Southwest Power Pool

GEN-2011-018 Impact Restudy for Generator Modification (Turbine Change)

SPP Generator Interconnection Studies

GEN-2011-018
April 2013

Executive Summary

The generation interconnection customer for GEN-2011-018 has requested an impact restudy to determine the effects of changing wind turbine generators from the previously studied Siemens 2.3MW wind turbine generators to a combination of GE 1.6MW and GE 1.7MW wind turbine generators. The GEN-2011-018 generation interconnection request, using Siemens 2.3MW wind turbine generators, was first studied in the DISIS-2011-001 Definitive Impact Study which was posted in December 2011. Mitsubishi Electric Power Products, Inc (MEPPI) performed the current impact restudy, and a report of its analysis is attached.

In this restudy the project uses twelve (12) GE 1.6MW and thirty-two (32) GE 1.7MW wind turbine generators for an aggregate power of 73.6MW and is to be located in Jefferson County, NE. The project has one 34.5/115kV substation transformer that will connect the Customer's 115kV transmission line to the Point of Interconnection (POI), the Steele City 115kV substation. This restudy assumes that the reactive capability of both GE wind turbine generators is +/- 0.90PF based on documentation provided by the generation interconnection customer.

The findings of this restudy show that no stability problems were found during summer peak conditions due to the use of the GE wind turbine generators. However, for the winter peak case instability was seen for the prior outage of the Marshall to Smittyville 115kV line (see fault description for FLT28-3PH in Table 2-4 of the MEPPI report). For this contingency GEN-2009-040 became unstable which affected the voltage on the nearby 115kV busses. Because the condition that causes the potential instability is a prior outage condition (n-1-1 condition), the mitigation can be accomplished without the addition of transmission reinforcements. In discussions with MEPPI it was determined that this instability can be mitigated in two ways.

First, the reduction of the power output of both GEN-2009-040 and GEN-2011-018 when the Marshall to Smittyville 115kV line is out of service was evaluated. SPP verified that by reducing each generation facility to 80% of maximum power, any potential instability was alleviated for the subsequent outage. Figure 1 shows a plot of the voltages in the vicinity of the two generation facilities. From the plot it can be seen that voltages are stable and at acceptable levels.

It was also determined that when the Marshall to Smittyville 115kV line is out of service, switching on the 13.9Mvar capacitor bank at Knob Hill will alleviate any potential instability for the subsequent outage. This analysis is discussed in the MEPPI report. There are also required capacitor banks at the GEN-2009-040 wind farm that could serve for this purpose.

A power factor analysis was performed in this restudy. The power factor analysis results show that the facility will be required to maintain a 95% lagging (providing VARs) and 95% leading (absorbing VARs) power factor at the point of interconnection.

With the assumptions outlined in this report and with all the required network upgrades from the DISIS-2011-001 Impact Study in place, the restudy showed that no stability problems were found during the summer or the winter peak conditions as a result of changing to the GE 1.6MW and GE 1.7MW wind turbine generators. Additionally, the project wind farm is found to stay connected during the contingencies that were studied, and therefore, will meet the Low Voltage Ride Through (LVRT) requirements of FERC Order #661A.

Nothing in this study should be construed as a guarantee of transmission service. If the customer wishes to sell power from the facility, a separate request for transmission service shall be requested on Southwest Power Pool's OASIS by the Customer.

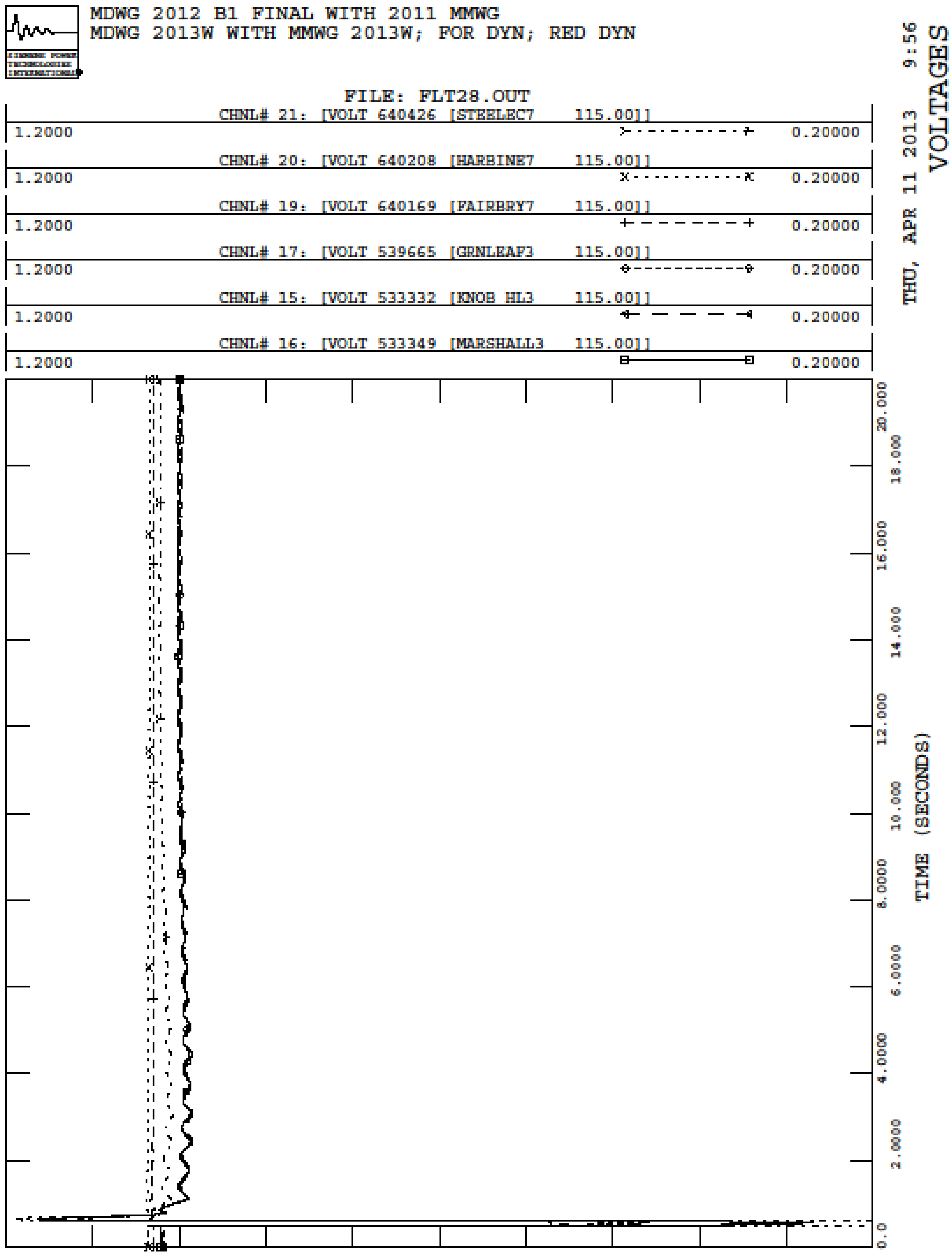

Figure 1 -- Voltages of nearby 115kV bus

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Southwest Power Pool, Inc. (SPP)

GEN-2011-018 System Impact Restudy

Final Report

PXE-0675
Revision #01

April 2013

Submitted By:
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EXECUTIVE SUMMARY

SPP requested a restudy for GEN-2011-018. The restudy required a Power Factor Analysis and a Stability Analysis detailing the impacts of the interconnecting projects as shown in Table ES-1.

Table ES-1
Interconnection Projects Evaluated

Request	Size (MW)	TurbineModel	Point of Interconnection (POI)
GEN-2011-018	73.6	(12) GE 1.6MW and (32) GE 1.7MW	Steele City 115kV (640426)

SUMMARY OF POWER FACTOR ANALYSIS

The Power Factor Analysis shows that GEN-2011-018 has a power factor range of 0.9554 to 0.9998 leading (absorbing).

SUMMARY OF STABILITY ANALYSIS

For the summer peak case, the Stability Analysis determined that there was no wind turbine tripping or system instability that occurs from interconnecting GEN-2011-018 at 100% output.

For the winter peak case, the Stability Analysis determined that there was no wind turbine tripping or system instability that occurs from interconnecting GEN-2011-018 at 100% output for N-1 contingencies. When interconnecting GEN-2011-018 at 100% output for prior line outage contingencies, N-1-1, Contingency #28 was observed to have an unstable wind farm (GEN-2011-018, Marshall County Wind Project) and unstable bus voltages. There are two possible mitigation techniques for this case. The generation at GEN-2011-018 and GEN-2009-040 can be reduced during the prior line outage condition or the 13.9 Mvar capacitor bank at Knob Hill 115 kV can be switched online. With either of these two mitigations in place, the system remained stable and no wind turbine tripping was observed.

