SPP
Southwest
Power Pool

GEN-2008-016
Impact Restudy

SPP Generation
Interconnection Studies

GEN-2008-016

September 2010

Executive Summary

This report contains the findings of a restudy of GEN-2008-016. The GEN-2008-016 interconnection request was studied as part of the “1st Cluster” in ICS-2008-001 which Impact Study was posted in July 2009. Subsequent restudies were posted in January, May, and August of 2010. This restudy was performed solely to evaluate the effects of a turbine manufacturer change of switching wind turbine manufacturers from Vestas (V90-1.8MW) to Siemens (SWT-2.3-101).

The findings of the restudy show that for an outage of the Grassland to Jones 230kV line, the voltage at the Grassland bus (the point of interconnection or POI for GEN-2008-016) oscillated between 0.83 per unit (PU) and 0.98 PU for about four seconds after the clearing of the fault. After four seconds the POI voltage returned close to the pre-fault level. The study report indicates that the Siemens wind turbine controls may have some short term instability for this particular outage. Further analysis was done to determine the feasibility of using dynamic voltage compensation to improve the wind farm response. The results show that 75 MVAR SVC on the POI will improve the response (that is, in reducing the magnitude of the oscillations). However, the oscillations were not entirely eliminated.

It is recommended that the wind turbine manufacturer (Siemens) be consulted to determine if the controls can be adjusted to improve performance. Due to the system configuration of the Grassland bus and the short circuit ratio with the outage of the Grassland – Jones 230kV line (given by ABB as 2.16), it would be beneficial for the Customer to lower the amount of generation being requested from 248.4 MW. It cannot be determined from this study whether the Siemens turbines can interconnect into the Grassland 230kV bus.

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.

Interconnection Impact Re-study for GEN-2008-016

REPORT NO.: E-00005002 R2
Issued On: August 26, 2010

Prepared for:
Southwest Power Pool, Inc.

ABB Inc.
Power Systems Division
Grid Systems Consulting
940 Main Campus Drive, Suite 300
Raleigh, NC 27606

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ABB Inc – Grid Systems Consulting

Technical Report

Southwest Power Pool, Inc.	**No.** E-00005002 R2	
Interconnection Impact Re-study for GEN-2008-016	Date: 08/26/10	# Pages 23

Author(s):	**Reviewed by:**	**Approved by:**
B Kondala Rao	Seshadri Subramanian	Willie Wong

Executive Summary

Southwest Power Pool, Inc. (SPP) commissioned ABB Inc. to perform an Interconnection Impact Re-study for the GEN-2008-016 generation project, to evaluate the impacts of its interconnection on the system performance of the transmission systems in the interconnection vicinity, in view of a change in the Wind Turbine Technology that is being presently considered. The proposed project is a wind-farm generation with an output (Gross) of 248.4 MW to be interconnected at Grassland 230 kV substation (Point of Interconnection – POI) and is located in Lynn County, Texas:

Request	Size	Wind Turbine Model	Point of Interconnection	County
GEN-2008-016	248.4	Siemens SWT 2.3MW	Grassland 230kV (bus #526677)	Lynn ,Texas

The main objectives of this study were:

1) To determine the need for added reactive power compensation, if any, for the proposed wind farm
2) To determine the impact of proposed GEN-2008-016 project on the stability of SPP transmission systems and nearby generating stations.
3) To validate the compliance with FERC LVRT requirement for the subject wind farm interconnection.

To achieve these objectives the following analyses were performed on the 2010 Summer Peak and 2009 Winter Peak system conditions with GEN-2008-016 in-service:

- Power factor analysis for selected contingencies.
- Transient stability analysis for several local and regional contingencies.
- LVRT performance evaluation for selected contingencies near the POI.

A summary of the study findings is given below:

Power factor analysis

SPP requires that the Interconnection Customer's wind farm maintain a minimum of +/- 0.95 power factor at the POI under all system conditions (i.e. system intact and contingencies). An analysis was conducted to determine whether the proposed wind-farm has sufficient reactive power capability to meet the above power factor criteria. The results from this analysis indicated sufficient reactive power capability in the wind-farm to maintain +/-0.95 power factor at the POI and therefore no additional reactive power compensation is necessary.

Stability Analysis

A stability analysis was performed to determine the impact, if any, of the proposed project on the stability of SPP system. The system was found to be stable for all the tested 3-phase faults and single-line-to-ground (SLG) faults (with line re-closing, where applicable). Disturbances (faults) leading to outage of the Grassland to Jones 230 kV line (or any series element in that path – i.e. Jones – Tuco etc.) showed oscillations (of ~2 Hz) on the GEN-2008-016 wind farm speed as well as on the POI voltage traces. These oscillations were however damped out within 5 seconds after fault clearing. A detailed evaluation that followed indicated that these oscillations are likely the result of "control instability" within the wind farm, which is a concern for wind farms that are interconnected to "weak" networks.

The wind farm POI is tied to the rest of the SPP system through, three outlets; a 230 kV tie to Jones which ties to Tuco substation, a 230 kV tie to the Borden 230 kV substation which has a step-down to 138 kV connecting to rest of the system via long, 138 kV circuit, and a double circuit 115 kV line (with two 230/115 kV autotransformers) connecting to the Graham 115 kV bus. Consequently, upon outage of the tie to Jones, the connection of the GEN-2008-016 wind farm to the system is significantly weakened.

Whereas with all lines in service, the strength of the system at the POI (Grassland 230 kV), measured in terms of Short Circuit Ratio (SCR) (ratio of System Short Circuit MVA and Size of the wind farm) is adequate (2246/248.4 = 9.0), following outage of the Grassland – Jones 230 kV line it drops significantly (537/248.4 = 2.16). In general, a short circuit ratio less than 3 is considered low, and requires more in-depth analysis, usually with more detailed tools and models (e.g. PSCAD/EMTP-type).

As a next step, the above simulation (3-phase fault with tripping of Grassland-Jones 230 kV) was repeated with the addition of dynamic compensation. The goal here was to verify if the provision of dynamic voltage support (i.e. to help quick recovery and stabilize the voltage) will help the wind farm controls to function well. For this purpose we modeled an SVC at the POI. A 75 MVAR SVC was found to reduce the magnitude of the oscillations, but did not completely eliminate these oscillations. Any further increase in the SVC size did not show any marked improvement. it is therefore, suggested that first the wind turbine manufacturer be consulted to seek their advice on whether adjustments to the wind farm controls could lead to similar, or better, result.

FERC Order 661A Compliance

Selected faults were simulated at the Point of Interconnection (POI) of the proposed GEN-2008-016 wind farm to determine the compliance with FERC 661 – A; post-transition period LVRT standard. The results indicated that the proposed project met the FERC LVRT requirement for wind farm interconnection.

The results of this analysis are based on available data and assumptions made at the time of conducting this study. If any of the data and/or assumptions made in developing the study model change, the results provided in this report may not apply and additional analysis may be required.

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0	Draft Report	7/22/2010	B Kondalarao	Subramanian, S	Wong, W
1	Draft Report	8/02/2010	B Kondalarao	Subramanian, S	Wong, W
2	Draft Report	8/24/2010	B Kondalarao	Subramanian, S	Wong, W
DISTRIBUTION: Ray Offenbacker, Juliano Freitas– Southwest Power Pool, Inc.					

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INTRODUCTION

Southwest Power Pool, Inc. (SPP) commissioned ABB Inc. to perform an Interconnection Impact Re-study for Gen-2008-016 Project, which included a wind-based generation of 248.4 MW (Queue # GEN-2008-016) on the SPP system. The proposed wind farm is located in Lynn County, Texas and the POI is at Grassland 230 kV. Figure 0-1 shows the POI of the proposed generation project on a Geographical Transmission Map.

This study evaluated the impact of the GEN-2008-016 project on the SPP Transmission System. The scope of this study was limited to the transient stability analysis and power factor evaluation.

The main objectives of this study were

1) To determine the need of reactive power compensation, if any, for the proposed wind farm
2) To determine the impact of the proposed Project on the stability of SPP transmission system and nearby generating stations.
3) To validate the compliance with FERC LVRT requirement for the wind farm.

To achieve these objectives the following analyses were performed on the 2010 Summer Peak and 2009 Winter Peak system conditions with GEN-2008-016 in-service

- Power factor analysis for selected contingencies.
- Transient stability analysis for various local and regional contingencies.
- LVRT performance under selected contingencies near the POI.

The study was performed on 2010 Summer Peak and 2009 winter peak cases, provided by SPP. This report documents the methods, analysis and results of the system impact study.

Table 0-1: GEN-2008-016 Project Details

Project	Size (MW)	Wind Turbine Type	Point of Interconnection	Location
GEN-2008-016	248.4	Siemens SWT 2.3MW	Grassland 230kV (bus #526677)	Lynn, Texas

1.1 *REPORT ORGANIZATION*

This report is organized as follows:

Section 2: Description of project
Section 3: Study methodology
Section 4: Model Development
Section 5: Power Factor Analysis Results
Section 6: Stability Analysis Results
Section 7: Conclusions

The detailed study results are included in separate Appendices.

Figure 0-1 Geographical Transmission Map with Gen-2008-016 Project location

DESCRIPTION OF THE PROJECT

The details of load flow and dynamic data for the Gen-2008-016 wind farm project is included in Appendix A.

