Southwest Power Pool

Impact Re-Study For Generation Interconnection Request GEN-2006-020S

SPP Tariff Studies

(#GEN-2006-020S)

December 2010

Summary

Pursuant to the tariff and at the request of the Southwest Power Pool (SPP), AMEC Earth and Environmental performed the following Impact restudy to satisfy the Impact Study Agreement executed by the requesting Customer and SPP for SPP Generation Interconnection request #GEN-2006-020S. This generation interconnection request was originally studied with GE 1.5 MW wind turbines at 19.5MW. The Customer has subsequently asked for a restudy assuming the facility will contain DeWind D8.2 2.0MW wind turbines at 20MW total capacity.

This generation interconnection request currently has an executed Interconnection Agreement.

The stability study results show that with the Customer requested GE wind turbines the transmission system remains stable for all simulated contingencies studied. If the Customer changes the manufacturer or type of wind turbines from the DeWind D8.2 2.0MW, a new impact study will be required.

The stability study results show that the wind farm will meet FERC Order #661A's Low Voltage Ride Through (LVRT) provisions with the DeWind 8.2 turbines.

The impact study shows that a unity power factor will be adequate to maintain voltage schedules and stability considerations for the wind farm. The network upgrade costs and the interconnection facilities costs are found in the Facilities Study for Generation Interconnection Request GEN-2006-020S dated May 2007.

GEN-2006-020S Restudy

December 8, 2010

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EXECUTIVE SUMMARY

The Southwest Power Pool (SPP) has a requested a restudy of a generator interconnection request for a 115 kV interconnection of a 20 MW wind farm in the northern Texas panhandle. This wind farm will be interconnected into a new 115kV substation. The interconnection customer has asked for a study case of 100% MW output (with dynamic reactive compensation if required). This substation is owned by SPS.

Request	Size (MW)	Wind Turbine Model	Point of Interconnection
GEN-2006-020S	20	DeWind D8.2	Moore County-Hitchland 115kV (523160)

The case will contain the following previous queued and later queued requests. These projects will be monitored and their generating status shall be reported for each contingency. The projects are as follows:

Request	Size (MW)	Wind Turbine Model	Point of Interconnection
GEN-2002-006	150	GE 1.5MW	Texas Co. 115kV (523090)
GEN-2002-008	240	GE 1.5MW	Hitchland 345kV (523097)
GEN-2002-009	80	Suzlon 2.1MW	Hansford 115kV (523195)
GEN-2003-013	196	GE 1.5 MW	Hitchland – Finney 345kV (560029)
GEN-2003-020	160	GE 1.5 MW	Carson Co. 115kV (523924)
GEN-2005-017	340	GE 1.5 MW	Hitchland – Potter 345kV (51700)

SPP requested a stability analysis and a power factor analysis as part of the restudy of GEN-2006-020S. SPP did not request an Available Transfer Capability (ATC) study as part of this study.

Transient stability analysis shows no problems with the dynamic response of study generation in the region of interest for the faults and clearing times studied. All generators in the monitored area remain stable during the studied faults.

GEN-2006-020S has the capability of pre-contingency voltage recovery. The 115 kV POI voltage recovered to between 1.0086 and 1.0322 pu for all faults studied.

Low Voltage Ride Through (LVRT) analysis shows no generators tripping due to low voltage.

The power factor analysis indicated that no supplemental reactive capability would be necessary in order to meet the study requirements.

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1. INTRODUCTION

The Southwest Power Pool (hereafter referred to as SPP) commissioned AMEC Earth and Environmental (hereafter referred to as AMEC) to restudy the impact of generator GEN-2006-020S in the SPP interconnection queue. The site studied is in the northern panhandle of Texas. This restudy is at the customer's request.

SPP did not request an Available Transfer Capability (ATC) study. The ATC study will be required when the generation companies request transmission service.

SPP requested a power factor analysis and stability analysis based on a list of faults provided by SPP. The results of this study

a. Determined the equivalent amount of reactive compensation required at the 115kV POI to maintain adequate post contingency voltage with GEN-2006-020S modeled at the 115kV POI bus with 0 Var output.

b. Determine the ability of the wind farm to meet FERC Order 661A (low voltage ride through and wind farm recovery to pre-fault voltage) with and without additional reactive power support.

c. Determine the ability of the generators to remain in synchronism following three-phase and single-line-to-ground faults.

