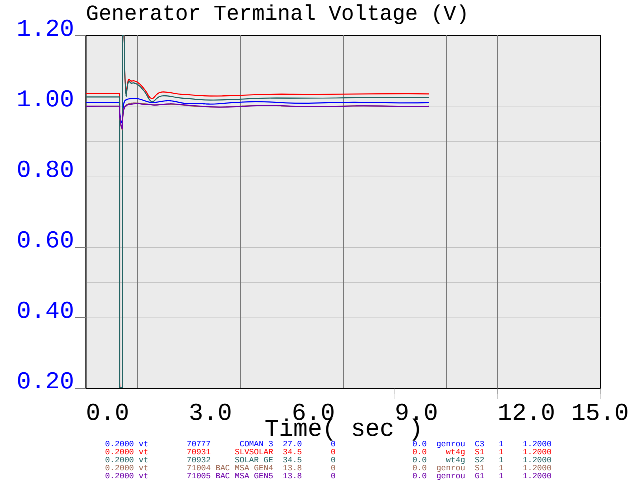
Acceptable* denotes results are inferred by applying engineering judgment to the transient stability plots in Appendix C. The maximum transient voltage dips were within the WECC criteria. No generator tripped and positive damping was exhibited.

Appendix C – Transient Stability Plots

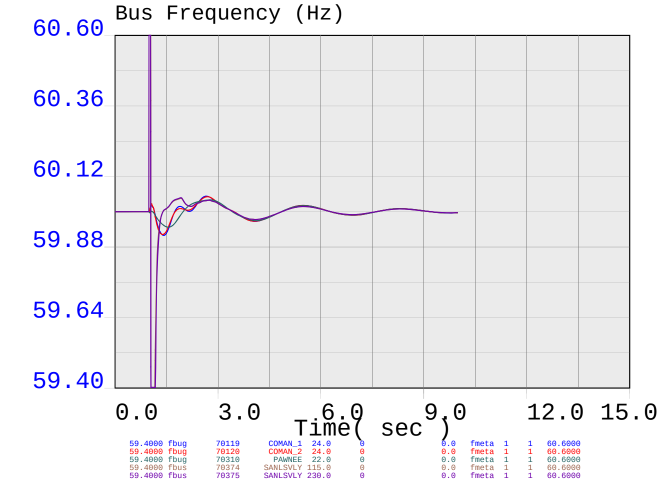
Bus Voltage (p.u.)



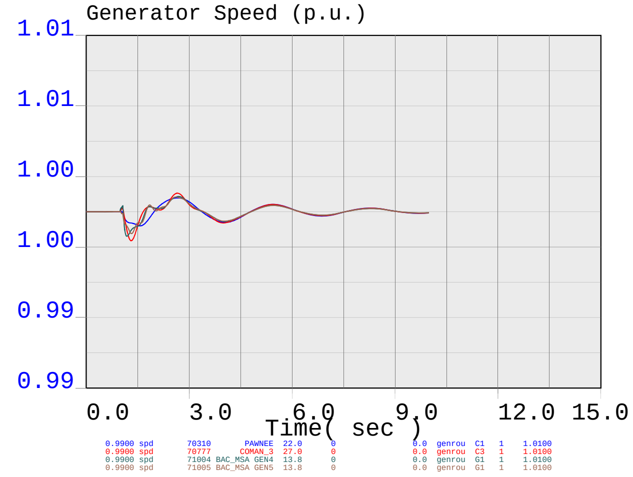
Generator Terminal Voltage (V)



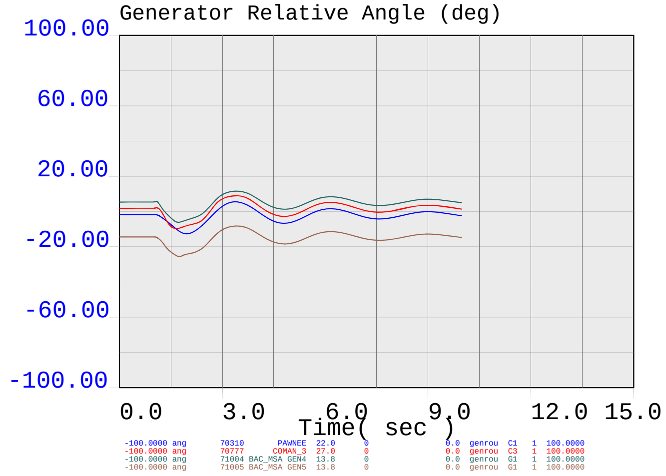
Bus Frequency (Hz)