- Wind farm output: 248.4 MW
- Interconnection:
  - Voltage: 230 kV
  - POI: Grassland 230kV substation. The wind-farm will be connected to the POI via 230 kV line.
  - Transformer: Two (2) step-up transformer connecting to the 230 kV
    - MVA: 80 MVA
    - Voltage: 230/34.5 kV
    - Z: 9.0 % on 80 MVA
- Wind Turbines:
  - Number: One hundred and eight (108)
  - Manufacturer: Siemens
  - Type: Doubly-fed induction generator (DFIG)

Machine Terminal voltage: 0.69 kV

  - Rated Power: 2.3 MW
  - Frequency: 60 Hz
  - Generator Step-up Transformer
    - MVA: 2.6
    - High voltage: 34.5 kV
    - Low voltage: 0.69 kV
    - Z: 6.06% on 2.6 MVA
- Reactive Power Capability: 0.9 lagging/ 0.9 leading
- Fault Ride-through: Manufacturer’s default ride-through capability was modeled
- PSSE Model Used SMK223_model.obj

STUDY METHODOLOGY

POWER FACTOR ANALYSIS

SPP requires that the Interconnection Customer's wind farm maintain a minimum of +/- 0.95 power factor at the POI for any system condition. The purpose of the power factor analysis was to determine whether the proposed wind farm project will meet the power factor requirement at the Point of Interconnection (POI) for system intact as well as contingency conditions.

The Power Factor Analysis involved the following Steps:

- A VAR generator with large capacity (e.g. +/- 9999 MVar) was modeled at the POI of the subject wind farm. The VAR generator was set to hold the POI voltage consistent with the voltage schedule in the power flow base cases. The reactive power capability of the wind farm was set to zero.
- Contingencies in the vicinity of the subject wind farm were simulated. The results were used to identify the most-limiting contingency from steady state voltage and power factor perspective.
- If the required reactive power support, to maintain an acceptable power factor at the POI, was found to be beyond the capability of proposed wind-farm then the additional reactive power compensation (e.g. static capacitor banks) was considered.

It is important to note that the reactive power compensation identified in this analysis was primarily needed to meet steady state criteria. The need for dynamic reactive power support, if any, was determined through transient stability analysis.

TRANSIENT STABILITY ANALYSIS

The purpose of the transient stability analysis is to determine the impact, if any, of the proposed wind farm project on the stability performance of the SPP transmission system and generating stations in the interconnection vicinity.

Stability analysis was performed using Siemens-PTI's PSS/E^{TM} dynamics program V30.3.3. Three-phase and single-line-to-ground (SLG) (with re-closure where applicable) were simulated for the specified duration and synchronous machine rotor angles and wind turbine generator speeds were monitored to check whether the system is stable following the fault clearing. In addition, the voltage at the wind-farm POI and vicinity was also monitored.

For three-phase faults, a fault admittance of –j2E9 was used (essentially infinite admittance representing a bolted fault). The PSS/E dynamics program only simulates the positive sequence network. However, the unbalanced fault current computation (e.g. single-phase-ground) requires the knowledge of positive, negative, and zero sequence impedances. For a single-line-to-ground (SLG) fault, the fault admittance then equals the inverse of the sum of the positive, negative and zero sequence impedances. Typically, a single line to ground fault results in a voltage of roughly 60%. The admittance needed (over and above the positive sequence) to achieve this voltage value was computed using activity TYSL in PSS/E. This additional admittance value is the equivalent of the sum of positive and negative sequence admittances. The admittance value computed in the above step is then inserted at the faulted bus and the single line to ground fault current is computed.

The voltages at all local buses (115 kV and above) were monitored for all tested contingencies.

Another important aspect of the stability analysis was to determine the ability of the wind generators to stay connected to the grid during disturbances. This is primarily determined by their low-voltage ride-through capabilities – or lack thereof – as represented in the models by low-voltage trip settings. The Federal Energy Regulatory Commission (FERC) Post-transition period LVRT standard for Interconnection of Wind generating plants includes a Low Voltage Ride Through (LVRT) requirement. The key features of LVRT requirements are:

- A wind generating plant must remain in-service during three-phase faults with normal clearing (maximum 9 cycles) and single-line-to-ground faults with delayed clearing, and have subsequent post-fault recovery to pre-fault voltage unless the clearing of the fault effectively disconnects the generator from the system.
- The maximum duration the wind generating plant shall be required to withstand a three-phase fault shall be 9 cycles after which, if the fault remains following the location-specific normal clearing time for three-phase faults, the wind generating plant may disconnect from the transmission system. A wind generating plant shall remain interconnected during such a fault on transmission system for a voltage level as low as zero volts, as measured at the high voltage side of the GSU connected at POI.

These criteria were used to evaluate the LVRT capability of the wind farm.

MODEL DEVELOPMENT

SPP provided two power flow cases for this study – i) “DISIS_10SP-G6.sav” and ii) “DISIS_09WP-G6.sav” –representing respectively the 2010 Summer Peak and 2009 Winter Peak conditions.

MODEL DEVELOPMENT FOR GEN-08-016 PROJECT

The models (power flow and dynamics) for the proposed project were included in the data supplied by SPP; however these models were based on the original impact study for this project. The present study is meant to re-evaluate the system impact in view of a change in the wind-farm generator technology. For the purpose of this study, the Siemens SWT 2.3 MW WTG is being considered.

A detailed review of the study models was performed to ensure the wind farm and the associated collector system representation is in agreement with the data provided for this re-study. Some minor discrepancies were noted in the cable parameters for Feeder #8 and #9, upon comparison of the reactance data from PSS/E and the cable data (“Cable impedance Rev1.xlsx”). The PSS/E data was revised to reflect the cable parameters in the above data sheet. The equivalent WTG representation in the original power flow was then replaced with the new WTG type and size (individual WTG of 2.3 MW; therefore two equivalent generators were represented, each representing 54 WTGs and with an output of 124.2 WM). The reactive power capability of the WTGs (DFIG technology with +/- 0.95 pf) was appropriately represented. The original wind farm model did not seem to have inherent reactive power capability and hence static capacitor compensation was necessary at the POI in order to meet SPP’s interconnection standards. Due to the inherent reactive power capability of the Siemens machines, the static capacitors represented with the original models were removed from the power flow.

The original power flow cases were revised to reflect the above changes and these were subsequently named as ‘DISIS_10SP-G6-ABB.sav’ (2010 summer peak) and ‘DISIS_09WP-G6-ABB.sav’ (2009 winter peak).

Fig. 4-1 and Fig. 4-3 show the one-line diagram in the local area of Gen-2008-016 for 2010 summer peak and 2009 winter peak conditions respectively.

The “DYRE” file containing the dynamic data was revised by replacing the original WTG model with the new, Siemens SWT 2.3 MW WTG data. A new “snapshot” file was created to run the stability simulations.