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SECTION 1: OBJECTIVES

The objective of this report is to provide Southwest Power Pool, Inc. (SPP) with the deliverables for the "GEN-2011-018 System Impact Restudy." SPP requested an Interconnection System Impact Restudy for GEN-2011-018 which requires a Power Factor Analysis, a Stability Analysis, and an Impact Study Report.

SECTION 2: BACKGROUND

The Siemens Power Technologies, Inc. PSS/E power system simulation program Version 32.2.0 was used for this study. SPP provided the stability database cases for summer peak and winter peak seasons and a list of contingencies to be examined. The model includes the study project and the previously queued projects as listed in Table 2-1 and Table 2-2, respectively. The cases used for this study also include several general units located in the WAPA system, modeled at 100% PMAX, listed in Table 2-3. Refer to Appendix A for the steady-state and dynamic model data for the study projects. A power flow one-line diagram of GEN-2011-018 interconnection project is shown in Figure 2-1.

For this System Impact Restudy, the previous wind turbine version of GEN-2011-018, Siemens 2.3 MW, was replaced with 12 units of the GE 1.6 MW wind turbine and 32 units of the GE 1.7 MW wind turbine in both seasonal saved cases supplied by SPP.

The Stability Analysis will determine the impacts of the new interconnecting project on the stability and voltage recovery of the nearby system and the ability of the interconnecting project to meet FERC Order 661A. If problems with stability or voltage recovery are identified, the need for reactive compensation or system upgrades will be investigated. Three-phase and single-phase faults will be examined as listed in Table 2-4.

The Power Factor analysis will determine the power factor at the point of interconnection for the wind interconnection project for pre-contingency and post-contingency conditions. Table 2-4 lists the contingencies developed from the three-phase fault definitions provided in the Group's interconnection impact study request.

Table 2-1
Interconnection Projects Evaluated

Request	Size (MW)	TurbineModel	Point of Interconnection (POI)
GEN-2011-018	73.6	(12) GE 1.6MW and (32) GE 1.7MW	Steele City 115kV (640426)

Table 2-2
Previously Queued Nearby Interconnection Projects Included

Request	Size (MW)	TurbineModel	Point of Interconnection (POI)
GEN-2003-021N	75	GE 1.5MW	Tap on the Ainsworth – Calamus 115kV line (640050)
GEN-2004-005N	30	GE 1.5MW	St Francis 115kV (640351)
GEN-2004-023N	75	GENROU	Columbus 115kV (640119)
GEN-2006-020N	42	Vestas 3.0MW	Bloomfield 115kV (640084)
GEN-2006-037N1	75	GE 1.5MW	Broken Bow 115kV (640089)
GEN-2006-038N005	79.5	GE 1.5MW	Broken Bow 115kV (640089)
GEN-2006-038N019	79.5	Generic wind turbine 1.5MW	Petersburg 115kV (640444)
GEN-2006-044N	40.5	GE 1.5MW	Petersburg 115kV (640444)
GEN-2007-011N08	81	Vestas 3.0MW	Bloomfield 115kV (640084)
GEN-2007-015	135	GE 1.5MW	Tap Kelly – S1399 161kV (560610)
GEN-2008-086N02	199.5	GE 1.5MW	Tap on the Columbus – Ft Randall 230kV line (560006)
GEN-2008-119O	60	GE 1.5MW	S1399 161kV (646399)
GEN-2008-123N	89.7	SMK203	Tap on the Pauline – Guide Rock 115kV (560137)
GEN-2009-040	73.8	Vestas V90 1.8MW	Marshall 115kV (533349)
GEN-2010-041	10.5	GE 1.5MW	S1399 161kV (646399)
GEN-2010-044	99	Siemens 3.0MW	Harbine 115kV (640208)
GEN-2010-051	200	GE 1.6MW	Tap on the Twin Church – Hoskins 230kV line (560347)
GEN-2011-027	120	Nordex N100 2.5MW	Hoskins 230kV (640227)
GEN-2011-055	52.8	GE 1.6MW	South Sterling 69kV (S969, 647969)
GEN-2011-056	3.6 MW increase	GENSAL	Jeffrey 115kV (640238)
GEN-2011-056A	3.6 MW increase	GENSAL	Johnson 1 115kV (640240)
GEN-2011-056B	4.5 MW increase	GENSAL	Johnson 2 115kV (640242)
GEN-2012-017	115 MW increase	GENROU	Cooper 345kV (640139)
GEN-2012-021	4.8 MW	GENROU	84th & Bluff 115kV (650275)

Table 2-3
Adjacent WAPA Generating Units

Bus #	Bus Name	Pmax (MW)	kV	Unit ID
652546	FTRDL12G	44/37	13.8	1
652546	FTRDL12G	44/37	13.8	2
652547	FTRDL34G	44/37	13.8	3
652547	FTRDL34G	44/37	13.8	4
652548	FTRDL56G	44/37	13.8	5
652548	FTRDL56G	44/37	13.8	6
652549	FTRDL78G	44/37	13.8	7
652549	FTRDL78G	44/37	13.8	8
652575	GAVINS1G	26	13.8	1
652576	GAVINS2G	26	13.8	2
652577	GAVINS3G	26	13.8	3
659116	SPIRI71G	53	13.8	1
659117	SPIRI72G	52	13.8	2

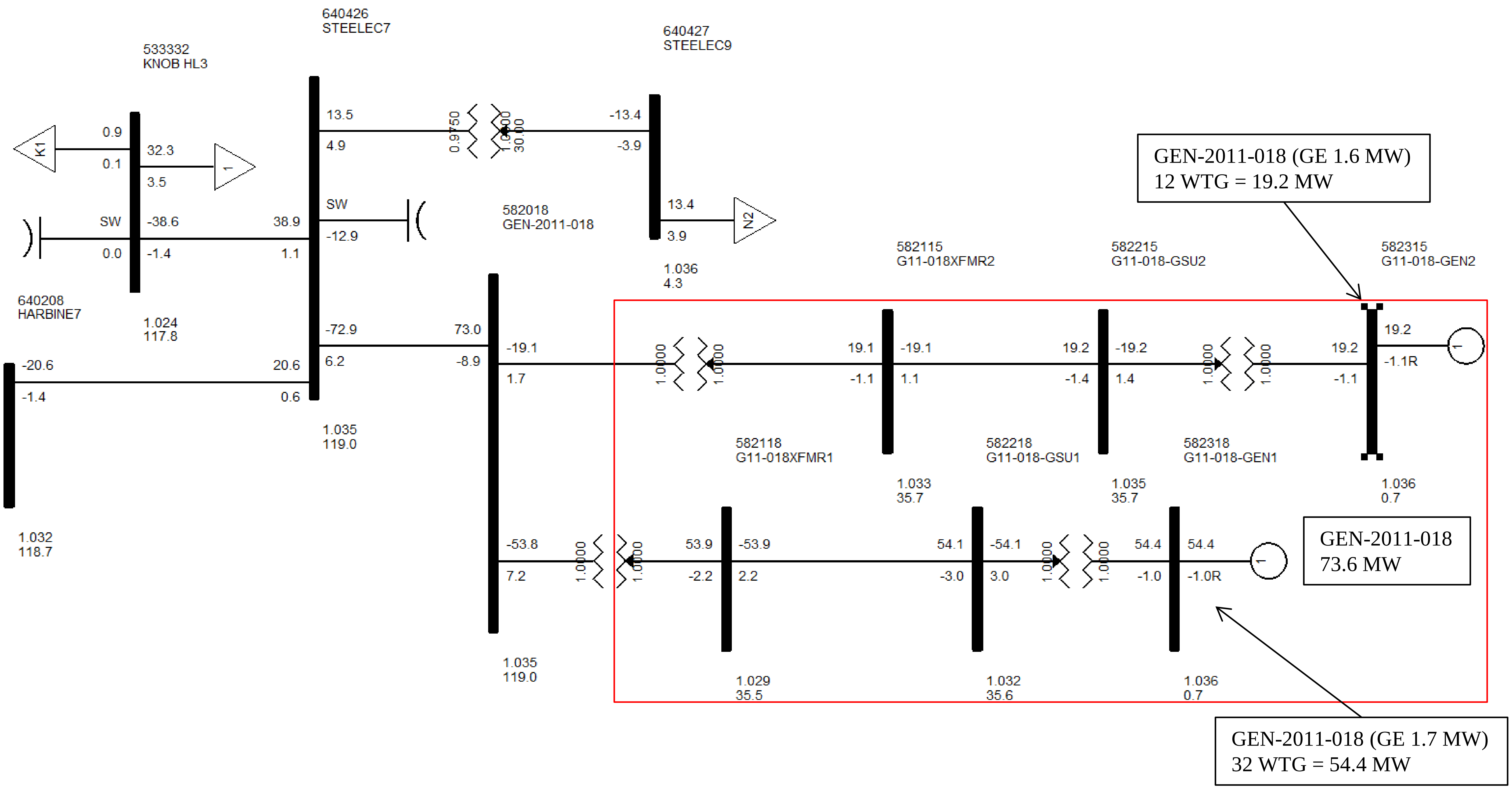

Figure 2-1. Power flow one-line diagram for interconnection project GEN-2011-018 (73.6 MW).