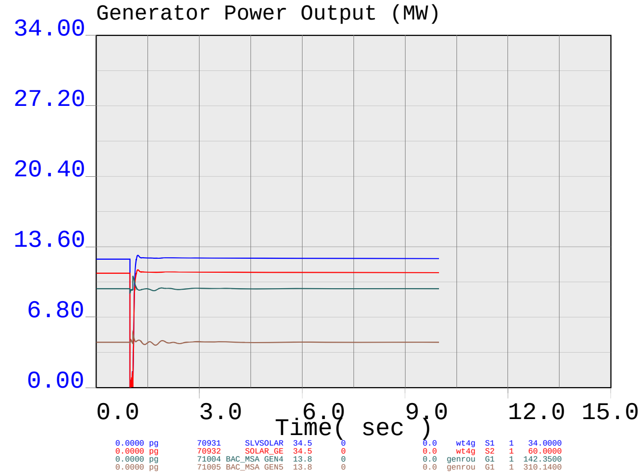
Generator Speed (p.u.)



Generator Relative Angle (deg)



Generator Power Output (MW)



line_1
line PONCHA to SANLSVLY 230, PONCHA end
October 21, 2015

GI-2016-9stab-run-line_1.chf

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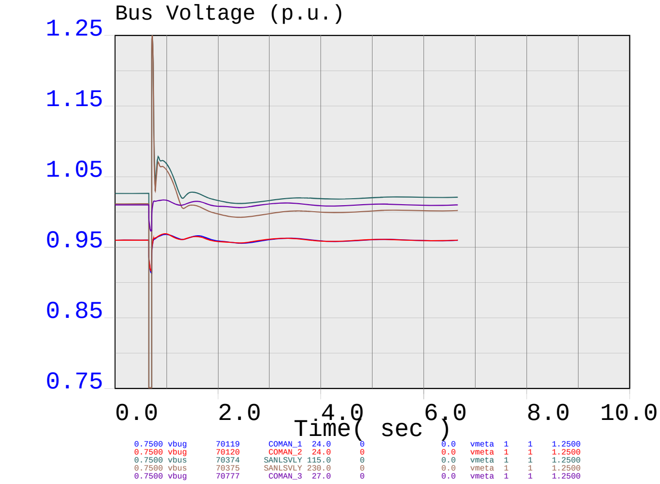
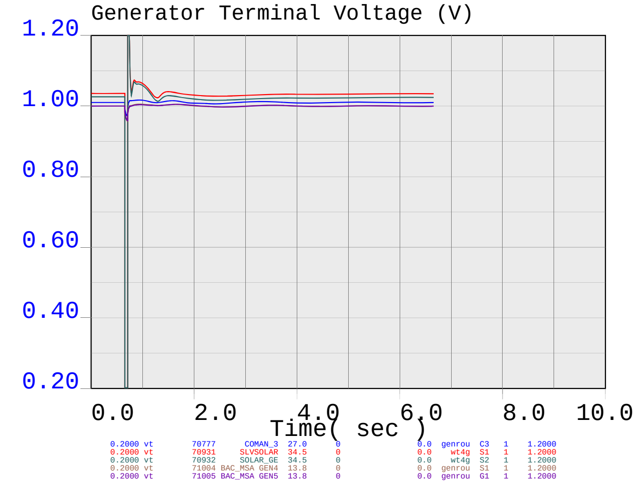
Fri Aug 25 14:07:58 2017