2. STUDY METHODOLOGY

SPP provided 2010 summer peak and 2011 winter peak load flow cases in PSS/E format. Table 1 below shows the total demand and generation in the monitored areas.

Table 1: Description of Study Areas

Area No.	Area Name	2011 Summer Peak		2011 Winter Peak	
		Load (MW)	Generation (MW)	Load (MW)	Generation (MW)
520	AEPW	10245.5	9213.8	7877.4	6835.7
524	OKGE	5955.8	6768.9	4193.9	4558.3
525	WFEC	1416.9	1216.6	1306.2	1054.5
526	SPS	5614	6550.9	4037.8	5088.1
534	MIDW	545.1	581.3	447.1	548.9
539	SUNC	559.2	471.9	451.1	241.4

- **POWER FACTOR ANALYSIS**

A power factor analysis was performed to determine if additional reactive compensation was required to hold the voltage at the point of interconnection consistent with the voltage schedule in the base case or 1.0 PU, whichever is higher. The equivalent wind farm model of GEN-2006-020S was disconnected from the point of interconnection. There are no previously queued generation interconnection requests at the point of interconnection. A generator with the equivalent real power MW and no reactive capability was modeled at the POI. A var generator was modeled at the queued wind farm's substation high voltage bus POI. The var generator was set to hold a voltage schedule at the POI consistent with the voltage schedule provided in the base case or 1.0 PU voltage (whichever is higher).

A list of contingencies shown in Table 2 was simulated. Additional reactive compensation was modeled at the 115kV side of the POI of the wind farm collector substation to maintain 1.00 PU post contingency bus voltage.

Table 2: Steady-State Contingency Descriptions

Cont No.	Description
FLT01	Wind Farm (523160)-Hitchland (523093) 115kV line
FLT03	Wind Farm (523160)-Sherman Tap (523175)115kV line
FLT05	Moore (523309)-Potter (523959) 230kV line
FLT07	Texas County (523090) – TCMMRY (523113) 115kV line
FLT09	Spearman (523186) – Hansford (523195) 115kV line
FLT11	Spearman (523186) – Pringle (523266) 115kV line
FLT13	Plant X (525481) - Potter (523959) 230kV line
FLT15	Q_Ryton_Tp (523478) -Blackhawk (523344)115kV line
FLT17	Pringle (523267) -Harrington (523979) 230kV line

Tables 3 contains the results of the powerflow analysis for each of the fault conditions specified in Table 2 for the summer and winter conditions. The table contains bus voltage at the POI and the supplemental reactive support from the equivalent var generator modeled at the POI 115kV substation bus.

Table 3: Voltage at POI and Supplemental Reactive

Cont. No.	GEN-2006-020S							
	Summer				Winter			
	Voltage (PU)	P (MW)	Mvar at POI	Net PF	Voltage (PU)	P (MW)	Mvar at POI	Net PF
Base Case	1.008	20	0	1.0	1.037	20	0	1.0
FLT01	1.009	20	0	1.0	1.019	20	0	1.0
FLT03	1.015	20	0	1.0	1.020	20	0	1.0
FLT05	1.009	20	0	1.0	1.027	20	0	1.0
FLT07	1.007	20	0	1.0	1.020	20	0	1.0
FLT09	1.004	20	0	1.0	1.016	20	0	1.0
FLT11	1.007	20	0	1.0	1.020	20	0	1.0
FLT13	1.008	20	0	1.0	1.020	20	0	1.0
FLT15	1.008	20	0	1.0	1.020	20	0	1.0
FLT17	1.009	20	0	1.0	1.022	20	0	1.0

- **DYNAMIC ANALYSIS**

The study areas shown in Table 1 were monitored in the dynamic analysis. The transmission line and transformer faults were simulated and synchronous machine rotor angles and wind turbine generator speeds were monitored to check whether synchronism of the synchronous machines is maintained and whether the wind turbine generators trip offline during the disturbance.

Following is a summary of the faults simulated in this analysis.

Table 4: Fault Descriptions

Cont. No.	*Cont. Name*	*Description*
1	FLT01-3PH	3 phase fault on the Wind Farm (523160)-Hitchland (523093) 115kV line 1. Apply fault at Wind Farm 115kV bus (523160). 2. Clear fault after 5 cycles by removing the line from service. 3. Wait 20 cycles, and then re-close the line into the fault. 4. Leave fault on for 5 cycles, then trip and lock out the line.