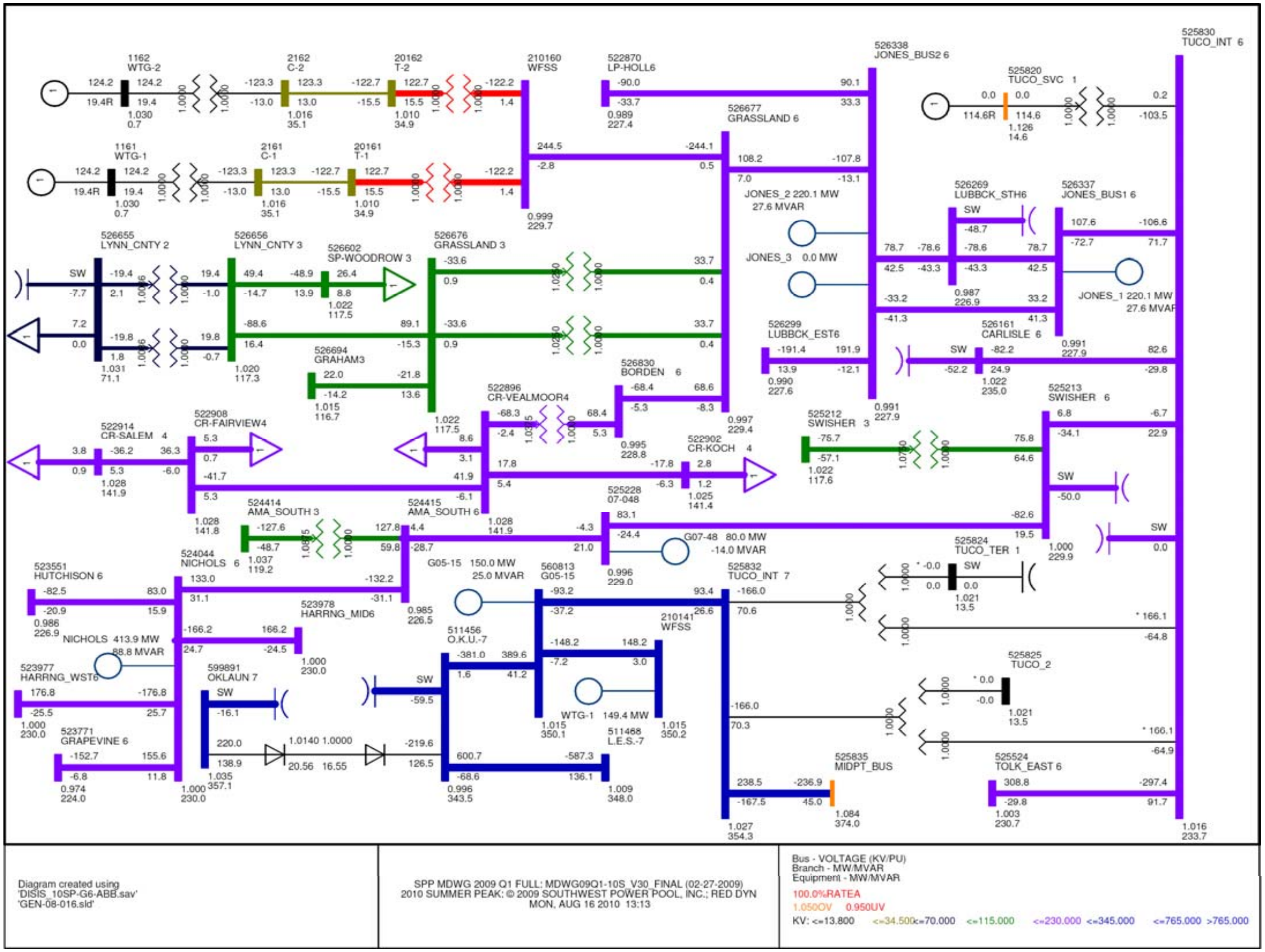

Figure 0-1 One-line Diagram of the local area of Gen-08-016 (2010 Summer Peak)

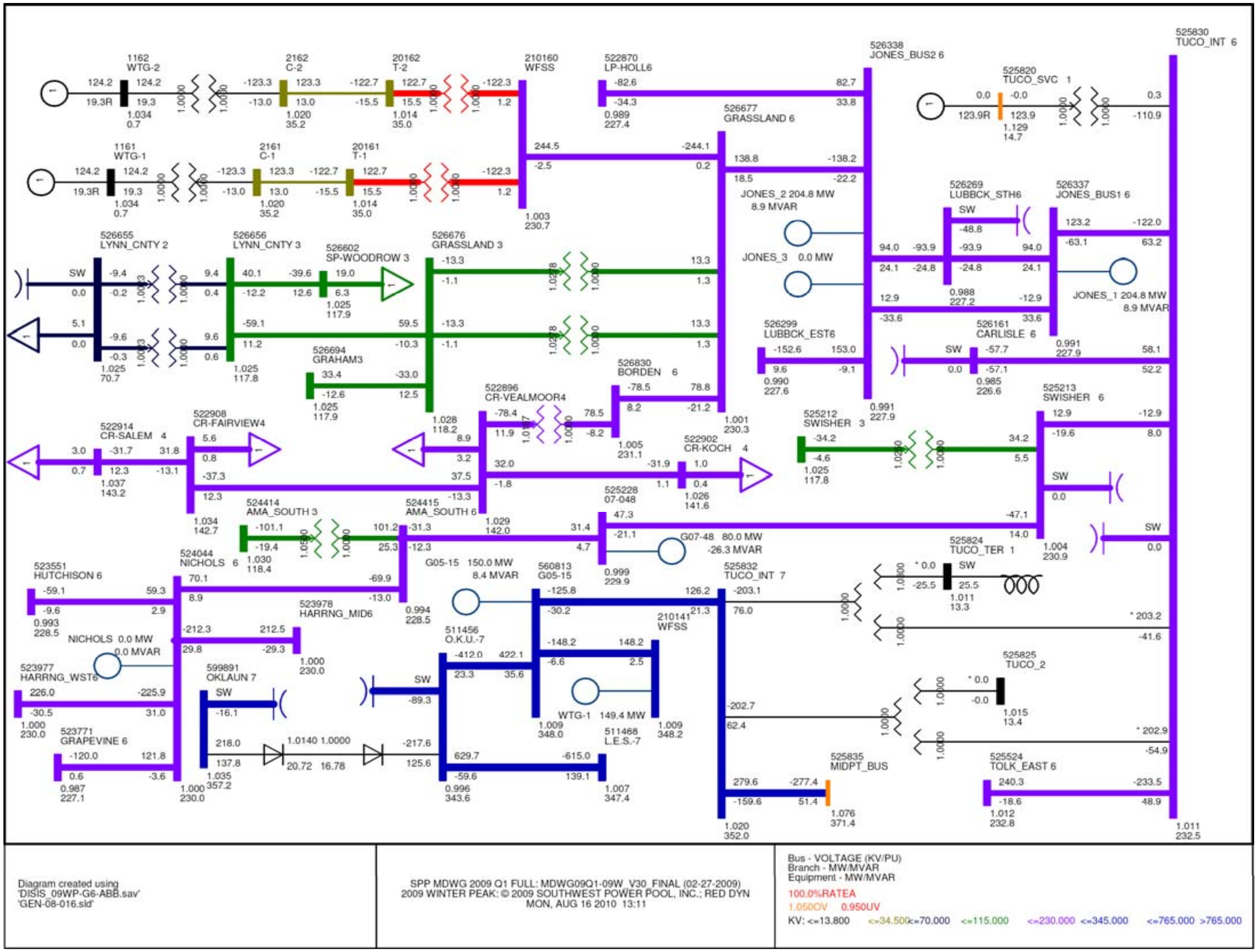

Figure 0-2 One-line Diagram of the local area of Gen-08-016 (2009 Winter Peak)

POWER FACTOR ANALYSIS

The Power Factor analysis was performed to verify that the wind-farm interconnection met SPP's standard in terms of power factor and voltage requirements at the POI. Table 0-1 lists the contingencies simulated for Power Factor analysis.

Table 0-1: List of contingencies simulated for Power Factor Analysis

Contingency Name	Contingency Description
CONT_01	Loss of Grassland (526677) to the Jones_Bus2 (526338) 230kV line
CONT_02	Loss of Grassland (526677) to the Borden (526830) 230kV line
CONT_03	Loss of Grassland (526677) 230 kV to 115 kV (526676) transformer
CONT_04	Loss of Jones_Bus2 (526338) to Jones_Bus1 (526337) 230 kV line
CONT_05	Loss of Borden 230 kV (526830) to 138 kV (522896) transformer
CONT_06	Loss of Cr-Vealmoor4 (522896) to Cr-Fairview4 (522908) 138 kV line
CONT_07	Loss of Cr-Vealmoor4 (522896) to Cr-Koch (522902) 138 kV line
CONT_08	Loss of Grassland (526676) to Lynn_Cnty (526656) 115 kV line
CONT_09	Loss of Grassland (526676) to Graham3 (526694) 115 kV line
CONT_10	Loss of Graham 115 kV (526694) to 69 kV (526693) transformer
CONT_11	Loss of Tuco (525830) to Swisher (525213) 230kV line
CONT_12	Loss of Jones Bus1 (526337) to Tuco (525830) 230kV line
CONT_13	Loss of GEN-2005-015 (560813) to Tuco (525832) 345kV line
CONT_14	Loss of Midpoint (525835) to Tuco (525832) 345kV line

As described in section 0, a VAR generator was modeled at POI. The VAR generator was set to hold the 230 kV POI voltage at 1.0 p.u, following the procedures in Section 3-1. The reactive power capability of the wind farm was set to zero.

The contingencies shown in Table 0-1 were simulated on 2010 summer peak and 2009 winter peak load conditions. For year 2010 summer peak and 2009 winter peak load conditions, *CONT*_02 (Grassland (526677) to Borden (526830) 230kV line outage) showed maximum reactive power output from the VAR generator at POI following interconnection of GEN-2008-016 project. This implies that this contingency requires the highest amount of reactive power to meet the power factor requirements. However, the reactive power requirements (see Table 5-2) are within the capability of the GEN-2008-016 WTG and therefore no added reactive power support is necessary in the steady state.

Table 0-2 VAR generator output at the GEN-08-016 POI

Contingency	2010 Summer Peak	2009 Winter Peak
BASE CASE	51.4**	35.7**
CONT_01	38.5	29.6
CONT_02	**55.5**	**52.8**
CONT_03	51.6	35.6
CONT_04	51.4	35.7
CONT_05	39.3	36.7
CONT_06	53.8	44.2
CONT_07	45.4	34.6
CONT_08	58.5	43.7
CONT_09	44.2	29.4
CONT_10	43.3	28.4
CONT_11	51.4	35.7
CONT_12	51.1	35.7
CONT_13	51.2	35.7
CONT_14	52.7	37.1

**The reactive power capability of the wind farm was set to unity p.f at machine terminal (i.e Qmax=Qmin=Qgen= 0 Mvar).

Next, the same contingencies (Table 5-1) were re-simulated, but without the VAR generator at the POI, for verification purposes. The power factor at the POI was computed; the POI bus voltage was monitored. The power factor as well as the bus voltage was acceptable for all tested conditions. The loss of Grassland to Borden 230kV line (*CONT_02)* resulted in lowest voltage at POI in post-contingency conditions in both summer peak and winter peak system conditions. Table 0-3 summarizes the post-contingency voltage and p.f. at the POI for the above contingency. The complete results of the above analysis are included in Appendix B.