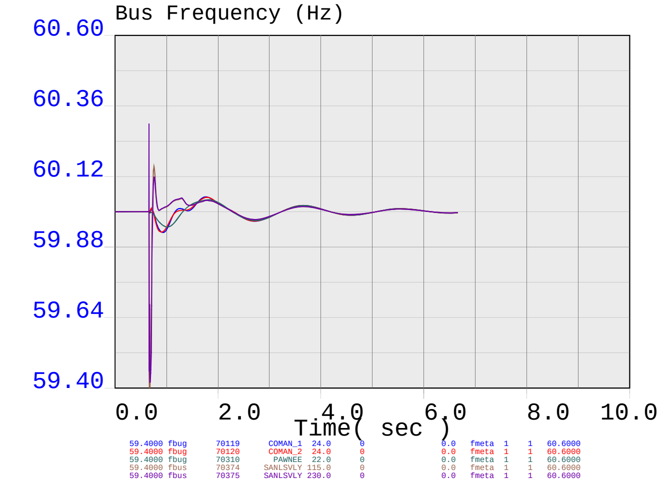
Bus Voltage (p.u.)



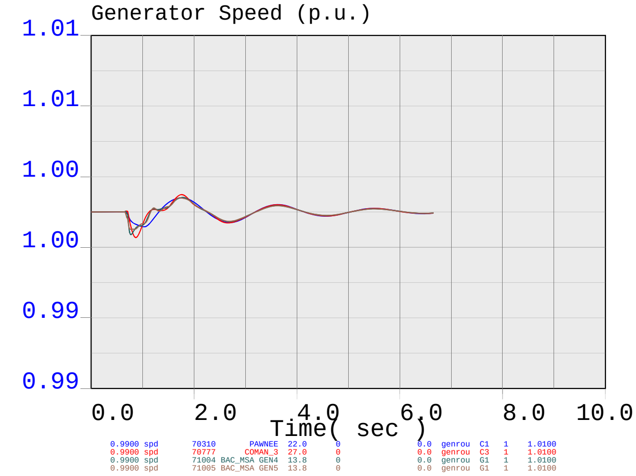
Generator Terminal Voltage (V)



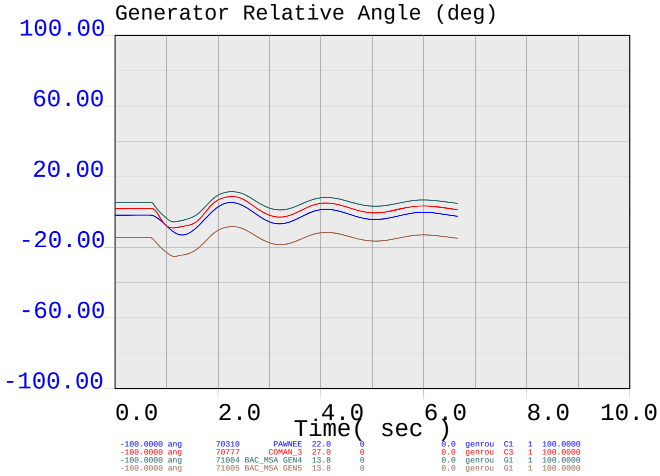
Bus Frequency (Hz)



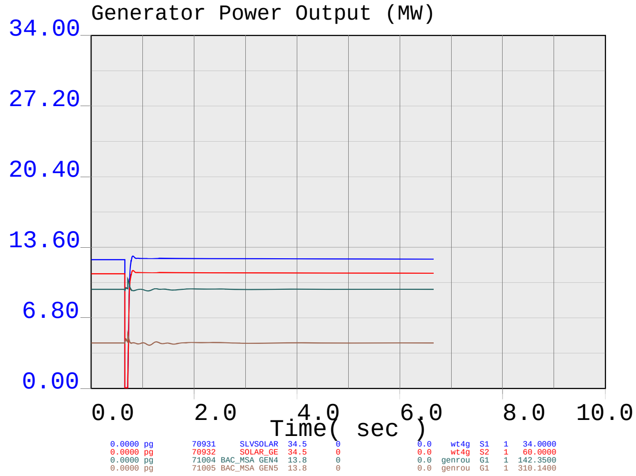
Generator Speed (p.u.)