Table 2-4
Case List with Contingency Description

Ref. No.	Case Name	Description
1	FLT01-3PH	3 phase fault on the Steele City (640426) to Harbine (640208) 115kV line, near Steele City. a. Apply fault at Steele City 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line.
2	FLT02-3PH	3 phase fault on the Steele City (640426) to Knob Hill (533332) 115kV line, near Steele a. Apply fault at Steele City 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line.
3	FLT03-3PH	3 phase fault on the Harbine (640208) to Fairbury (640169) 115kV line, near Harbine. a. Apply fault at Harbine 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line.
4	FLT04-3PH	3 phase fault on the Harbine (640208) to Beatrice (640076) 115kV line, near Harbine. a. Apply fault at Harbine 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line.
5	FLT05-3PH	3 phase fault on the Harbine (640208) to Crete (640153) 115kV line, near Harbine. a. Apply fault at Harbine 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line.
6	FLT06-3PH	3 phase fault on the Beatrice (640076) to Beatrice Power Station (640088) 115kV CKT2, near Beatrice. a. Apply fault at Beatrice 115kV bus. b. Clear fault after 6.5cycles by tripping the faulted line.
7	FLT07-3PH	3 phase fault on the Beatrice (640076) to Steiner (640361) 115kV line, near Beatrice. a. Apply fault at Beatrice 115kV bus. b. Clear fault after 6.5cycles by tripping the faulted line.
8	FLT08-3PH	3 phase fault on the Hebron North (640218) to Hebron (640220) 115kV line, near Hebron North. a. Apply fault at Hebron North 115kV bus. b. Clear fault after 6.5cycles by tripping the faulted line.
9	FLT09-3PH	3 phase fault on the Hebron North (640218) to Carlton Jct (640105) 115kV line, near a. Apply fault at Hebron North 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line.
10	FLT10-3PH	3 phase fault on the Crete (640153) to Friend (640174) 115kV line, near Crete. a. Apply fault at Crete 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line.
11	FLT11-3PH	3 phase fault on the Crete (640153) to Sheldon (640278) 115kV line, near Crete. a. Apply fault at Crete 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line.
12	FLT12-3PH	3 phase fault on the Sheldon (640278) 115kV to Moore (640277) 230kV/Moore (640280) 13.8kV transformer at the 115kV bus. a. Apply fault at the Sheldon 115kV bus. b. Clear fault after 5.5 cycles by tripping the transformer
13	FLT13-3PH	3 phase fault on the Kelly (533217) 115kV to Kelly (532913) 161kV/Kelly (532942) 13.8kV transformer at the 115kV bus. a. Apply fault at the Kelly 115kV bus. b. Clear fault after 5 cycles by tripping the transformer
14	FLG14-3PH	3 phase fault on the Concordia (539657) 115kV to Concordia (539658) 230kV/ Concordia (539904) 13.8kV transformer at the 115kV bus. a. Apply fault at the Concordia 115kV bus. b. Clear fault after 5 cycles by tripping the transformer

Table 2-4 (Continued)
Case List with Contingency Description

Ref. No.	Case Name	Description
15	FLT15-3PH	3 phase fault on the Knob Hill (533332) to Marshall (533349) 115kV line, near Knob Hill. a. Apply fault at Knob Hill 115kV bus. b. Clear fault after 5 cycles by tripping the faulted line. c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
16	FLT16-1PH	*Single phase fault and sequence like previous*
17	FLT17-3PH	3 phase fault on the Knob Hill (533332) to Greenleaf (539665) 115kV line, near Knob Hill. a. Apply fault at Knob Hill 115kV bus. b. Clear fault after 5 cycles by tripping the faulted line. c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
18	FLT18-1PH	*Single phase fault and sequence like previous*
19	FLT19-3PH	3 phase fault on the Marshall (533349) to Smittyville (533338) 115kV line, near Marshall. a. Apply fault at Marshall 115kV bus. b. Clear fault after 5 cycles by tripping the faulted line. c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
20	FLT20-1PH	*Single phase fault and sequence like previous*
21	FLT21-3PH	3 phase fault on the Concordia (539657) to Beloit (539650) 115kV line, near Concordia. a. Apply fault at Concordia 115kV bus. b. Clear fault after 5 cycles by tripping the faulted line. c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
22	FLT22-31PH	*Single phase fault and sequence like previous*
23	FLT23-3PH	3 phase fault on the Concordia (539657) to Jewell (539669) 115kV line, near Concordia. a. Apply fault at Concordia 115kV bus. b. Clear fault after 5 cycles by tripping the faulted line. c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
24	FLT24-1PH	*Single phase fault and sequence like previous*
25	FLT25-3PH	3 phase fault on the Concordia (539657) to Clifton (539656) 115kV line, near Concordia. a. Apply fault at Concordia 115kV bus. b. Clear fault after 5 cycles by tripping the faulted line. c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
26	FLT26-1PH	*Single phase fault and sequence like previous*
27	FLT27-3PH	**Prior outage of the Knob Hill (533332) to Greenleaf (539665) 115kV line.** 3 phase fault on the Steele City (640426) to Harbine (640208) 115kV line, near Steele City. a. Apply fault at Steele City 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line
28	FLT28-3PH	**Prior outage of the Marshall (533349) to Smittyville (539665) 115kV line.** 3 phase fault on the Steele City (640426) to Harbine (640208) 115kV line, near Steele City. a. Apply fault at Steele City 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line
29	FLT29-3PH	**Prior outage of the Harbine (640208) to Fairbury (640169) 115kV line.** 3 phase fault on the Steele City (640426) to Knob Hill (533332) 115kV line, near Steele a. Apply fault at Steele City 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line
30	FLT30-3PH	**Prior outage of the Harbine (640208) to Beatrice (640076) 115kV line.** 3 phase fault on the Steele City (640426) to Knob Hill (533332) 115kV line, near Steele a. Apply fault at Steele City 115kV bus. b. Clear fault after 6.5 cycles by tripping the faulted line

SECTION 3: STABILITY ANALYSIS

The objective of the stability analysis was to determine the impacts of the new wind farms on the stability and voltage recovery on the SPP transmission system. If problems with stability or voltage recovery were identified the need for reactive compensation or system upgrades were investigated.

Approach

The winter peak and summer peak power flows provided by SPP contained the previous version of the wind farm being studied. The previous version of the wind farm to be studied was a Siemen's 2.3 MW wind turbine and will be replaced by a GE 1.6 MW wind turbine and a GE 1.7 MW wind turbine. The new equivalent wind farm model was developed and is incorporated in the winter peak and summer peak power flows. Both winter peak and summer peak power flows were examined prior to the Stability Analysis to ensure they contained the previously queued projects listed in Table 2-2. There was no suspect power flow data in the study area. The dynamic datasets were also verified and stable initial system conditions (i.e., "flat lines") were achieved. Three-phase and single line-to-ground faults listed in Table 2-4 were examined. Single-phase fault impedances were calculated to result in a voltage of approximately 60% of the pre-fault voltage. Refer to Table 3-1 for a list of the calculated single-phase fault impedances used for this analysis.

Table 3-1
Calculated Single-Phase Fault Impedances

Ref. No.	Casename	Single-Phase Fault Impedance (MVA)	
		Summer Peak	Winter Peak
16	FLT16-1PH	-750.0	-687.5
18	FLT18-1PH	-750.0	-687.5
20	FLT20-1PH	-687.5	-687.5
22	FLT22-1PH	-750.0	-687.5
24	FLT24-1PH	-750.0	-687.5
26	FLT26-1PH	-750.0	-687.5

Bus voltages and previously queued generation in the study area were monitored in addition to the bus voltages in the following areas:

- 531 MIDW
- 534 SUNC
- 536 WERE
- 540 GMO
- 541 KCPL

- 640 NPPD
- 645 OPPD
- 650 LES
- 652 WAPA

The results of the analysis are to be used to determine if reactive compensation or system upgrades are required to obtain acceptable system performance. If additional reactive compensation was required, the size, type, and location were determined. The proposed reactive reinforcements would ensure the wind farm meets FERC Order 661A low voltage requirements and return the wind farm to its pre-disturbance operating voltage. If the results indicated the need for fast responding reactive support, dynamic support such as an SVC or STATCOM was investigated. If tripping of the prior queued projects was observed during the stability analysis (for under/over voltage or under/over frequency) the simulations were re-ran with the prior queued project's voltage and frequency tripping disabled.