Cont. No.	Cont. Name	Description
2	FLT02-1PH	Single line to ground fault same as FLT01-3PH
3	FLT03-3PH	3 phase fault on the Wind Farm (523160)-Sherman Tap (523175)115kV line 1. Apply fault at Sherman Tap (523175). 2. Clear fault after 5 cycles by removing the line from service. 3. Wait 20 cycles, and then re-close the line into the fault. 4. Leave fault on for 5 cycles, then trip and lock out the line.
4	FLT04-1PH	Single line to ground fault same as FLT03-3PH
5	FLT05-3PH	3 phase fault on the Moore (523309)-Potter (523959) 230kV line 1. Apply fault at Moore (523309). 2. Clear fault after 5 cycles by removing the line from service. 3. Wait 20 cycles, and then re-close the line into the fault. 4. Leave fault on for 5 cycles, then trip and lock out the line.
6	FLT06-1PH	Single line to ground fault same as FLT05-3PH
7	FLT07-3PH	3 phase fault on the Texas County (523090) – TCMMRY (523113) 115kV line 1. Apply fault at the TCMMRY 115kV bus. 2. Clear fault after 5 cycles by removing the line from service. 3. Wait 20 cycles, then reclose the line into the fault. 4. Leave fault on for 5 cycles, then trip and lock out the line.
8	FLT08-1PH	Single line to ground fault same as FLT07-3PH
9	FLT09-3PH	3 phase fault on the Spearman (523186) – Hansford (523195) 115kV line 1. Apply fault at the Spearman (523186) 115kV bus. 2. Clear fault after 5 cycles by removing the line from service. 3. Wait 20 cycles, and then re-close the line into the fault. 4. Leave fault on for 5 cycles, then trip and lock out the line.
10	FLT10-1PH	Single line to ground fault same as FLT09-3PH
11	FLT11-3PH	3 phase fault on the Spearman (523186) – Pringle (523266) 115kV line, CKT 1 1. Apply fault at the Spearman 115kV bus. 2. Clear fault after 5 cycles by removing the line from service. 3. Wait 20 cycles, and then re-close the line into the fault. 4. Leave fault on for 5 cycles, then trip and lock out the line.
12	FLT12-1PH	Single line to ground fault same as FLT11-3PH
13	FLT13-3PH	3 phase fault on the Plant X (525481) - Potter (523959) 230kV line 1. Apply fault at the Plant X 230kV bus. 2. Clear fault after 5 cycles by tripping the Plant X - Potter 230kV line 3. Wait 20 cycles, then reclose the line into the fault 4. Leave fault on for 5 cycles, then trip and lock out the line.
14	FLT14-1PH	Single line to ground fault same as FLT13-3PH

Cont. No.	Cont. Name	Description
15	FLT15-3PH	3 phase fault on the Q_Ryton_Tp (523478) -Blackhawk (523344)115kV line 1. Apply fault at the Blackhawk 115kV bus. 2. Clear fault after 5 cycles by tripping the Pringle-Blackhawk 115kV line 3. Wait 20 cycles, then reclose the line into the fault 4. Leave fault on for 5 cycles, then trip and lock out the line.
16	FLT16-1PH	Single line to ground fault same as FLT15-3PH
17	FLT17-3PH	3 phase fault on the Pringle (523267) -Harrington (523979) 230kV line 1. Apply fault at the Pringle 230kV bus. 2. Clear fault after 5 cycles by tripping the Pringle-Harrington 230kV line 3. Wait 20 cycles, then reclose the line into the fault 4. Leave fault on for 5 cycles, then trip and lock out the line.
18	FLT18-1PH	Single line to ground fault same as FLT17-3PH

In order to simulate 1PH faults, equivalent shunt Mvar[1] were determined to be applied at the faulted buses. Table 5 presents equivalent reactors used in the transient stability study.

Table 5: Equivalent Shunt Mvar at Faulted Bus for Single-Line-to-Ground Faults

Fault No.	Faulted Bus No.	2011 Summer Peak (Mvar)	2011 Winter Peak (Mvar)
FLT02-1PH	523160	-772.1	-786.7
FLT04-1PH	523160	-772.1	-786.7
FLT06-1PH	523309	-1640.7	-1635.0
FLT08-1PH	523113	-786.1	-787.7
FLT10-1PH	523186	-1124.4	-1138.4
FLT12-1PH	523186	-1124.4	-1138.4
FLT14-1PH	525481	-5126.9	-4005.4
FLT16-1PH	523344	-1689.0	-1682.7
FLT18-1PH	523267	-1184.9	-1183.7

Another important aspect of the dynamic analysis was to check FERC Order 661A compliance. The turbine generators were monitored to determine whether they stayed connected to the grid (Low Voltage Ride Through - LVRT) following the faults defined in Table 5. The wind farm capability of post-fault voltage recovery at the POI was also checked.