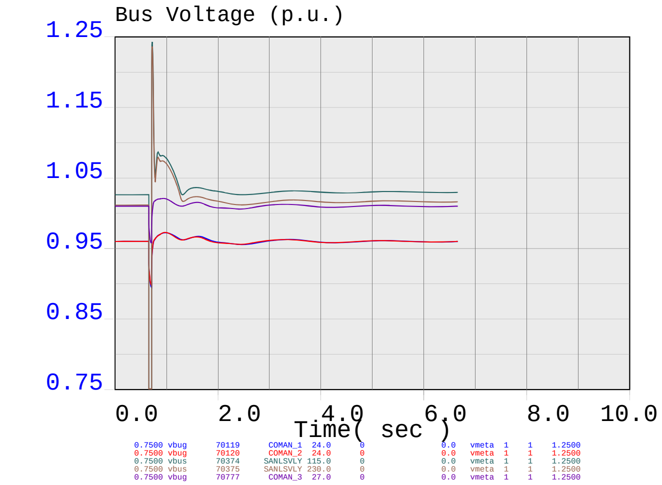
Generator Relative Angle (deg)

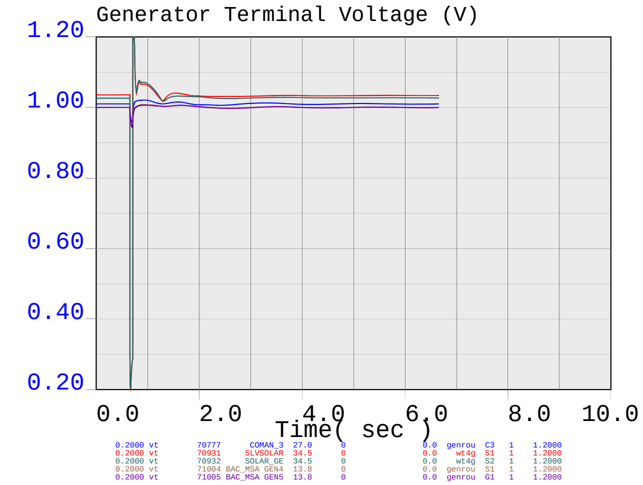


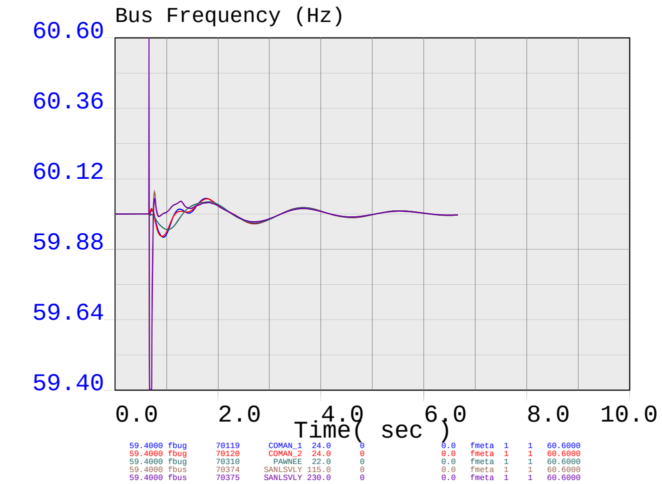
Generator Power Output (MW)