Results

Refer to Table 3-2 for a summary of the Stability Analysis results. For summer peak conditions, all contingencies remained stable, there were no wind turbines tripping offline and no system instability was observed. For winter peak conditions, contingencies without prior line outages remained stable, there were no wind turbines tripping offline and no system instability was observed. Refer below for the results for winter peak contingencies with prior line outages. Refer to Appendix B and C for plots of all of the contingencies for summer peak and winter peak conditions, respectively.

Table 3-2
Stability Analysis Summary of Results

Ref. No.	Casename	Summer		Winter	
		Stable?	Acceptable Voltages?	Stable?	Acceptable Voltages?
1	FLT01-3PH	Yes	Yes	Yes	Yes
2	FLT02-3PH	Yes	Yes	Yes	Yes
3	FLT03-3PH	Yes	Yes	Yes	Yes
4	FLT04-3PH	Yes	Yes	Yes	Yes
5	FLT05-3PH	Yes	Yes	Yes	Yes
6	FLT06-3PH	Yes	Yes	Yes	Yes
7	FLT07-3PH	Yes	Yes	Yes	Yes
8	FLT08-3PH	Yes	Yes	Yes	Yes
9	FLT09-3PH	Yes	Yes	Yes	Yes
10	FLT10-3PH	Yes	Yes	Yes	Yes
11	FLT11-3PH	Yes	Yes	Yes	Yes
12	FLT12-3PH	Yes	Yes	Yes	Yes
13	FLT13-3PH	Yes	Yes	Yes	Yes
14	FLT14-3PH	Yes	Yes	Yes	Yes
15	FLT15-3PH	Yes	Yes	Yes	Yes
16	FLT16-1PH	Yes	Yes	Yes	Yes
17	FLT17-3PH	Yes	Yes	Yes	Yes
18	FLT18-1PH	Yes	Yes	Yes	Yes
19	FLT19-3PH	Yes	Yes	Yes	Yes
20	FLT20-1PH	Yes	Yes	Yes	Yes
21	FLT21-3PH	Yes	Yes	Yes	Yes
22	FLT22-1PH	Yes	Yes	Yes	Yes
23	FLT23-3PH	Yes	Yes	Yes	Yes
24	FLT24-1PH	Yes	Yes	Yes	Yes
25	FLT25-3PH	Yes	Yes	Yes	Yes
26	FLT26-1PH	Yes	Yes	Yes	Yes

Table 3-2 (Continued)
Stability Analysis Summary of Results

Ref. No.	Casename	Summer		Winter	
		Stable?	Acceptable Voltages?	Stable?	Acceptable Voltages?
27	FLT27-3PH	Yes	Yes	Yes	Yes
28	FLT28-3PH	Yes	Yes	Yes[1]	Yes[1]
29	FLT29-3PH	Yes	Yes	Yes	Yes
30	FLT30-3PH	Yes	Yes	Yes	Yes

[1]FLT28-3PH for winter peak is unstable and does not have acceptable voltages under base conditions (no mitigation). With the Knob Hill 115 kV capacitor bank (13.9 Mvar) switched online, the system instability and unacceptable voltages are mitigated.

Contingencies FLT27-3PH through FLT30-3PH are prior line outage contingencies, referred as N-1-1 contingencies. All N-1-1 contingencies, except Contingency FLT28-3PH for winter peak conditions, remained stable. Contingency FLT28-3PH for winter peak conditions was observed to have an unstable wind turbine (Marshall County Wind Project) and unstable bus voltages. This fault is a three phase fault on the Steele City to Harbine 115 kV line with a prior line outage of Marshall to Smittyville 115 kV line. Refer to the following plots for winter peak contingency FLT28-3PH with no mitigation:

- Figure 3-1 shows a plot of the bus voltage at Steele City 115 kV, Knob Hill 115 kV, Marshall 115 kV, and Concord 115 kV.
- Figure 3-2 shows a plot of the real power response of GEN-2011-018 (Steele Flats Wind Project) and GEN-2009-040 (Marshall County Wind Project).
- Figure 3-3 shows a plot of the reactive power response of GEN-2011-018 and GEN-2009-040.
- Figure 3-4 shows a plot of the frequency response of GEN-2011-018 and GEN-2009-040.

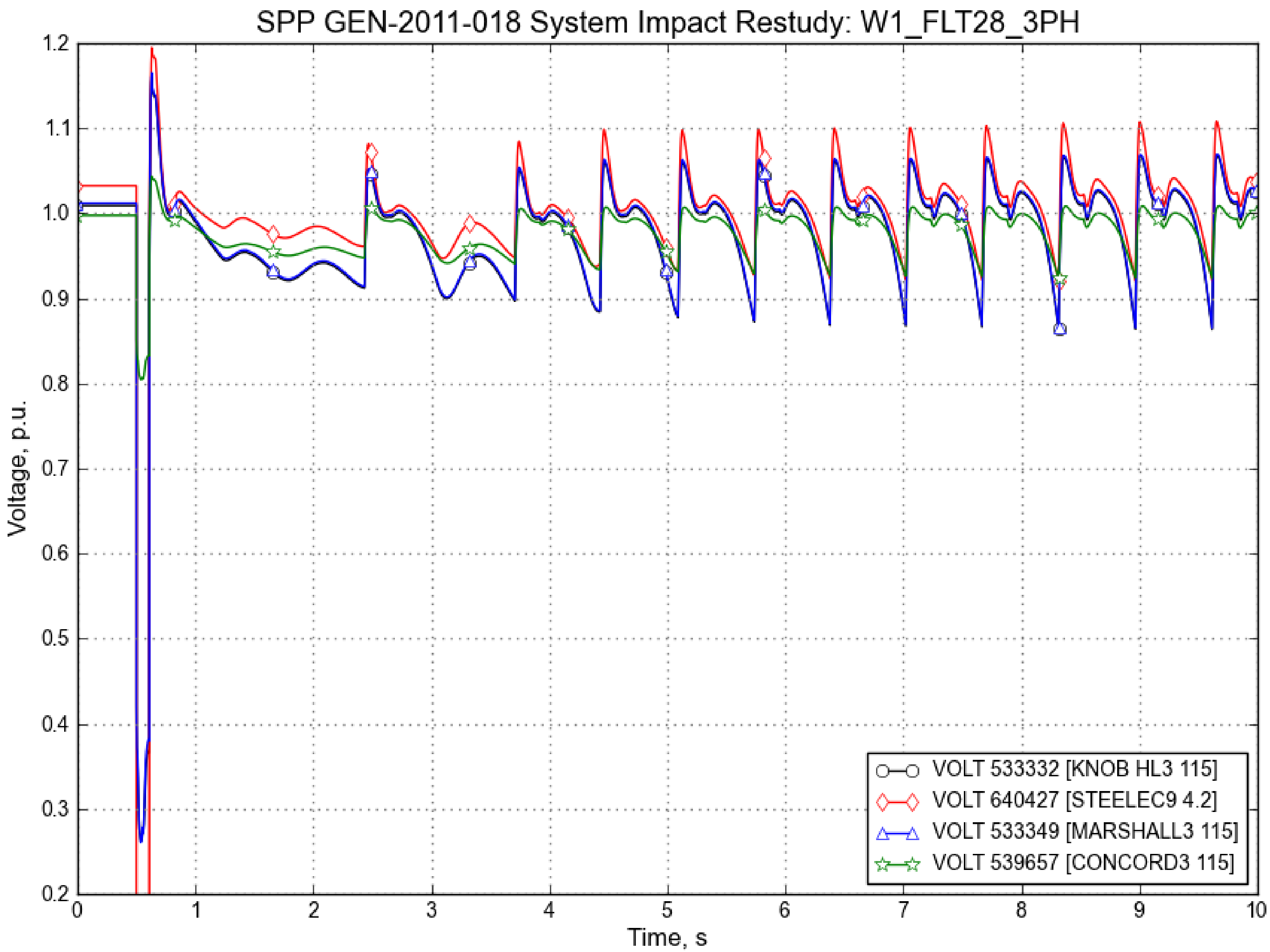

Figure 3-1. Plot of bus voltages for Winter Peak contingency FLT28-3PH.