Table 0-3: Voltage & p.f. at POI without VAR generator: GEN-2008-016

System condition		Voltage (in p.u.)	P.F.
2010 summer peak	System Intact	0.997	1.0
	Post-contingency (1)	0.996	1.0
2009 winter peak	System Intact	1.000	1.0
	Post-contingency (1)	0.997	1.0

(1) *CONT_02*: Loss of Grassland (526677) to the Borden (526830) 230kV line

STABILITY ANALYSIS

Stability simulations were performed to examine the transient behavior of GEN-2008-016 project and its impact on the SPP system. Several faults, both three-phase and single phase faults (with re-closing where applicable) were simulated. The fault clearing times and re-closing times used for the simulations are shown inTable 0-1.

Table 0-1: Fault Clearing Times

Faulted bus kV level	Normal Clearing	Time before reclosing
69	5 cycles	20 cycles
115	5 cycles	20 cycles
230	5 cycles	20 cycles

Seventeen (17) three phase and fourteen (14) single-line-to-ground faults (with re-closing where applicable) were simulated. For all tested cases the initial disturbance was applied at t = 0.1 seconds. The fault was cleared at the appropriate time following its inception. Table 0-2 lists all the faults simulated for transient stability analysis.

The system was stable for all the simulated 3-Phase and single-phase faults. The proposed GEN-2008-016 wind farm stayed on-line throughout the duration of the fault and thereof. The voltage recovery was acceptable, and the oscillations were damped out. Table 0-3 summarizes the stability analysis results for 2010 summer peak and 2009 winter peak system conditions.

Table 0-2 List of Simulated Faults for GEN-2008-016 SIS

Cont. No.	Cont. Name	Description
1	FLT01-3PH	Three phase fault on the Grassland (526677) to the Jones_Bus2 (526338), 230kV line. Apply Fault at the Grassland bus. a. Clear Fault after 5 cycles by removing the line from Grassland to Jones bus b. Wait 30 cycles, and then re-close the line in (b) back into the fault. c. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
2	FLT02-1PH	Single phase fault and sequence like Cont. No. 1
3	FLT03-3PH	Three phase fault on the Grassland (526677) to the Borden (526830), 230kV line. Apply Fault at the Grassland bus. a. Clear Fault after 5 cycles by removing the line from Grassland to Borden bus b. Wait 30 cycles, and then re-close the line in (b) back into the fault. c. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
4	FLT04-1PH	Single phase fault and sequence like Cont. No. 3
5	FLT05-3PH	Three phase fault on the Grassland 230/115 kV ckt1 transformer (526677). Apply Fault at the Grassland 230 kV side. a. Clear Fault after 5 cycles by removing the Grassland transformer ckt1.
6	FLT06-1PH	Single phase fault and sequence like Cont. No. 5
7	FLT07-3PH	Three phase fault on the Grassland 230/115 kV ckt1 transformer. Apply Fault at the Grassland 115 kV side. a. Clear Fault after 5 cycles by removing the Grassland transformer ckt1.
8	FLT08-1PH	Single phase fault and sequence like Cont. No. 7
9	FLT09-3PH	Three phase fault on the Jones_Bus2 (526338) to Jones_Bus1 (526337) 230 kV line. Apply fault at Jones_Bus2. a. Clear fault after 5 cycles by tripping the line from Jones_Bus1 to Jones_Bus2 . b. Wait 30 cycles, and then re-close the line in (b) back into the fault. c. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
10	FLT10-1PH	Single phase fault and sequence like Cont. No. 9
11	FLT11-3PH	Three phase fault on the Borden 230/138 kV transformer (526830). Apply Fault at the Borden 230 kV side. a. Clear Fault after 5 cycles by removing the Borden transformer.
12	FLT12-1PH	Single phase fault and sequence like Cont. No. 11
13	FLT13-3PH	Three phase fault on the Borden 230/138 kV transformer (526830). Apply Fault at the Borden 138 kV side. a. Clear Fault after 5 cycles by removing the Borden transformer. .
14	FLT14-1PH	Single phase fault and sequence like Cont. No. 13
15	FLT15-3PH	Three phase fault on the Cr-Vealmoor4 (522896) to Cr-Fairview4 (522908) 138 kV line. Apply fault at Cr-Vealmoor4. a. Clear fault after 5 cycles by tripping the line from Cr-Velamoor4 to Cr-Fairview4. b. Wait 30 cycles, and then re-close the line in (b) back into the fault. c. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

Cont. No.	Cont. Name	Description
16	FLT16-1PH	Single phase fault and sequence like Cont. No. 15
17	FLT17-3PH	Three phase fault on the Cr-Vealmoor4 (522896) to Cr-Koch (522902) 138 kV line. Apply fault at Cr-Vealmoor4. a. Clear fault after 5 cycles by tripping the line from Cr-Velamoor4 to Cr-Koch. b. Wait 30 cycles, and then re-close the line in (b) back into the fault. c. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
18	FLT18-1PH	Single phase fault and sequence like Cont. No. 17
19	FLT19-3PH	Three phase fault on the Grassland (526676) to Lynn_Cnty (526656) 115 kV line. Apply fault at Grassland. a. Clear fault after 5 cycles by tripping the line from Grassland to Lynn_Cnty. b. Wait 300 cycles, and then re-close the line in (b) back into the fault. c. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
20	FLT20-1PH	Single phase fault and sequence like Cont. No. 19
21	FLT21-3PH	Three phase fault on the Grassland (526676) to Graham3 (526694) 115 kV line. Apply fault at Grassland. a. Clear fault after 5 cycles by tripping the line from Grassland to Graham3. b. Wait 30 cycles, and then re-close the line in (b) back into the fault. c. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
22	FLT22-1PH	Single phase fault and sequence like Cont. No. 21
23	FLT23-3PH	Three phase fault on the Graham 115/69 kV transformer (526694). Apply Fault at the Graham 115 kV side. a. Clear Fault after 5 cycles by removing the Graham transformer.
24	FLT24-1PH	Single phase fault and sequence like Cont. No. 23
25	FLT25-3PH	Three phase fault on the Graham 115/69 kV transformer (526694). Apply Fault at the Graham 69 kV side. a. Clear Fault after 5 cycles by removing the Graham transformer.
26	FLT26-1PH	Single phase fault and sequence like Cont. No. 25
27	FLT27-3PH	3 phase fault on the Tuco (525830) to Swisher (525213) 230kV line, near Tuco. a. Apply fault at the Tuco 230kV 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.
28	FLT28-1PH	Single phase fault and sequence like previous
29	FLT29-3PH	3 phase fault on the Jones Bus1 (526337) to Tuco (525830) 230kV line, near Jones Bus1. a. Apply fault at the Jones Bus1 230kV 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.
30	FLT30-3PH	3 phase fault on the GEN-2005-015 (560813) to Tuco (525832) 345kV line, near Tuco. a. Apply fault at the Tuco 345kV bus. b. Clear fault after 5 cycles by tripping the faulted line.
31	FLT31-3PH	3 phase fault on the Midpoint (525835) to Tuco (525832) 345kV line, near Tuco. a. Apply fault at the Tuco 345kV bus. b. Clear fault after 5 cycles by tripping the faulted line.

Table 0-3 Results of stability analysis

	2010 Summer Peak			2009 Winter Peak		
		Post-Project			Post-Project	
FAULT	Pre-Project	Stable?	Acceptable Voltages?	Pre-Project	Stable?	Acceptable Voltages?
FLT01-3PH	---	STABLE	YES	---	STABLE	YES
FLT02-1PH	---	STABLE	YES	---	STABLE	YES
FLT03-3PH	---	STABLE	YES	---	STABLE	YES
FLT04-1PH	---	STABLE	YES	---	STABLE	YES
FLT05-3PH	---	STABLE	YES	---	STABLE	YES

FAULT	2010 Summer Peak			2009 Winter Peak		
		Post-Project			Post-Project	
	Pre-Project	Stable?	Acceptable Voltages?	Pre-Project	Stable?	Acceptable Voltages?
FLT06-1PH	---	STABLE	YES	---	STABLE	YES
FLT07-3PH	---	STABLE	YES	---	STABLE	YES
FLT08-1PH	---	STABLE	YES	---	STABLE	YES
FLT09-3PH	---	STABLE	YES	---	STABLE	YES
FLT10-1PH	---	STABLE	YES	---	STABLE	YES
FLT11-3PH	---	STABLE	YES	---	STABLE	YES
FLT12-1PH	---	STABLE	YES	---	STABLE	YES
FLT13-3PH	---	STABLE	YES	---	STABLE	YES
FLT14-1PH	---	STABLE	YES	---	STABLE	YES
FLT15-3PH	---	STABLE	YES	---	STABLE	YES
FLT16-1PH	---	STABLE	YES	---	STABLE	YES
FLT17-3PH	---	STABLE	YES	---	STABLE	YES
FLT18-1PH	---	STABLE	YES	---	STABLE	YES
FLT19-3PH	---	STABLE	YES	---	STABLE	YES
FLT20-1PH	---	STABLE	YES	---	STABLE	YES
FLT21-3PH	---	STABLE	YES	---	STABLE	YES
FLT22-1PH	---	STABLE	YES	---	STABLE	YES
FLT23-3PH	---	STABLE	YES	---	STABLE	YES
FLT24-1PH	---	STABLE	YES	---	STABLE	YES
FLT25-3PH	---	STABLE	YES	---	STABLE	YES
FLT26-1PH	---	STABLE	YES	---	STABLE	YES
FLT27-3PH	---	STABLE	YES	---	STABLE	YES
FLT28-1PH	---	STABLE	YES	---	STABLE	YES
FLT29-3PH	---	STABLE	YES	---	STABLE	YES
FLT30-3PH	---	STABLE	YES	---	STABLE	YES
FLT31-3PH	---	STABLE	YES	---	STABLE	YES

The faults involving the outage of Grassland – Borden 230 kV line (FLT_03_3PH and FLT_04_1PH) or the 230/138 kV transformation at Borden 230 kV (FLT_11, FLT_12, FLT_13, FLT_14) indicated low voltages at the 138 kV level near Borden. The above contingencies render the 138 kV system at Borden radial via Vealmoor–Koch–Brown–Grady-Triangle-Midland 138 kV circuit; the Midland 230/138 kV being the only alternate feed for the outage of Borden 230 kV. This is however an issue un-related to the GEN-2008-016 interconnection and discussed here for information purpose only. This voltage problem is mostly a steady state problem; under transient conditions, the 138 kV at Borden recovered to approximately 0.85 p.u and remained at that value. Application of shunt capacitors (static) or other operator actions are expected to help mitigate the above voltage issue. Fig. 6-1 and Fig. 6-3 show the system response for the faults FLT_03_3PH and FLT_04_1PH that involve the loss of Grassland – Borden 230 kV. The low voltage observations noted here are applicable for both summer as well as winter peak load cases.