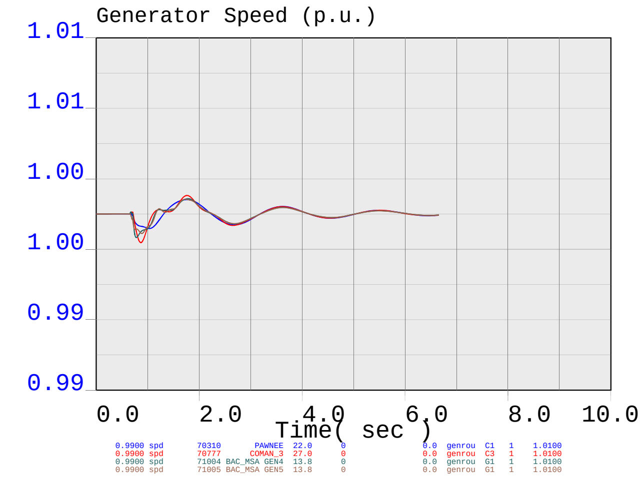


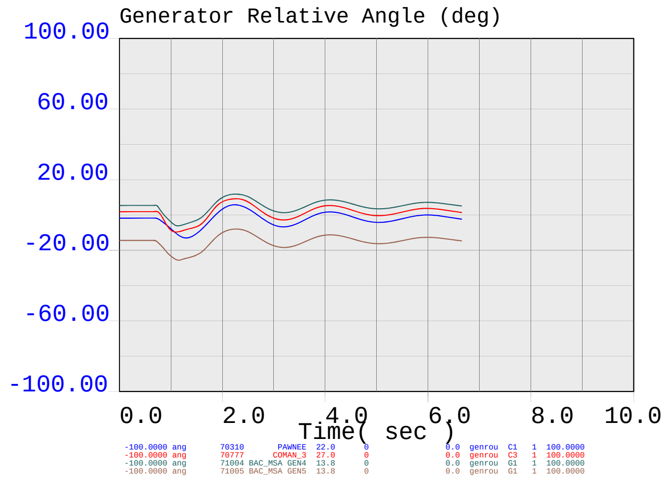
line_2
line PONCHA to SANLSVLY 230, SANLSVLY end
October 21, 2015

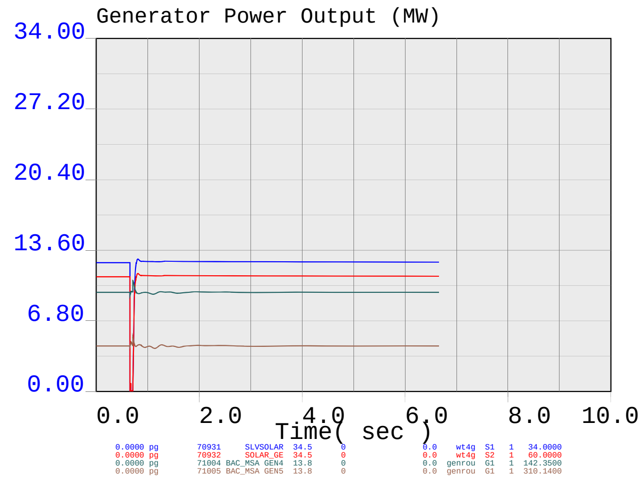












line_3
line PONCHA to SARGENT 115, PONCHA end
October 21, 2015

GI-2016-9stab-run-line_3.chf

ics data\DYTOOLS-HD\chans

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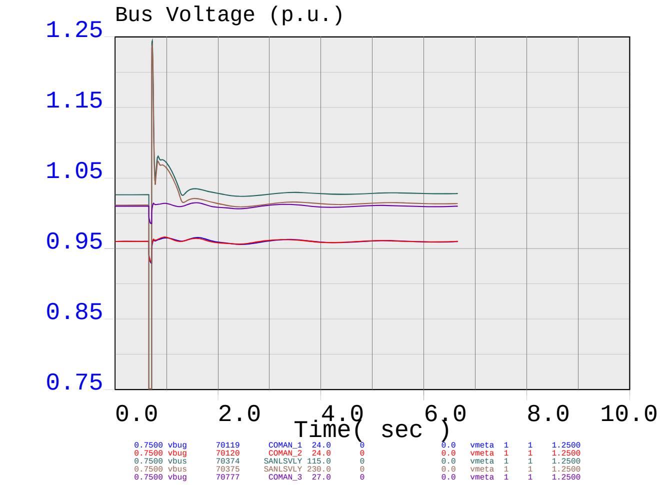