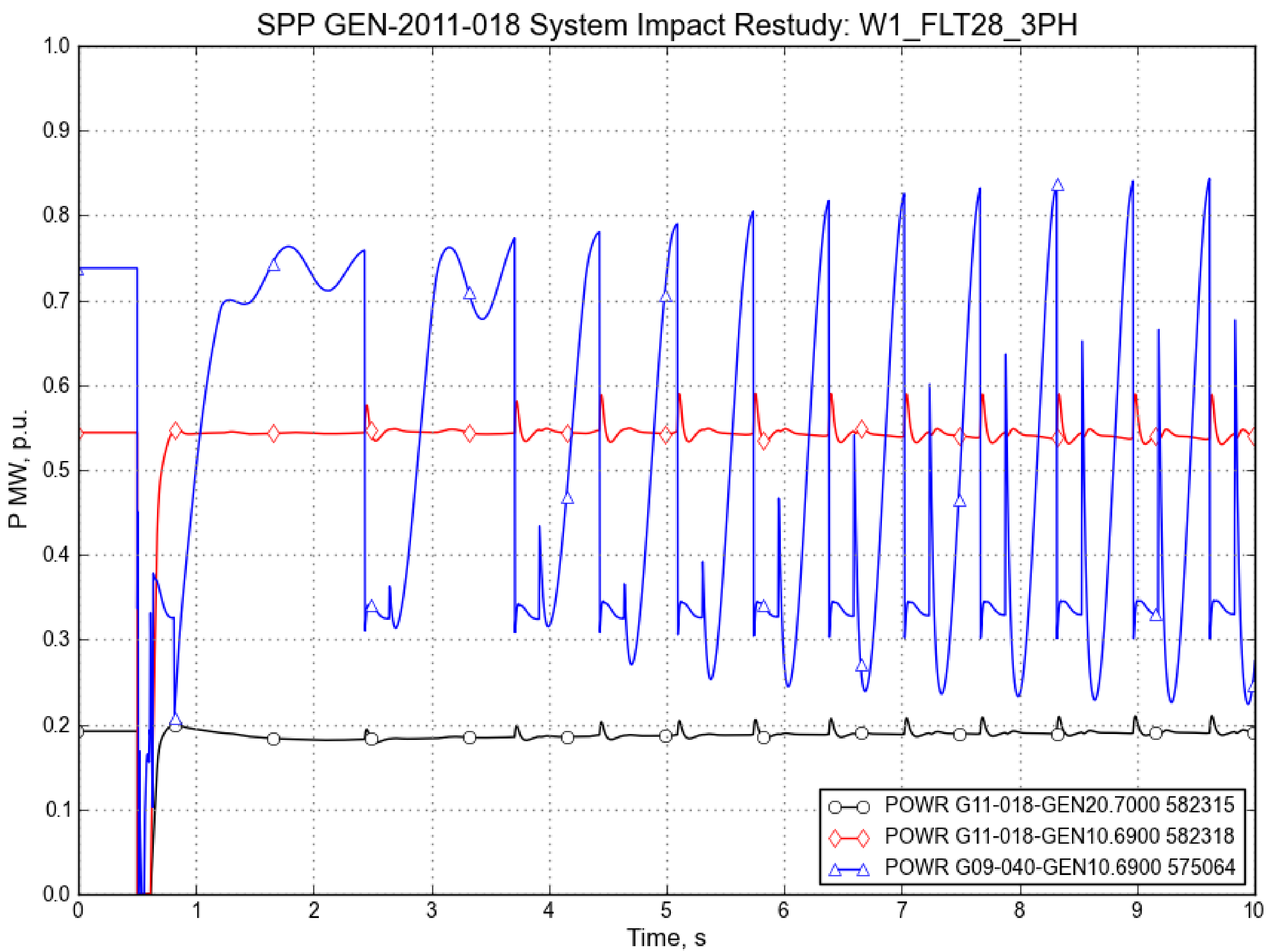

Figure 3-2. Real power response of GEN-2011-018 and GEN-2009-040 for Winter Peak FLT28-3PH.

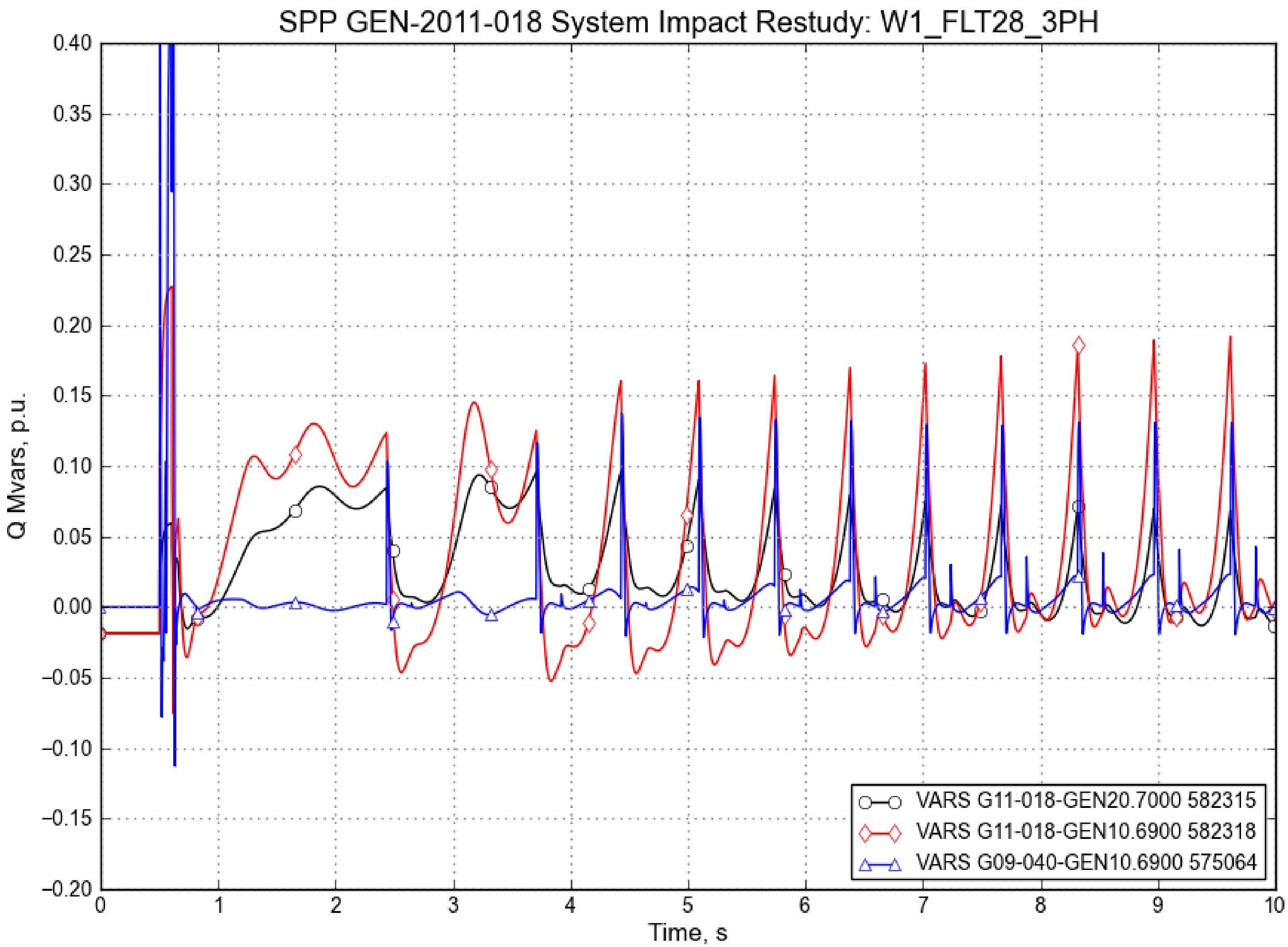

Figure 3-3. Reactive power response of GEN-2011-018 and GEN-2009-040 for Winter Peak FLT28-3PH.

