Southwest Power Pool

Impact Study for Generation Interconnection Request GEN – 2005 – 008

SPP Tariff Studies
(#GEN-2005-008)

January, 2006

Summary

Black & Veatch performed the following Study at the request of the Southwest Power Pool (SPP) for Generation Interconnection request GEN-2005-008. The request for interconnection was placed with SPP in accordance SPP's Open Access Transmission Tariff, which covers new generation interconnections on SPP's transmission system.

Pursuant to the tariff, Black & Veatch was asked to perform a detailed Impact Study of the generation interconnection request to satisfy the Impact Study Agreement executed by the requesting customer and SPP.

As detailed in the Study, Customer will be required to install a staged 15MVAR capacitor bank to maintain required power factor at the wind farm facility and for transmission support needed to export power from the interconnection point.

FERC Order #661A was issued in December, 2005, in which the Customer will be required to comply with the transitional provisions of the low voltage ride through standard. In the transitional provisions, the wind turbines shall be able to withstand a fault that produces 0.15 pu voltage at the point of interconnection for 9 cycles.

To comply with Order #661A, Customer will be required to purchase the GE turbines they propose to install with the low voltage ride through Option #1 package (LVRT) as detailed in the Study. In this package, the turbines will stay on for turbine voltage of 0.30 pu. As shown in contingency FLT213PH in the study, with the LVRT package, the turbines stay on line for a 3 phase fault at the point of interconnection (which equates to a 0.0 pu voltage). Otherwise the turbines trip off for several faults (some single phase faults) away from the point of interconnection.

IMPACT STUDY FOR SPP GENERATION

QUEUE POSITION GEN-2005-008

SOUTHWEST POWER POOL (SPP)

January 6, 2006

By

BLACK & VEATCH

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EXECUTIVE SUMMARY

A transient stability study has been performed for Southwest Power Pool (SPP) Interconnection Queue Position Gen-2005-008 as part of the System Impact Study. The Interconnection Queue Position Gen-2005-008 is a wind farm of 130.5 MW capacity proposed to be located within the service territory of Oklahoma Gas & Electric (OG&E). The wind farm would be interconnected to 138 kV of Woodward 138/69 kV substation with a 138 kV overhead transmission line of 23 miles. A prior queued project, Gen-2005-006, is also proposed to be connected to Woodward substation.

Transient Stability studies were conducted with the full output of 130.5 MW (100%). The wind farm was considered to contain GE 1.5 MW turbines in the study with the standard under voltage protection package.

The 2009 summer peak and 2006 light winter peak flow cases together with the SPP MDWG 2004 stability model were used as the base cases for the transient stability analysis. The study was performed using PTI's PSS/E program, which is an industry-wide accepted power system simulation program. The wind farm was modeled using the GE wind turbine model available in PSS/E.

Prior to the transient stability analysis, a power flow analysis was conducted to estimate the amount of additional shunt capacitors that would be needed at the wind farm 34.5 kV collector buses so as to have zero reactive power exchange between wind farm and the grid. It was found that about 15 MVAR capacitors would be needed in the summer peak load case.

Transient Stability studies were conducted with the Gen-2005-008 output at 130.5 MW (100%) for two scenarios, i.e., (i) summer peak load and (ii) winter peak load. Twenty two (22) contingencies were considered for each of the scenarios.

The study has not indicated any angular or voltage instability problem for the contingencies analyzed in both the scenarios. However, the study has indicated that all Gen-2005-008 generators would be disconnected for certain faults near the wind farm by the standard under voltage protection scheme.

With GE's Low Voltage Ride Through (LVRT) protection scheme, instead of the standard package, Gen-2005-008 generators were found to stay connected to the grid for all the contingencies considered.

Based on the study results, the Customer shall discuss with GE, the turbine manufacturer, the LVRT control and protection packages available for the GE 1.5 MW wind turbines which would enable the turbine generators to ride through low voltages for most of the faults.

If any previously queued projects that were included in this study drop out then this System Impact Study may have to be revised to determine the impacts of this Interconnection Customer's project on SPS transmission facilities.

1. INTRODUCTION

This report discusses the results of a transient stability study performed for Southwest Power Pool (SPP) Interconnection Queue Position Gen-2005-008.

The Interconnection Queue Position Gen-2005-008 is a wind farm of 130.5 MW capacity proposed to be located within the service territory of Oklahoma Gas & Electric (OG&E). The wind farm would be interconnected to Woodward 138 kV substation with a 138 kV overhead transmission line of 23 miles. The system one line diagram of the area near the Queue Position Gen-2005-008 is shown in below. A prior queued project, Gen-2005-006, is also proposed to be connected to Woodward substation.