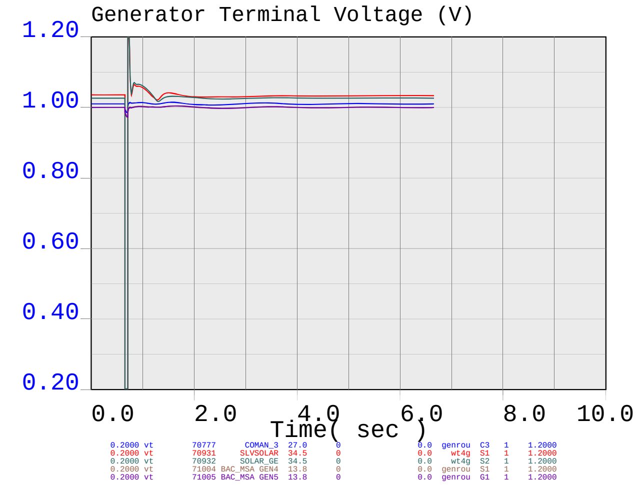

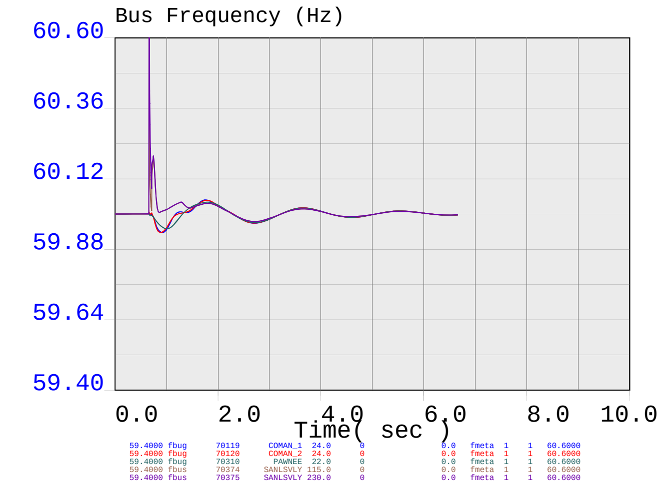

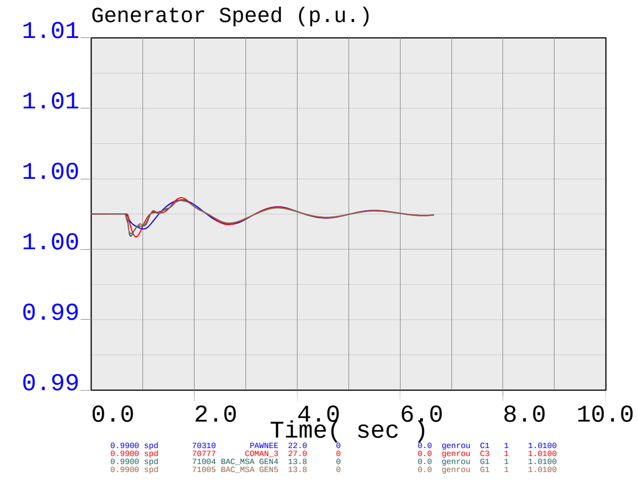

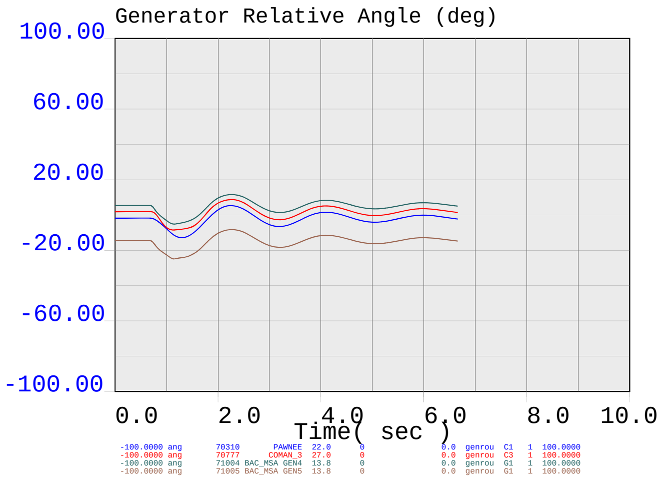

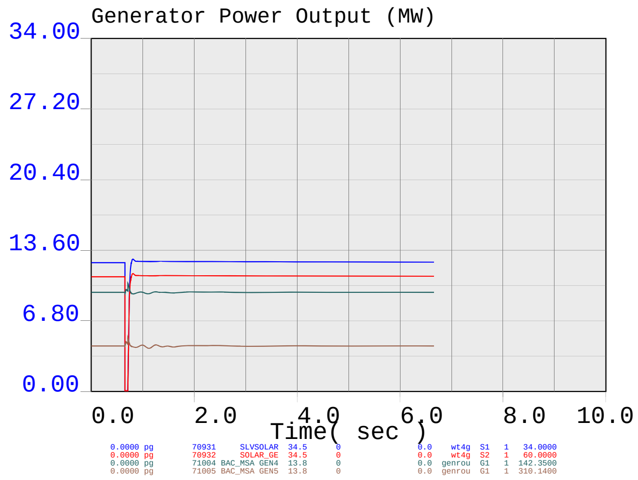

line_4
line SARGENT to SANLSLY 115, SANLSLY end