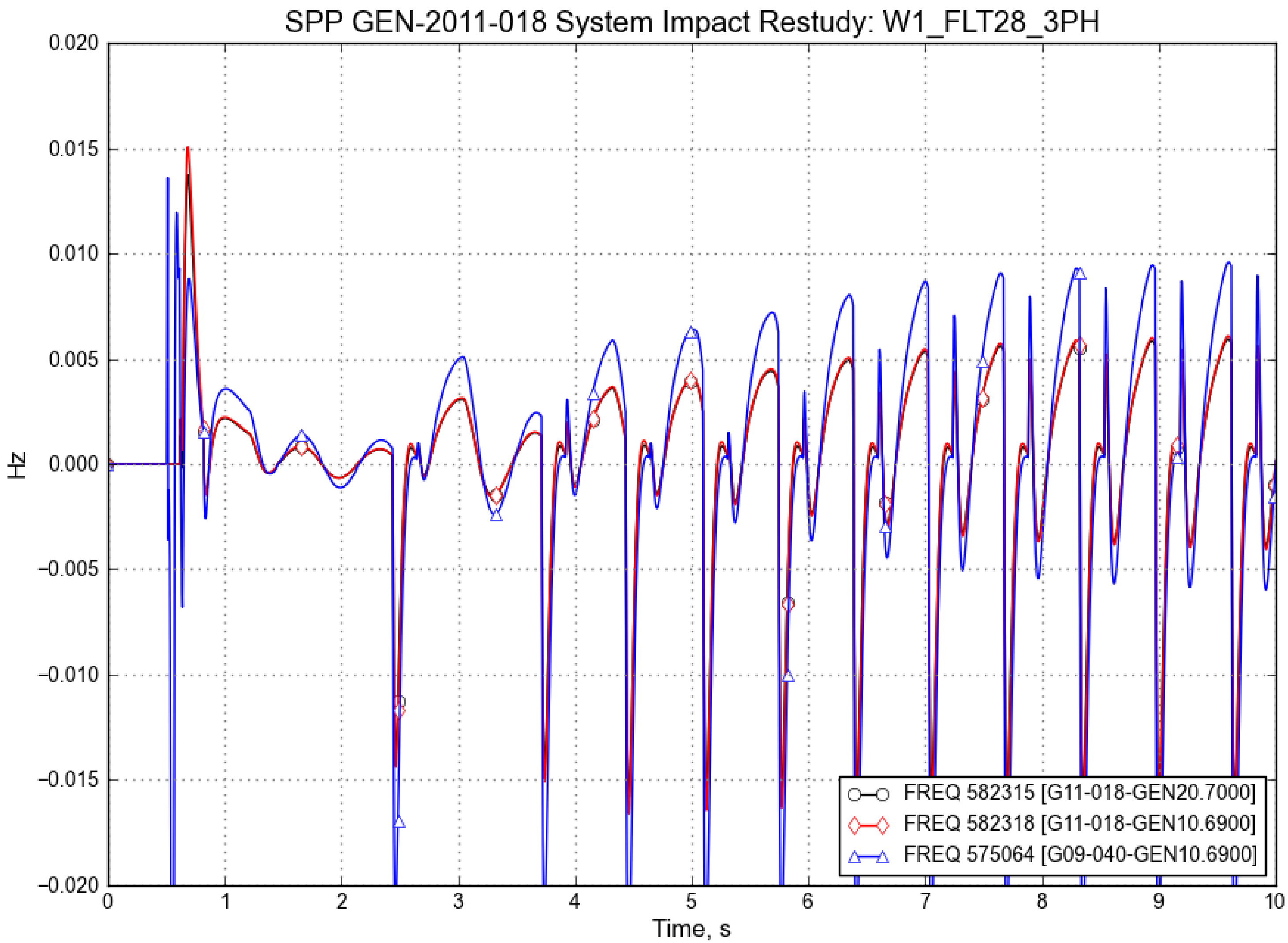

Figure 3-4. Frequency response of GEN-2011-018 and GEN-2009-040 for Winter Peak FLT28-3PH.

In discussion with SPP, two possible mitigations exist for the prior line outage condition. Since the voltage instability is local to the GEN-2011-018 (study project) and GEN-2009-040 facilities, one mitigation solution for this is to reduce the generation output of both of these generators for the prior line outage. A second mitigation solution for the unstable wind turbine and unstable bus voltages is listed here for reference. To mitigate the unstable wind turbine and unstable bus voltages, the 13.9 Mvar capacitor bank was switched online at Knob Hill 115 kV. Refer to the following plots for Winter Peak contingency FLT28-3PH with the additional capacitor bank online:

- Figure 3-5 shows a plot of the bus voltage at Steele City 115 kV, Knob Hill 115 kV, Marshall 115 kV, and Concord 115 kV.
- Figure 3-6 shows a plot of the real power response of GEN-2011-018 (Steele Flats Wind Project) and GEN-2009-040 (Marshall County Wind Project).
- Figure 3-7 shows a plot of the reactive power response of GEN-2011-018 and GEN-2009-040.
- Figure 3-8 shows a plot of the frequency response of GEN-2011-018 and GEN-2009-040.

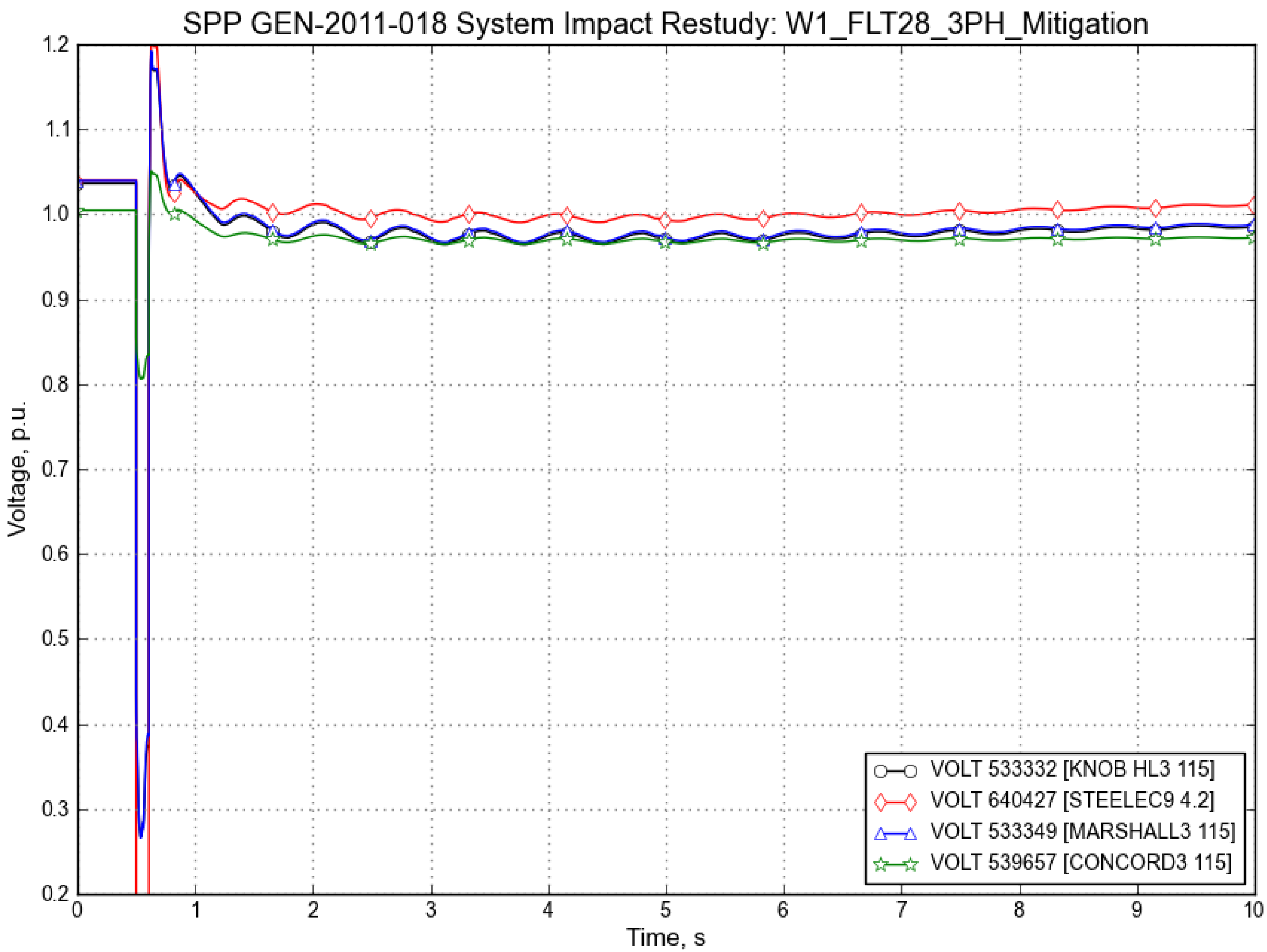

Figure 3-5. Plot of bus voltages for Winter Peak contingency FLT28-3PH with mitigation.