The plots from the transient stability analysis are included in Appendix C.

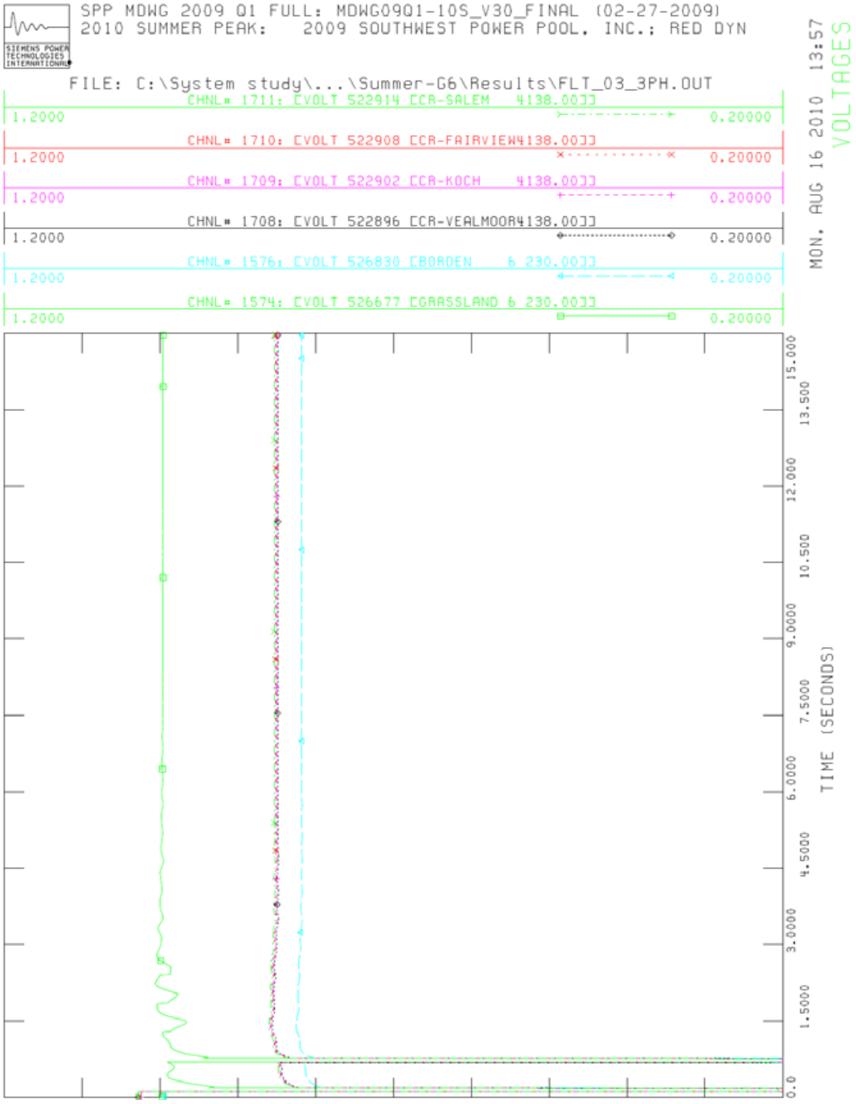

Figure 0-1 Voltage Plots in Borden Substation Vicinity (Summer Peak) -FLT_03_3PH

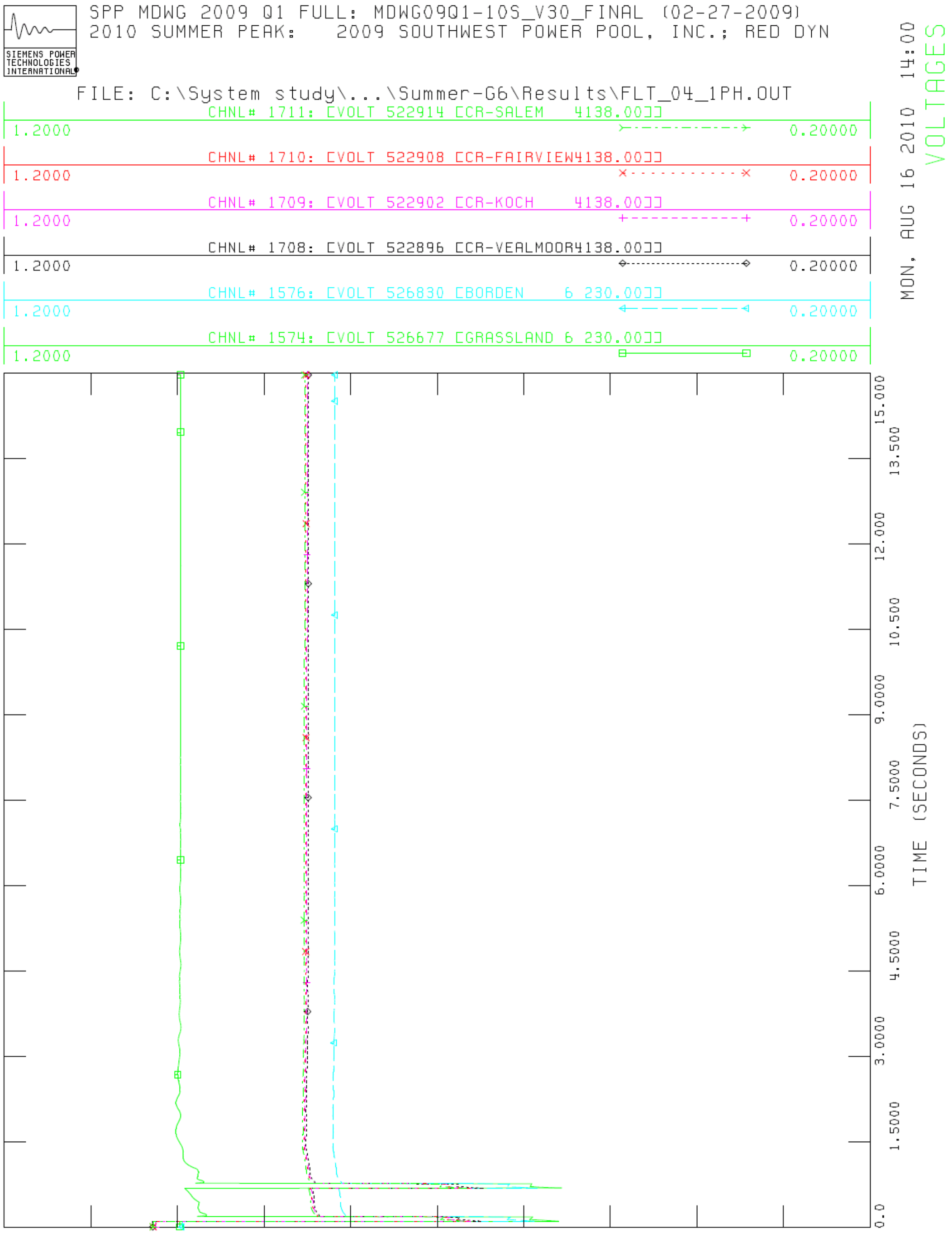

Figure 0-2 Voltage Plots in Borden Substation Vicinity (Summer Peak)- FLT_04_1PH

Disturbances (faults) leading to outage of the Grassland to Jones 230 kV line (or any series element in that path – i.e. Jones – Tuco etc.) showed oscillations (of ~2 Hz) on the GEN-2008-016 wind farm speed as well as on the POI voltage traces. The oscillations are damped out within 5 seconds after fault clearing (Fig 6-3). Although the subject wind farm remained on line following all such disturbances, an evaluation was performed to investigate the causes and mitigation of the observed oscillations. Simulation of the same disturbance for the pre-project conditions did not indicate any oscillations in the POI voltage (Fig .6-4).

The above simulation (refer Fig. 6-3) was repeated, but with the wind farm model replaced with a 248.4 MW equivalent negative load. The results did not show any oscillations (Fig 6-5), thus suggesting that the oscillations are likely the result of a "control instability" within the wind farm, which is a concern for wind farms that are interconnected to "weak" networks.