October 21, 2015

GI-2016-9stab-run-line_4.chf

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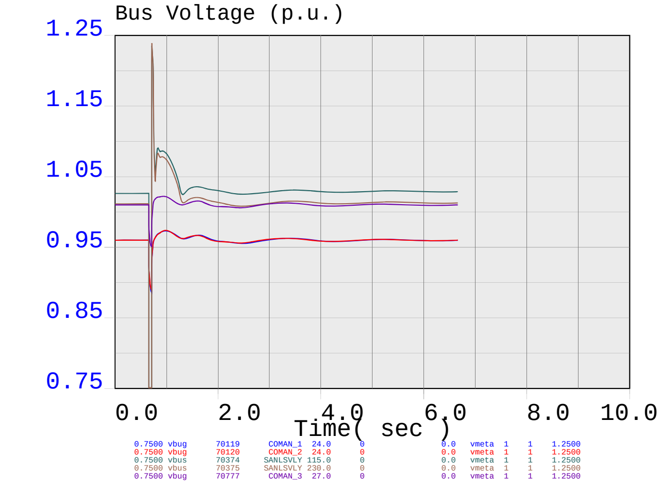
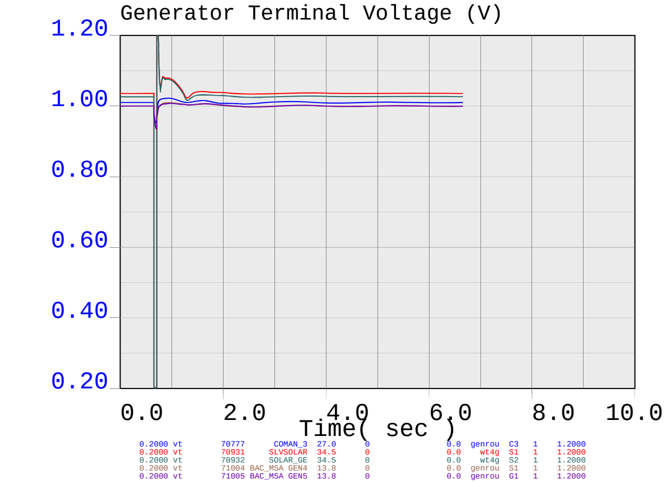
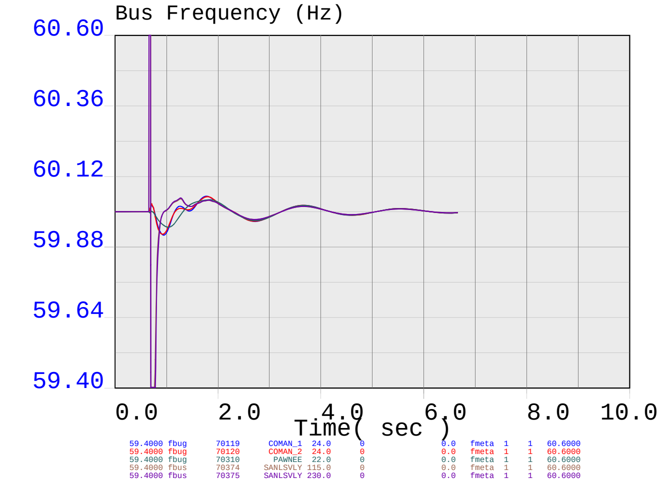
Bus Voltage (p.u.)