[1] The equivalent shunt Mvar causes the voltage at the faulted bus to drop to 0.60 PU.

3. PROJECT DESCRIPTION

Following is a table of the proposed wind farms in Group 1.

Table 6: Points of Interconnection Gen-2006-020

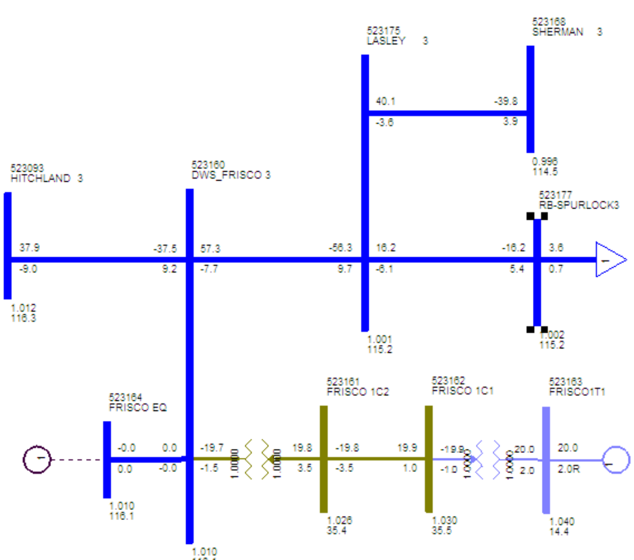
Request	Size (MW)	Turbine Model	Point Of Interconnection	
			Bus No.	Bus Name in model
GEN-2006-020S	20	DeWind D8.2	523160	DWS Frisco 3 115kV

The one-line diagram of GEN-2006-020S in Figure 1 uses the following color codes for nominal voltages:

Lt Blue **13.8 kV**
Red **34.5 kV**
Blue **115 kV**

All voltages and line flows are from the 2011 summer peak base case.

Figure 1: GEN-2006-020S Interconnection One-Line Diagram



As illustrated below, GEN-2006-020S is located in north of Amarillo in the Texas panhandle.

Figure 2: Geographical Location of GEN-2006-020S Project

The following is the detailed description of the wind project in GEN-2006-020S.

GEN-2006-020S

- Wind farm rating
  - Active power capability: 20 MW
  - Reactive power capability: 9.7 MVAR
- Interconnection:
  - Voltage: 115 kV
  - Location: New substation looped into SWPS Moore County-Hitchland 115 kV line
  - Transformer: One step-up transformer connecting to the 115 kV
    - MVA: Rate A - 15, Rate B - 20, Rate C - 25
    - Voltage: 115/34.5 kV
    - R: 0.267% on a 15 MVA base
    - X: 8% on a 15 MVA base
- Wind turbine:
  - Number: 10
  - Manufacturer: DeWind
  - Type: Synchronous generator (4-pole brushless) with hydraulic torque converter
  - Machine terminal voltage: 13.8 kV
  - Rated power: 2.0 MW
  - Frequency: 60Hz
  - Generator step-up transformer
    - MVA: 2.3
    - Voltage: 34.5/13.8 kV
    - R: 0.759% on a 2.3 MVA base
    - X: 5.70% on a 2.3 MVA base
- Generator protection
  - Undervoltage
    - Relay trips when V_{bus} = 0.00 pu for t = 0.15 s
      V_{bus} < 0.75 pu for t = 1.0 s
      V_{bus} < 0.85 pu for t = 2.0 s
  - Overvoltage
    - Relay trips when V_{bus} > 1.15 pu for t = 2.0 s
      V_{bus} > 1.25 pu for t = 0.1 s
      V_{bus} > 1.40 pu for t = 0.033 s
  - Underfrequency
    - Relay trips when F_{bus} < 55.5 Hz for t = 0.00 s
      F_{bus} < 56.5 Hz for t = 0.35 s
      F_{bus} < 57.0 Hz for t = 2.00 s