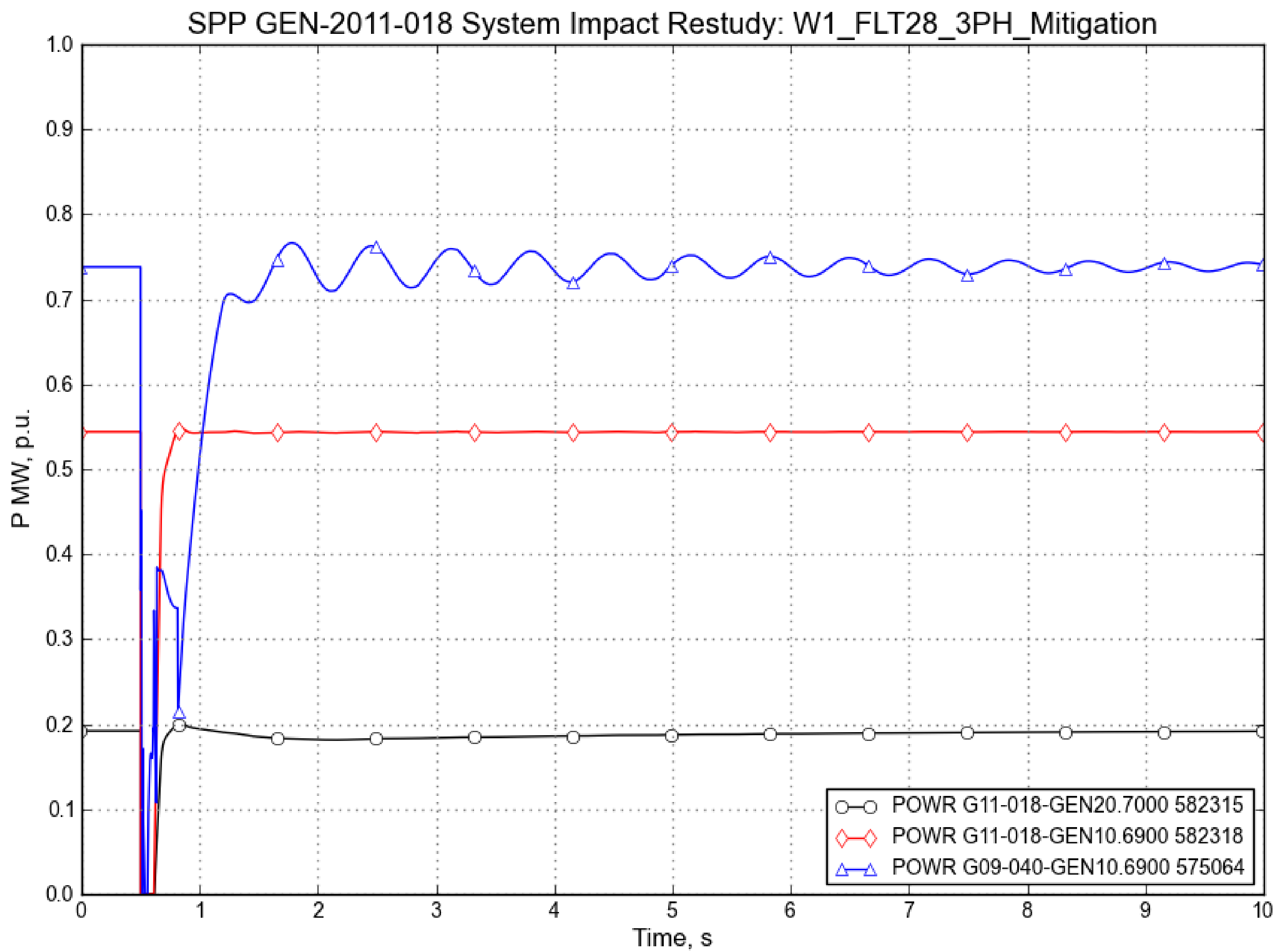

Figure 3-6. Real power response of GEN-2011-018 and GEN-2009-040 for Winter Peak FLT28-3PH with mitigation.

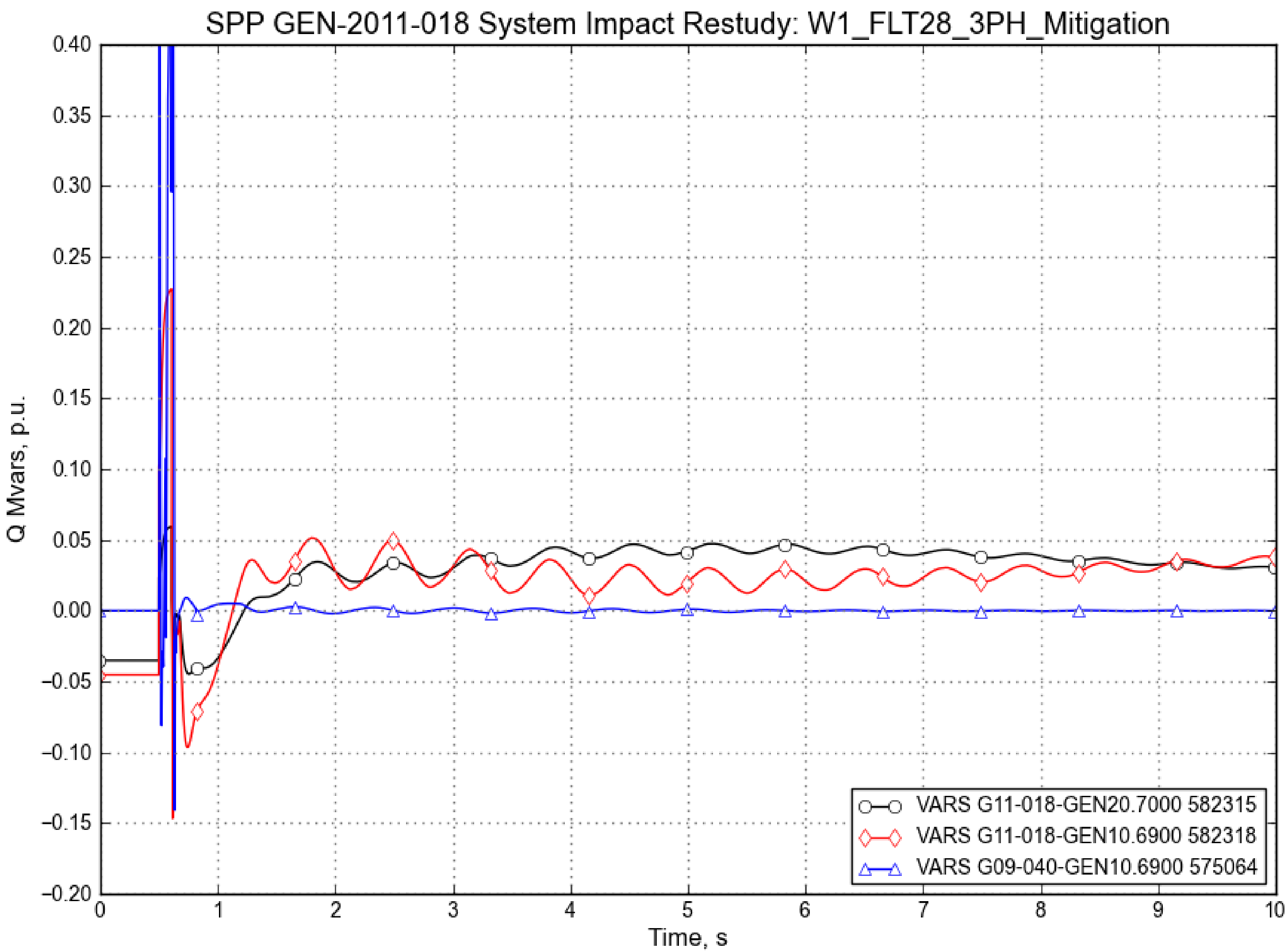

Figure 3-7. Reactive power response of GEN-2011-018 and GEN-2009-040 for Winter Peak FLT28-3PH with mitigation.