The wind farm POI is tied to the rest of the SPP system through, three outlets; a 230 kV tie to Jones which ties to Tuco substation, a 230 kV tie to the Borden 230 kV substation which has a step-down to 138 kV connecting to rest of the system via long, 138 kV circuit, and a double circuit 115 kV line (with two 230/115 kV autotransformers) connecting to the Graham 115 kV bus. Consequently, upon outage of the tie to Jones, the connection of the GEN-2008-016 wind farm to the system is significantly weakened.

The Grid Performance Specification[1] from the subject WTG manufacturer (Siemens) makes the following statement with regard to the wind farm controls:

"*The wind turbine is capable of riding through severe voltage dips in the HV Grid down to nil percent (0%) retained voltage up to 250 ms, down to fifteen percent (15%) retained voltage for up to 650 ms and down to seventy five percent (75%) retained voltage for up to 10 s when the installed amount of wind turbines is in the right proportion of the strength of the Grid. This means the short circuit ratio (Sk/Sn) and the X/R ratio of the grid at the wind turbine transformer terminals must be adequate*".

Whereas with all lines in service, the strength of the system at the POI (Grassland 230 kV), measured in terms of Short Circuit Ratio (SCR) (ratio of System Short Circuit MVA and Size of the wind farm) is adequate (2246/248.4 = 9.0), following outage of the Grassland – Jones 230 kV line it drops significantly (537/248.4 = 2.16). In general, a short circuit ratio less than 3 is considered low, and requires more in-depth analysis, usually with more detailed tools and models (e.g. PSCAD/EMTP-type).

As a next step, the above simulation (3-phase fault with tripping of Grassland-Jones 230 kV) was repeated with the addition of dynamic compensation. The goal here was to verify if the provision of dynamic voltage support (i.e. to help quick recovery and stabilize the voltage) will help the wind farm controls to function well. For this purpose we modeled an SVC at the POI. This analysis was performed iteratively, starting with a small SVC size and then incrementing the SVC size, should the oscillations still persist. The SVC parameters (gain, time constants etc.) were tuned based on the short circuit level at the POI, considering the contingency condition. We started with a 25 MVAR SVC. The performance was slightly better than that shown in Fig. 6-3. Next we repeated the simulations with incremental SVC sizes of 50 MVAR, 75 MVAR and 100 MVAR. With SVC sizes of 75 and 100 MVAR, there was a good improvement in the system performance (i.e. reduction in the magnitude of oscillations) when compared with those at smaller SVC values (Fig. 6-6). The oscillations were however not completely eliminated. Also, there was not much added value in terms of performance improvement when the SVC size was increased from 75 MVAR to 100 MVAR. The SVC response (admittance) for the 75 MVAR case is plotted in Fig. 6-7. It is therefore suggested that first the wind turbine manufacturer be consulted to seek their advice on whether adjustments to the farm controls could lead to similar, or better, results.

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[1] SWT-2.3 VS 60 Hz Grid Performance Specification: Document PG-R3146-30-0000-0186-01