Overfrequency

Relay trips when F_{bus} > 61.5 Hz for t = 90.0 s
F_{bus} > 63.0 Hz for t = 5.00 s
F_{bus} > 66.0 Hz for t = 0.00 s

4. POWER FACTOR RESULTS

The proposed GEN-2006-020S wind farm (20 MW) will be comprised of 10 DeWind 2 MW wind turbine generators. GEN-2006-020S was modeled as an equivalent 20 MW generator with 0 var capability at the 115kV POI at the DWS_Frisco substation. A continuously variable var generator was modeled at the 115kV POI and scheduled to maintain 1.00 PU post contingency voltages at the DWS_Frisco 115kV bus.

A contingency analysis was run for 2011 summer and winter peak conditions considering all of the faults described in Table 2.

The results listed in Tables 3 indicate that no additional reactive compensation at the 115kV POI is required to maintain 1.00 PU post contingency voltages.

5. VOLTAGE RECOVERY RESULTS

Dynamic simulations were performed using each fault Included in Table 5. Voltage recovery as determined via dynamic simulation was checked against all contingencies. If the post-fault voltage recovers to a steady-state level consistent with the steady-state simulation, the generator interconnection is considered acceptable from a voltage recovery standpoint.

In these dynamic simulations, real loads are modeled as constant current and reactive loads are modeled as constant admittance; i.e. MW loads are proportional to voltage and Mvar loads are proportional to voltage squared. In contrast, loads are modeled as constant MW and constant Mvar in steady-state simulations. Therefore, due to differences in load modeling, minor differences in voltages are to be expected between dynamic and steady-state simulations.

The dynamic simulation showed that GEN-2006-020S generators did not trip during any of the contingencies tested. That is, the wind farm GEN-2006-020S meets FERC Order 661A (low voltage ride through and wind farm recovery to pre-fault voltage). Table 8 lists the post-fault voltages at POI calculated with no reactive compensation on either side of the POI.

Table 7: Post-Fault Voltage Recovery by Dynamic Simulation

Fault Name	Voltage @ GEN-2006-020S POI (Moore County-Hitchland 115 kV bus) (pu)	
	Summer Peak	Winter Peak
FLT01 & FLT02	1.0122	1.0322
FLT03 & FLT04	1.0156	1.0187
FLT05 & FLT06	1.0101	1.0202
FLT07 & FLT08	1.0088	1.0196
FLT09 & FLT10	1.0062	1.0165
FLT11 & FLT12	1.0086	1.0203
FLT13 & FLT14	1.0088	1.0194
FLT15 & FLT16	1.0093	1.0206
FLT17 & FLT18	1.0101	1.0211

Figure 3 below shows the highest and lowest post-fault voltage at the POI resulting from FLT03-3PH/FLT04-1PH (highest) and FLT09-3PH/FLT10-1PH (lowest) for the summer case.