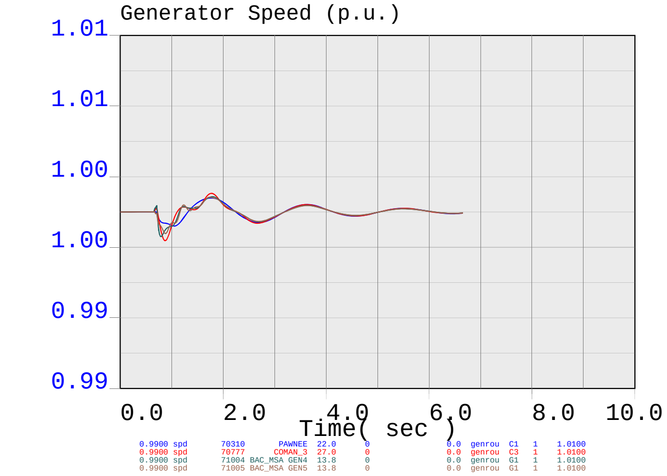
Generator Terminal Voltage (V)



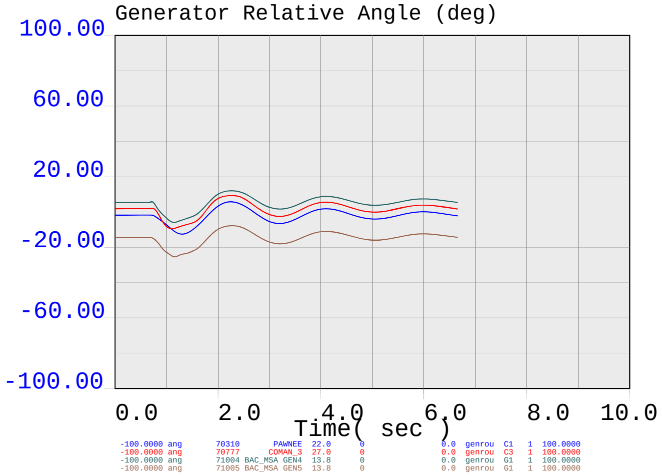
Bus Frequency (Hz)



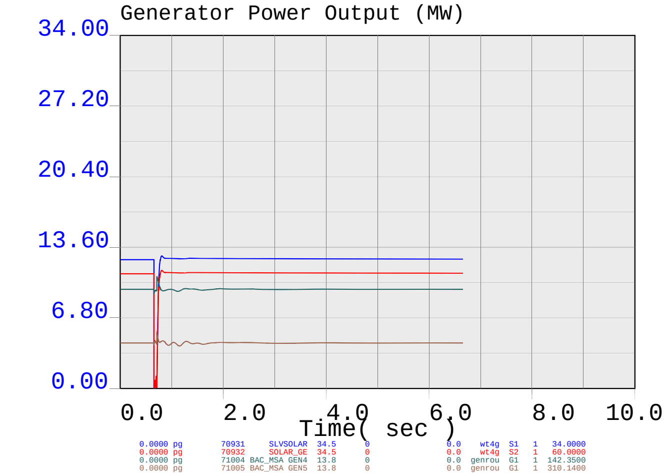
Generator Speed (p.u.)



Generator Relative Angle (deg)



Generator Power Output (MW)



bus_5
bus fault at PONCHA_PS 115
October 21, 2015

GI-2016-9stab-run-bus_5.chf

ics data\DYTOOLS-HD\chans

Fri Aug 25 14:09:50 2017