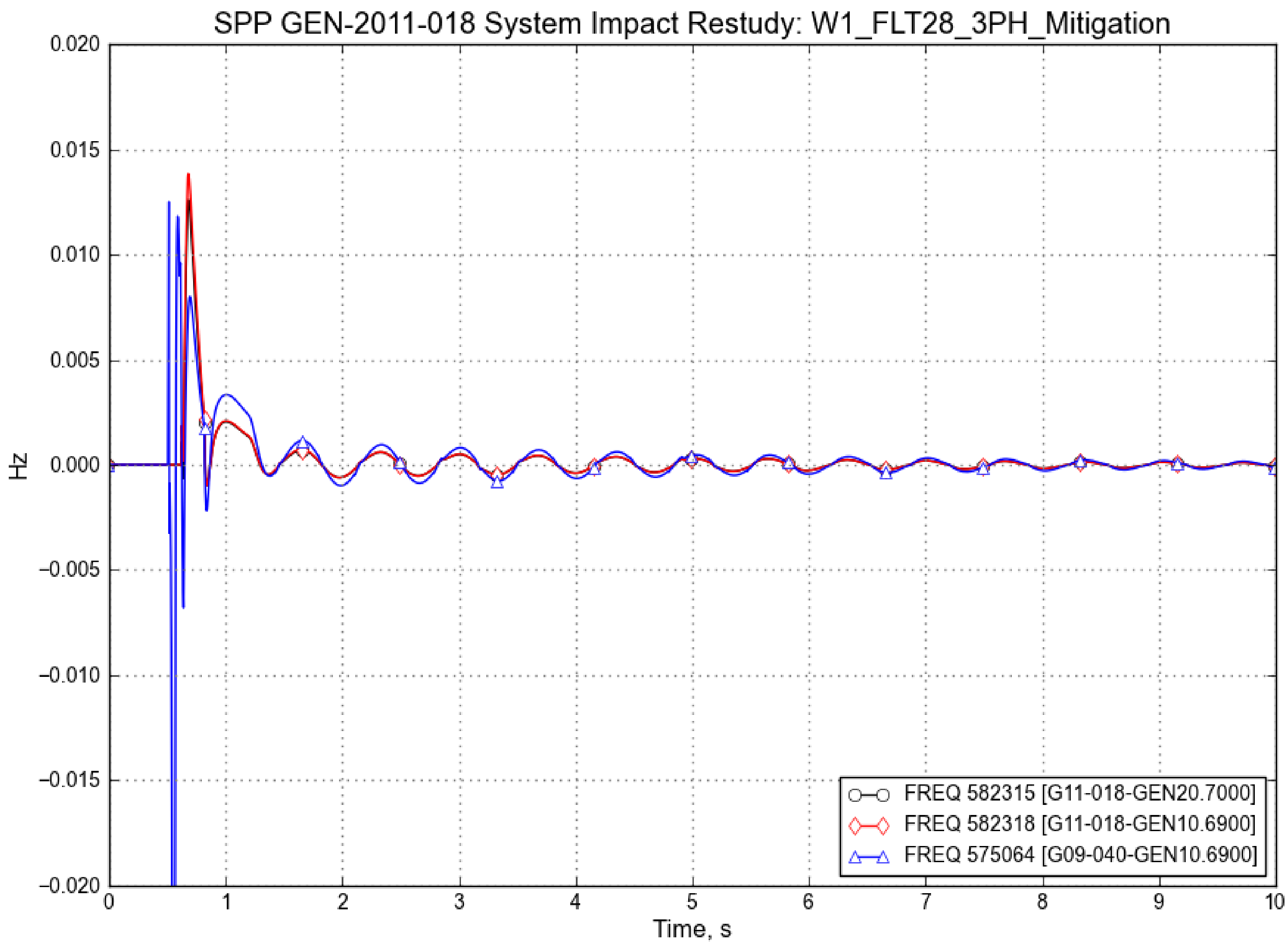

Figure 3-8. Frequency response of GEN-2011-018 and GEN-2009-040 for Winter Peak FLT28-3PH with mitigation.

Summary

For the summer peak case, the Stability Analysis determined that there was no wind turbine tripping or system instability that occurs from interconnecting GEN-2011-018 at 100% output.

For the winter peak case, the Stability Analysis determined that there was no wind turbine tripping or system instability that occurs from interconnecting GEN-2011-018 at 100% output for N-1 contingencies. When interconnecting GEN-2011-018 at 100% output for prior line outage contingencies, N-1-1, Contingency #28 was observed to have an unstable wind farm (GEN-2011-018, Marshall County Wind Project) and unstable bus voltages. There are two possible mitigation techniques for this case. The generation at GEN-2011-018 and GEN-2009-040 can be reduced during the prior line outage condition or the 13.9 Mvar capacitor bank at Knob Hill 115 kV can be switched online. With either of these two mitigations in place, the system remained stable and no wind turbine tripping was observed.

SECTION 4: POWER FACTOR ANALYSIS

The objective of this task is to quantify the power factor at the point of interconnection for the wind farms during base case and system contingencies. This is analyzed by having the wind farm maintain a prescribed voltage schedule at the point of interconnection of 1.0 p.u. voltage, or if the pre-project voltage is higher than 1.0 p.u., to maintain the pre-project voltage schedule.

After updating the wind turbine model for GEN-2011-018, both winter peak and summer peak power flows provided by SPP were examined prior to the Power Factor Analysis to ensure they contained the previously queued projects listed in Table 2-2. There was no suspect power flow data of concern in the study area. The proposed study project was turned off during the power factor analysis. The wind farms were then replaced by a generator modeled at the high side bus with the same real power (MW) capability as the wind farms and open limits for the reactive power set points (Mvar). The generator was set to hold the POI scheduled bus voltage or 1.0 p.u. voltage, whichever value is higher. Contingencies from the three-phase fault definitions provided in Table 2-4 were then applied and the reactive power required to maintain the bus voltage was recorded.

4.1 Study Project – GEN-2011-018

Approach

The study project (GEN-2011-018) was disabled and a generator was placed at the high side voltage bus. The generator was modeled with PGEN = 73.6 MW, QMin = -9999 Mvar, and QMax = 9999 Mvar. All buses and transformers connected from the study project's high side voltage bus to the generators were disabled. The pre-project voltage at the POI (Steele City 115 kV Bus – Bus 640246) for the summer peak conditions was 1.034 p.u. and for the winter peak conditions was 1.031 p.u. Therefore, the scheduled voltage for the POI was set to 1.034 p.u. for summer peak conditions and 1.031 p.u. for winter peak conditions.

Results

The power factor was calculated for summer and winter peak conditions. Table 4-1 shows the power factor results for GEN-2011-018 for summer and winter peak conditions. Note that a positive Q (Mvar) output illustrates that the generator is absorbing reactive power from the system, implying a leading power factor; a negative Q (Mvar) illustrates that the generator is supplying reactive power to the system, implying a lagging power factor.

Table 4-1
Power Factor Analysis: GEN-2011-018 (P_{GEN} = 73.6 MW)*

Case	Summer Peak			Winter Peak		
	Power Factor		Q** (MVAR)	Power Factor		Q** (MVAR)
Base	0.9913	Leading	9.80	0.9870	Leading	11.98
C1	0.9921	Leading	9.30	0.9998	Leading	1.37
C2	0.9771	Leading	16.01	0.9554	Leading	22.75
C3	0.9823	Leading	14.03	0.9898	Leading	10.59
C4	0.9984	Leading	4.20	0.9991	Leading	3.08
C5	0.9876	Leading	11.68	0.9775	Leading	15.87
C6	0.9921	Leading	9.31	0.9881	Leading	11.45
C7	0.9928	Leading	8.88	0.9893	Leading	10.84
C8	0.9926	Leading	9.01	0.9870	Leading	12.00
C9	0.9902	Leading	10.38	0.9887	Leading	11.14
C10	0.9912	Leading	9.82	0.9876	Leading	11.70
C11	0.9941	Leading	8.00	0.9887	Leading	11.15
C12	0.9944	Leading	7.85	0.9895	Leading	10.77
C13	0.9982	Leading	4.41	0.9878	Leading	11.61
C14	0.9949	Leading	7.49	0.9958	Leading	6.77
C15	0.9922	Leading	9.23	0.9870	Leading	11.98
C17	0.9926	Leading	9.01	0.9973	Leading	5.41
C19	0.9940	Leading	8.08	0.9870	Leading	11.98
C21	0.9907	Leading	10.09	0.9875	Leading	11.77
C23	0.9911	Leading	9.87	0.9874	Leading	11.80
C25	0.9858	Leading	12.55	0.9935	Leading	8.40

*The scheduled voltage for the POI (Steele City 115 kV) was 1.034 p.u. for summer peak and 1.031 p.u. for winter peak conditions.
**A positive Q (Mvar) output illustrates the generator is absorbing Mvars from the system, which implies a leading power factor; negative Q (Mvar) output shows the generator is supplying Mvars to the system implying a lagging power factor.

Summary

The Power Factor Analysis shows that GEN-2011-018 has a power factor range of 0.9554 to 0.9998 leading (absorbing).

4.2 Overall Summary

The Power Factor Analysis shows that GEN-2011-018 has a power factor range of 0.9554 to 0.9998 leading (absorbing).

SECTION 5: CONCLUSIONS

Power Factor Analysis

The Power Factor Analysis shows that GEN-2011-018 has a power factor range of 0.9554 to 0.9998 leading (absorbing).

Stability Analysis

For the summer peak case, the Stability Analysis determined that there was no wind turbine tripping or system instability that occurs from interconnecting GEN-2011-018 at 100% output.

For the winter peak case, the Stability Analysis determined that there was no wind turbine tripping or system instability that occurs from interconnecting GEN-2011-018 at 100% output for N-1 contingencies. When interconnecting GEN-2011-018 at 100% output for prior line outage contingencies, N-1-1, Contingency #28 was observed to have an unstable wind farm (GEN-2011-018, Marshall County Wind Project) and unstable bus voltages. There are two possible mitigation techniques for this case. The generation at GEN-2011-018 and GEN-2009-040 can be reduced during the prior line outage condition or the 13.9 Mvar capacitor bank at Knob Hill 115 kV can be switched online. With either of these two mitigations in place, the system remained stable and no wind turbine tripping was observed.