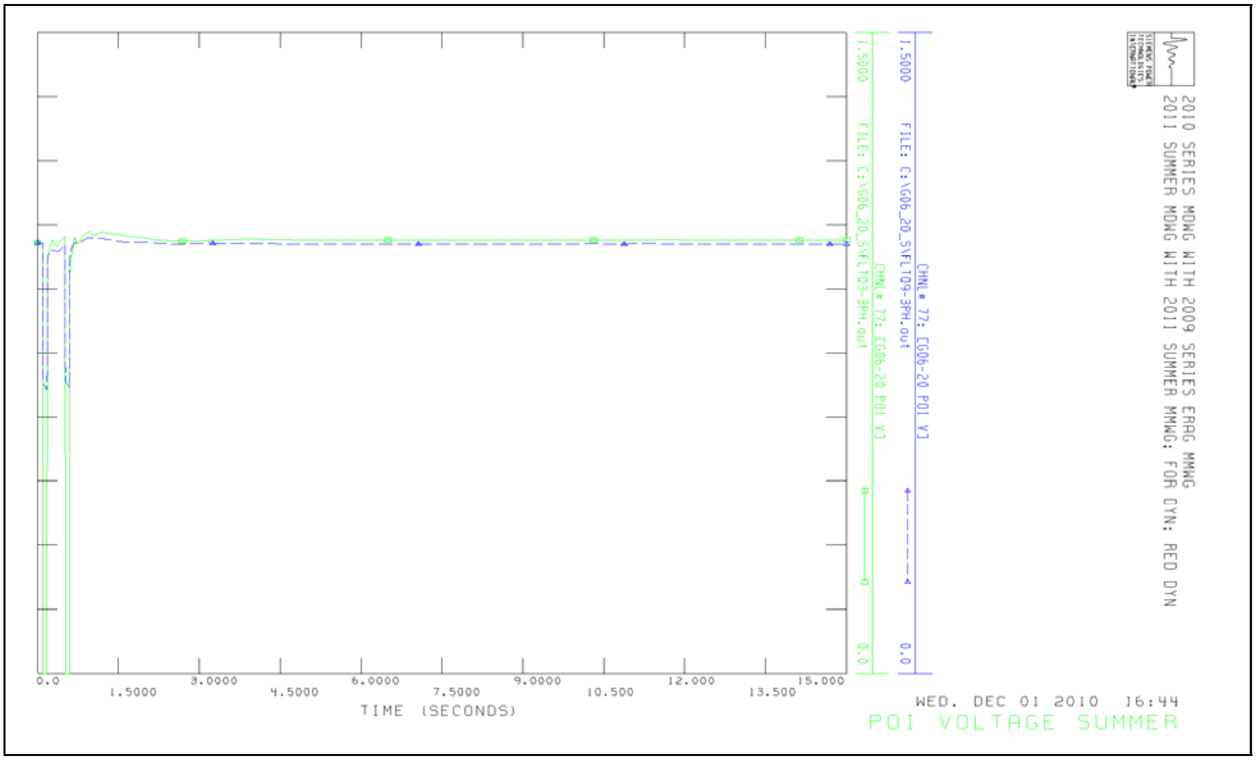


Figure 3: POI Voltage Recovery for FLT03/FLT04 and FLT09/FLT10, Summer Peak

Figure 4 below shows the highest and lowest post-fault voltage at the POI resulting from FLT01-3PH/FLT02-1PH (highest) and FLT09-3PH/FLT10-1PH (lowest) for the winter case.