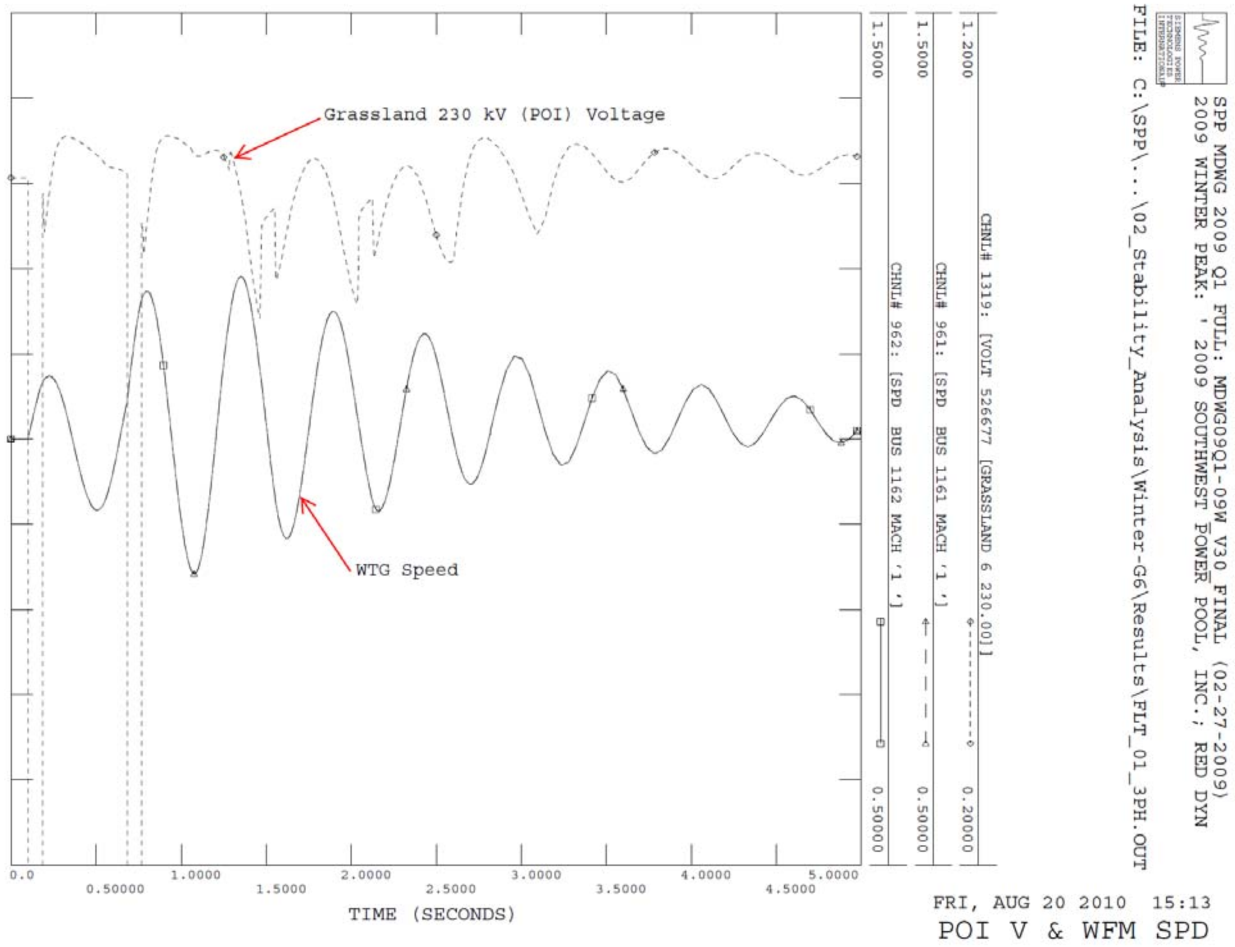

Fig. 6-3 Oscillations on WTG speed and POI Voltage – FLT-01-3PH

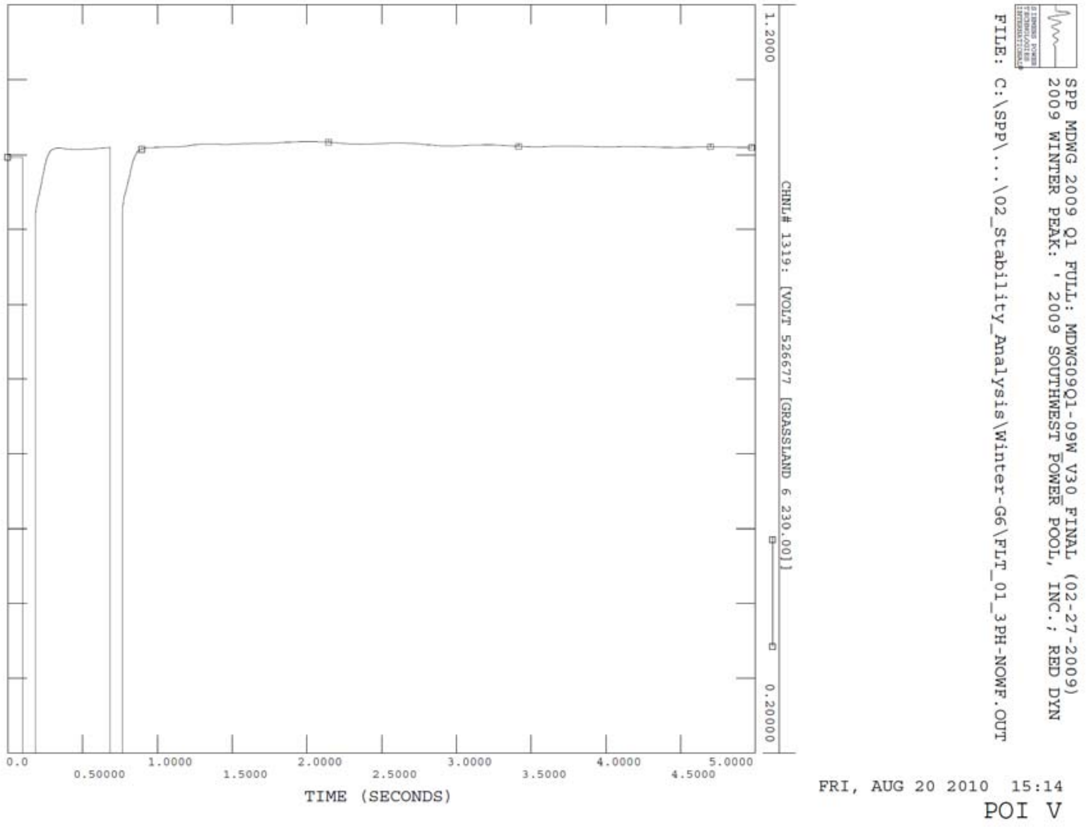

Fig.6-4 POI Voltage; Pre-project conditions – FLT-01-3PH

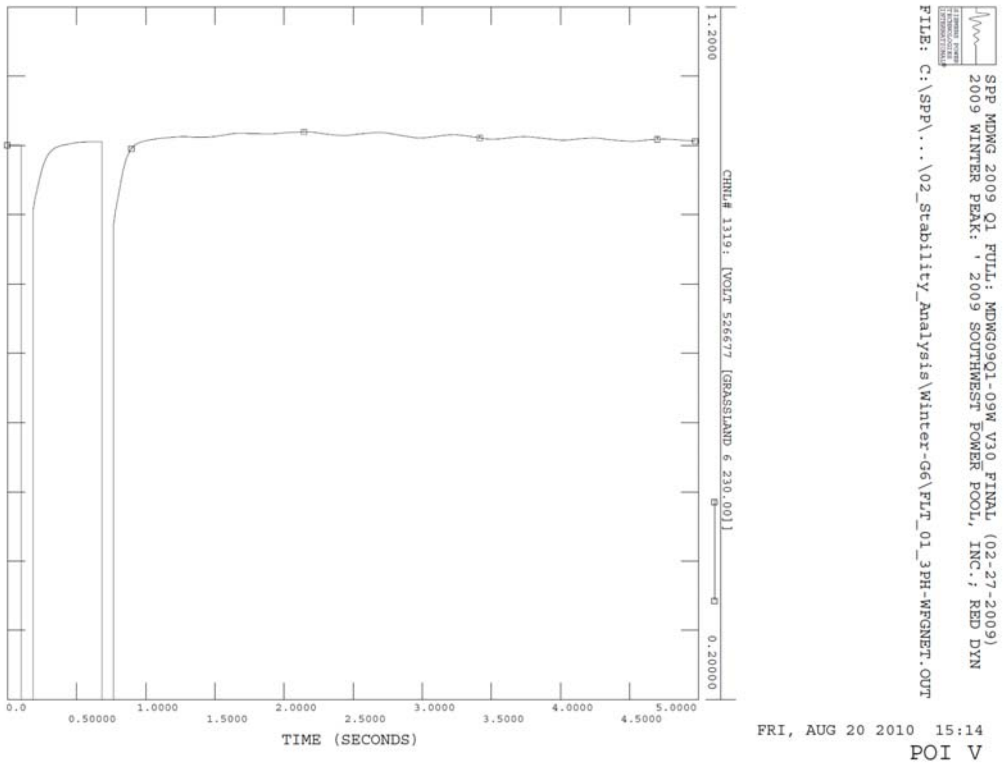

Fig.6-5 POI Voltage; Wind farm Replaced with Equivalent, Negative Load – FLT-01-3PH

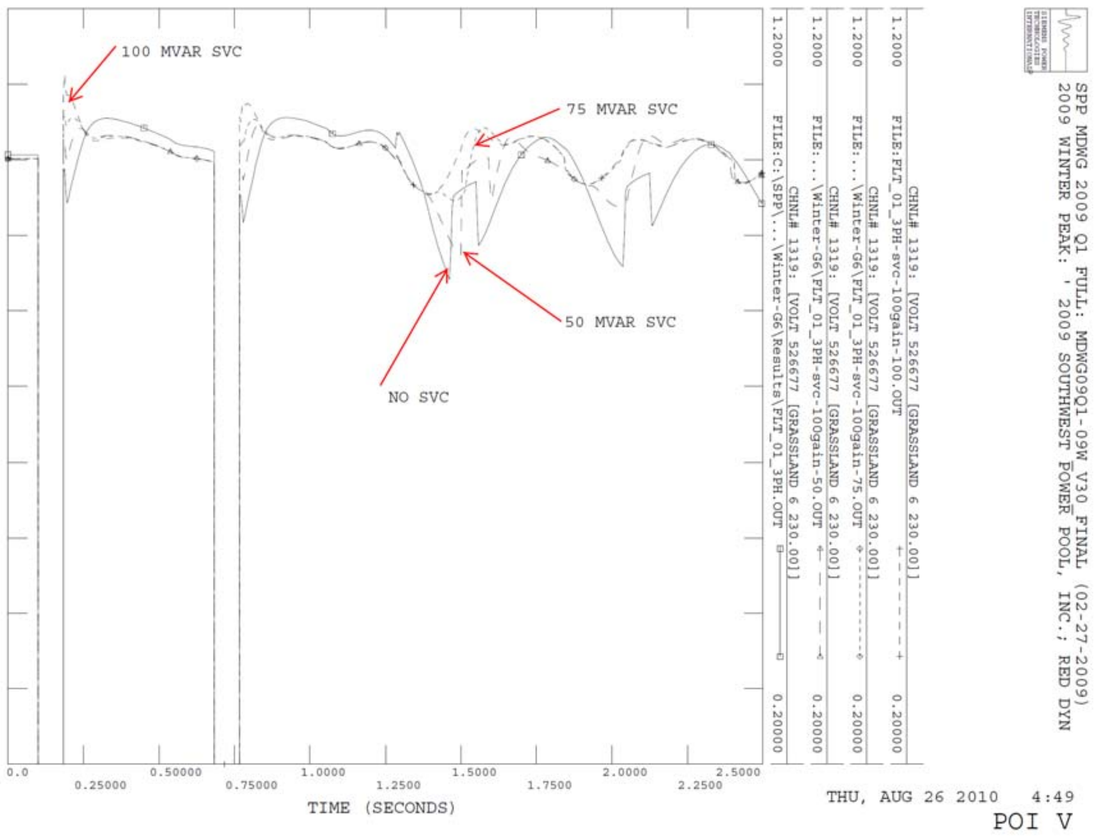

Fig.6-6 POI Voltage; Addition of SVC at Grassland 230 kV – FLT-01-3PH

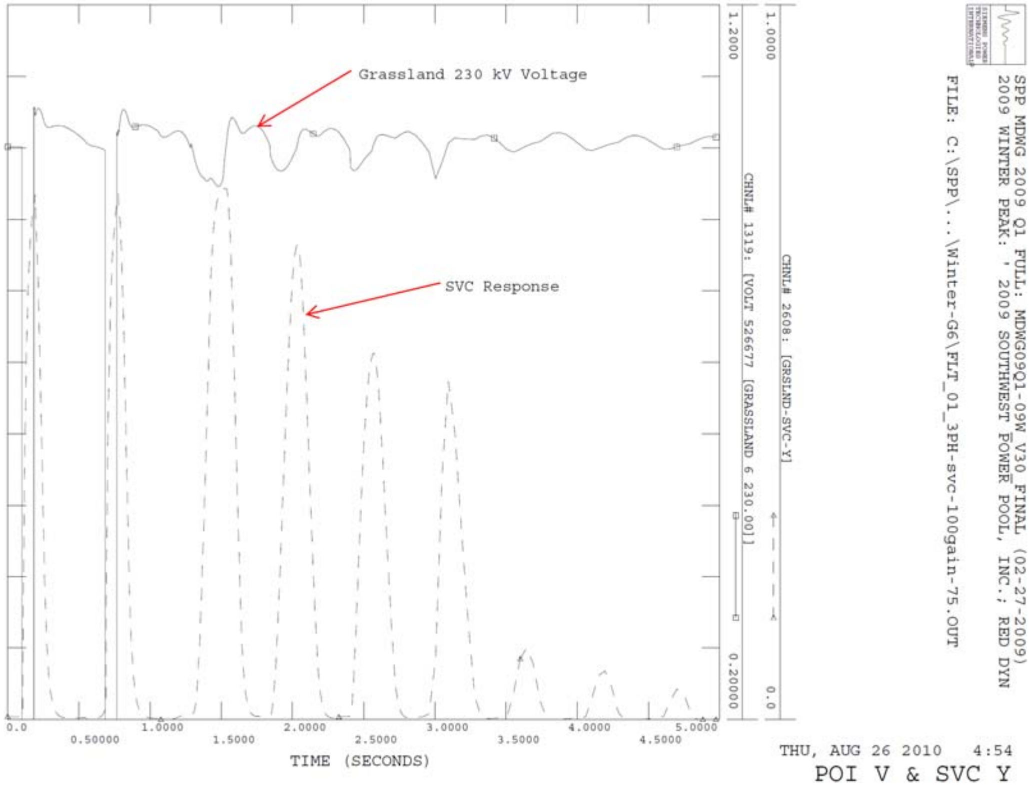

Fig.6-7 FLT-01-3PH – POI Voltage and SVC Admittance (p.u) – 75 MVAR SVC at Grassland 230 kV

FERC LVRT COMPLIANCE

This section discusses the FERC mandated LVRT compliance verification for GEN-2008-016 project. As explained in section 0, the proposed project was modeled with the low voltage ride through capability. To determine the compliance of the subject wind farm project six (6) faults were simulated. These faults were simulated at the POI of wind farm project and cleared after 9 cycles for 3-phase and 15 cycles for 1-phase faults (i.e. 9 cycle primary clearing followed by a 6 cycle back-up clearing due to a breaker stuck event). Table 0-4 gives the description of fault simulated for LVRT analysis.