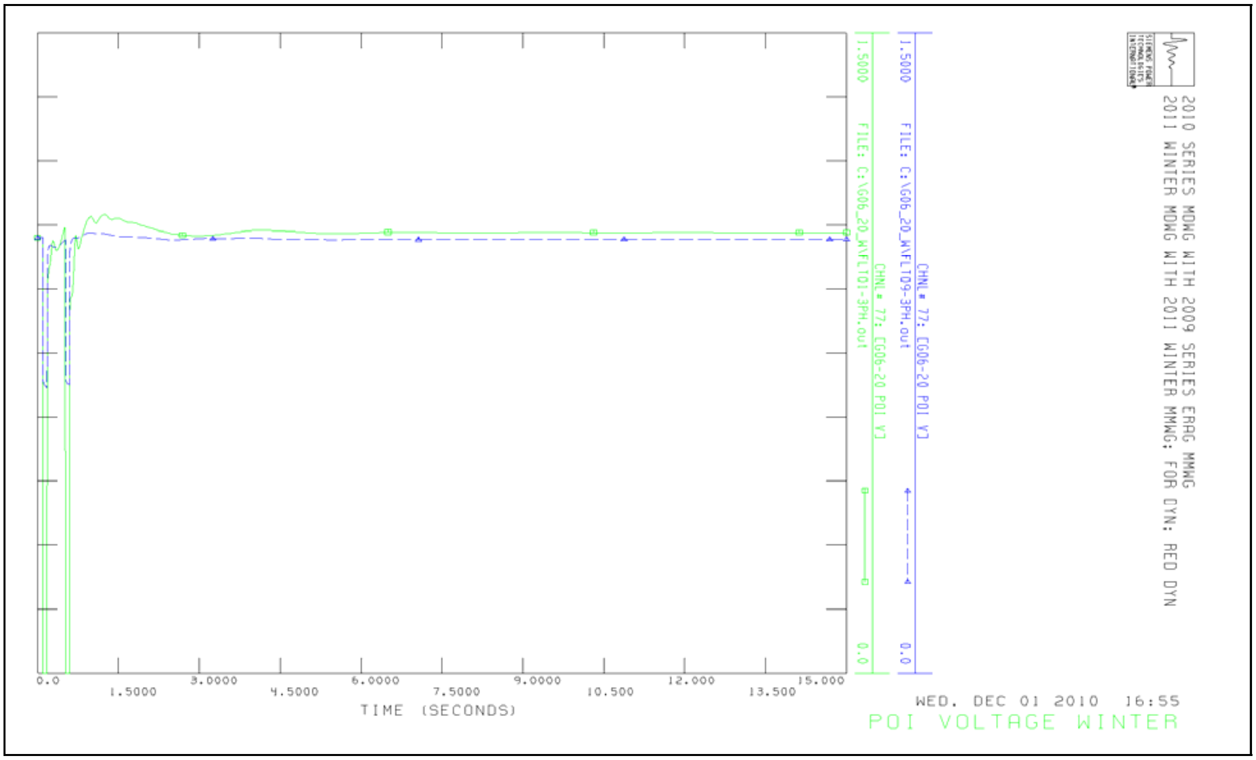


Figure 4: POI Voltage Recovery for FLT01/FLT02 and FLT09/FLT10, Winter Peak

6. TRANSIENT STABILITY RESULTS

Based on the dynamics results, GEN-2006-020S did not cause any new stability problems. For the faults studied, the three-phase faults are relatively more severe than the corresponding single-line- to-ground fault. No synchronous generators pulled out of synchronism with the grid, and no generators tripped due to over/under voltage or over/under frequency.

Following are plots of the rotor angle for GEN-2006-020S for the most severe faults: FLT01-3PH and FLT02-1PH. These faults are for the 115 kV line from the POI to Hitchland. In both the summer and winter cases, the rotor angles swing by approximately 70° in either direction from the equilibrium for FLT01-3PH. This suggests that, although the machines return to synchronism with the grid post-fault, the fault clearing time of 5 cycles is near the critical clearing time.

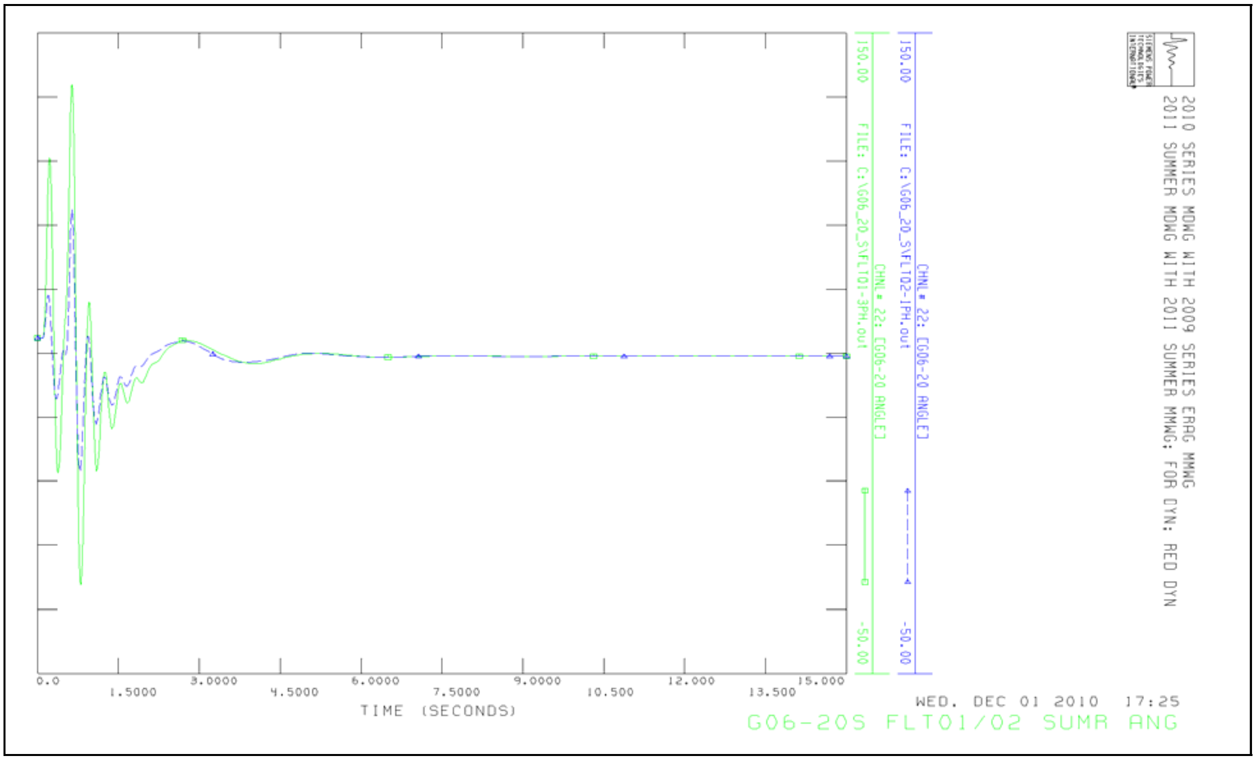


Figure 5: Response of GEN-2006-020S Wind Turbine Generator Rotor Angle to FLT01-3PH and FLT02-1PH, Summer Peak

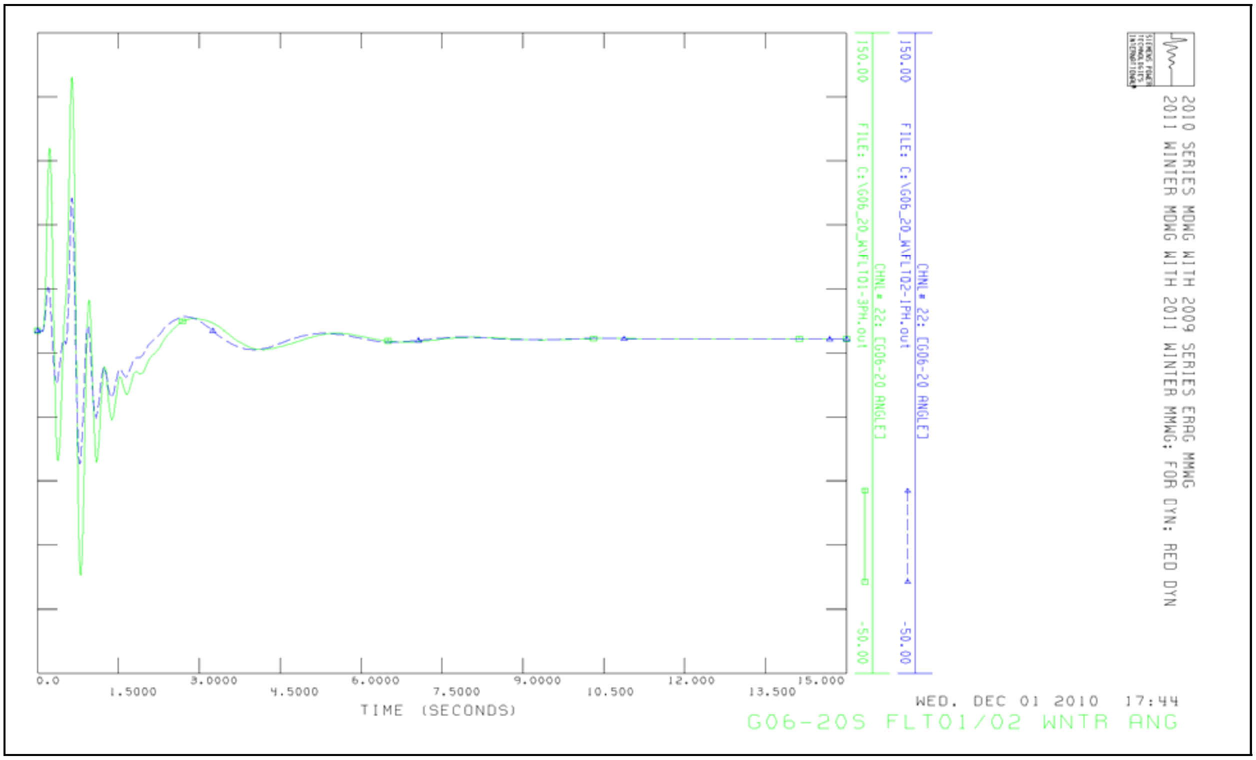


Figure 6: Response of GEN-2006-020S Wind Turbine Generator Rotor Angle to FLT01-3PH and FLT02-1PH, Winter Peak

7. CONCLUSIONS

Based on the results of the GEN-2006-020S restudy, the following findings had been observed:

- No additional reactive compensation is required to maintain post contingency POI bus voltage at 1.00 PU with GEN-2006-020S on line.
- GEN-2006-020S meets LVRT requirements. No wind turbine generators tripped off line under the fault conditions.
- GEN-2006-020S had the capability of recovering to the pre-contingency voltage following the fault disturbance.
- None of the synchronous machines in the studied areas suffered from instability for the faults studied.