Table 0-4: List of faults for FERC LVRT compliance

Fault Name	Description
FLT_01_LVRT_3PH	Three phase fault on the Grassland (526677) to the Jones_Bus2 (526338), 230kV line.
	a. Apply Fault at the Grassland 230kV bus.
	b. Clear fault after 9.0 cycles by tripping the faulted line.
FLT02-1PH_LVRT	*Single Phase fault Delayed Clearing (9 Cycles + 6 Cycles) and sequence like previous*
FLT03-3PH_LVRT	Three phase fault on the Grassland (526677) to the Borden (526830), 230kV line.
	a. Apply Fault at the Grassland 230kV bus.
	b. Clear fault after 9.0 cycles by tripping the faulted line.
FLT04-1PH_LVRT	*Single Phase fault Delayed Clearing (9 Cycles + 6 Cycles) and sequence like previous*
FLT05-3PH_LVRT	Three phase fault on the Grassland 230/115 kV ckt1 transformer (526677)
	a. Apply Fault at the Grassland 230kV bus.
	b. Clear fault after 9.0 cycles by tripping the faulted line.
FLT06-1PH_LVRT	*Single Phase fault Delayed Clearing (9 Cycles + 6 Cycles) and sequence like previous*

The results of the simulations indicated that the Gen-2008-016 wind farm project stayed online through the fault duration and recovered to acceptable speed and voltage post-fault clearing. Therefore the subject wind farm meets the FERC LVRT criteria for the interconnection (FERC Order 661 – A). The response of Gen-2008-016 project for FLT_03_LVRT_3PH is given in Figure 6-7. This fault is a 3 Phase fault at the POI.

The results from the FERC LVRT compliance evaluation are included in Appendix D.

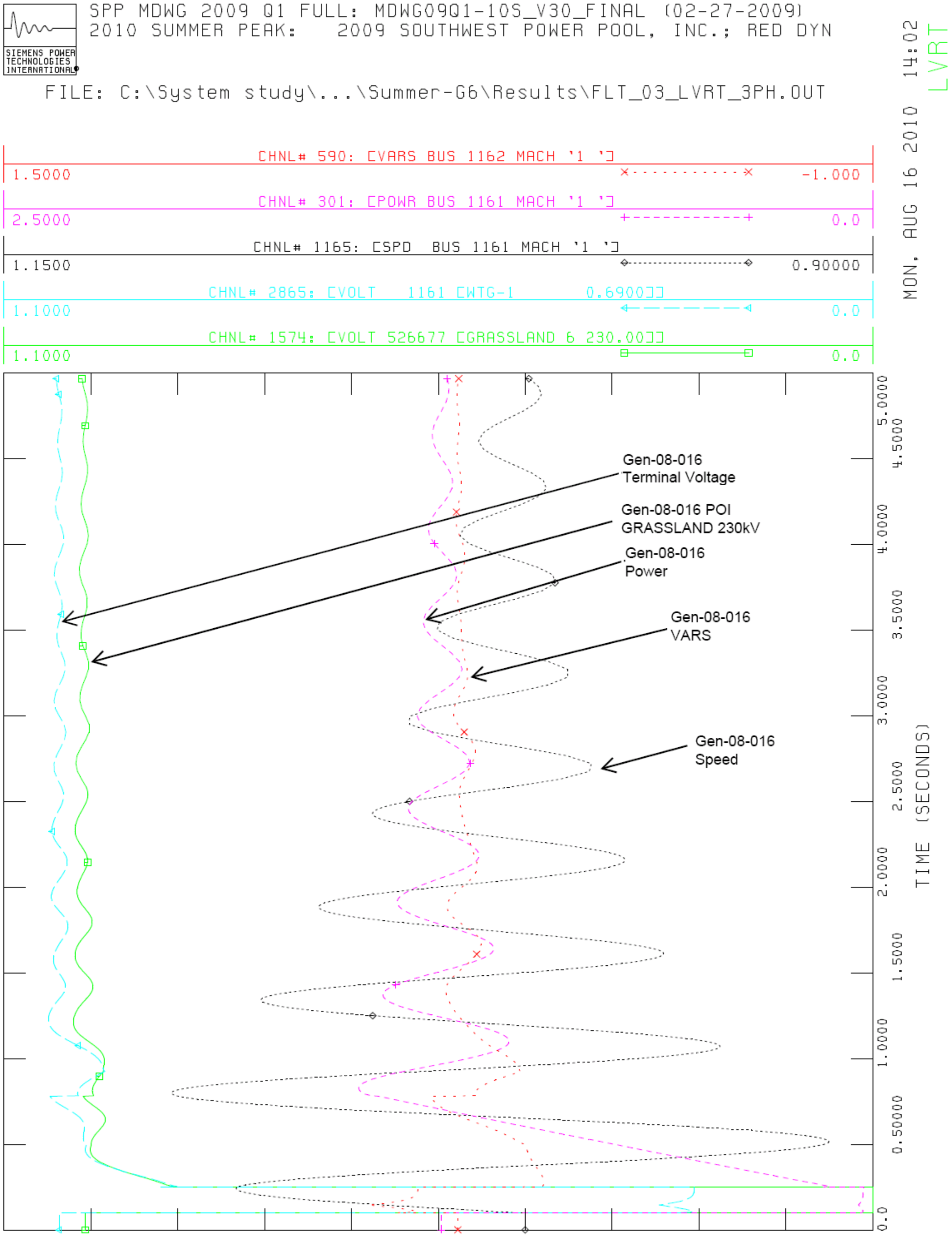

Figure 0-7 GEN-2008-016 response for FLT_03_LVRT_3PH (Summer Peak)

CONCLUSIONS

The main objectives of this study were

1) To determine the need for added reactive power compensation, if any, for the proposed wind farm in order to meet SPP's interconnection standards
2) To determine the impact of proposed GEN-2008-016 (248.4 MW) project on the transmission system and nearby generating stations.
3) To validate the compliance with FERC LVRT requirement for the subject wind farm interconnection.

To achieve these objectives the following analyses were performed on the 2010 Summer Peak and 2009 Winter Peak system conditions with GEN-2008-016 in-service

- Power factor analysis for selected contingencies.
- Transient stability analysis for various local and regional contingencies
- LVRT performance for selected contingencies near the POI.

A summary of the study findings is given below:

The results from Power Factor analysis indicated sufficient reactive power capability in the wind-farm to maintain at least +/-0.95 power factor at the POI and therefore no additional reactive power compensation is necessary.

A stability analysis was performed to determine the impact, if any, of the proposed project on the stability of SPP system. The system was found to be stable for all the tested 3-phase faults and single-line-to-ground (SLG) faults (with line re-closing, where applicable). Disturbances leading to outage of the Grassland to Jones 230 kV line (or any series element in that path – i.e. Jones – Tuco etc.) showed oscillations (of ~2 Hz) on the GEN-2008-016 wind farm speed as well as on the POI voltage traces. These oscillations were however damped out within 5 seconds after fault clearing. A detailed evaluation that followed indicated that these oscillations are likely the result of "control instability" within the wind farm, which is a concern for wind farms that are interconnected to "weak" networks.

The wind farm POI is tied to the rest of the SPP system through, three outlets; a 230 kV tie to Jones which ties to Tuco substation, a 230 kV tie to the Borden 230 kV substation which has a step-down to 138 kV connecting to rest of the system via long, 138 kV circuit, and a double circuit 115 kV line (with two 230/115 kV autotransformers) connecting to the Graham 115 kV bus. Consequently, upon outage of the tie to Jones, the connection of the GEN-2008-016 wind farm to the system is significantly weakened.

Whereas with all lines in service, the strength of the system at the POI (Grassland 230 kV), measured in terms of Short Circuit Ratio (SCR) (ratio of System Short Circuit MVA and Size of the wind farm) is adequate (2246/248.4 = 9.0), following outage of the Grassland – Jones 230 kV line it drops significantly (537/248.4 = 2.16). In general, a short circuit ratio less than 3 is considered low, and requires more in-depth analysis, usually with more detailed tools and models (e.g. PSCAD/EMTP-type).

As a next step, the above simulation (3-phase fault with tripping of Grassland-Jones 230 kV) was repeated with the addition of dynamic compensation. The goal here was to verify if the provision of dynamic voltage support (i.e. to help quick recovery and stabilize the voltage) will help the wind farm controls to function well. For this purpose we modeled an SVC at the POI. A 75 MVAR SVC was found to reduce the magnitude of the oscillations, but did not completely eliminate these oscillations. Any further increase in the SVC size did not show any marked improvement. it is therefore, suggested that first the wind turbine manufacturer be consulted to seek their advice on whether adjustments to the wind farm controls could lead to similar, or better, result.

Selected faults were simulated at the Point of Interconnection (POI) of the proposed GEN-2008-016 wind farm to determine the compliance with FERC 661 – A; post-transition period LVRT standard. The results indicated that the proposed project met the FERC LVRT requirement for wind farm interconnection.

The results of this analysis are based on available data and assumptions made at the time of conducting this study. If any of the data and/or assumptions made in developing the study model change, the results provided in this report may not apply and additional analysis may be required.