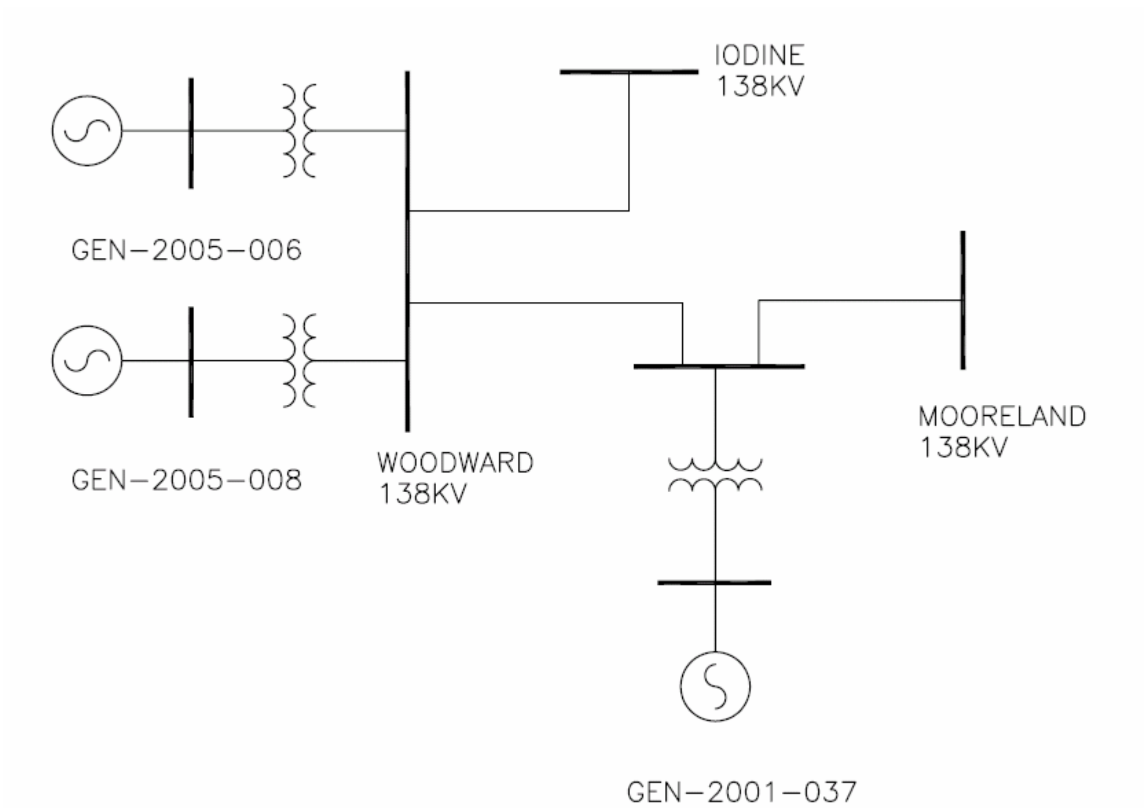

Figure 1 : System One Line Diagram near GEN-2005-008

Transient Stability studies were conducted with the full output of 130.5 MW (100%). The wind farm was considered to contain GE 1.5 MW turbines in the study with the standard low voltage ride thru package.

2. STABILITY STUDY CRITERIA

The 2009 summer peak and 2006 winter peak load flow cases together with the SPP MDWG 2004 stability model were used as the base cases for the transient stability analysis. These models were provided by SPP.

Using Planning Standards approved by NERC, the following stability definition was applied in the Transient Stability Analysis:

"Power system stability is defined as that condition in which the difference of the angular positions of synchronous machine rotor becomes constant following an aperiodic system disturbance."

Disturbances such as three phase and single phase line faults were simulated for a specified duration and the synchronous machine rotor angles were monitored for their synchronism following the fault removal.

The ability of the wind generators to stay connected to the grid during the disturbances and during the fault recovery was also monitored.

3. SIMULATION CASES

Transient Stability studies were conducted with the Gen-2005-008 output at 130.5 MW (100%) for two scenarios, i.e., (i) 2009 summer peak load and (ii) 2006 winter peak load.

Table 1 indicates the contingencies which were studied for each of the two cases.

Fault Number	Fault Definition
FLT13PH	Three phase fault on the Mooreland – Gen-2001-037 Wind Farm 138 kV line, near Mooreland.
FLT21PH	Single phase fault on the Mooreland – Gen-2001-037 Wind Farm 138 kV line, near Mooreland.
FLT33PH	Three phase fault on the Mooreland – Iodine 138 kV line, near Mooreland.
FLT41PH	Single phase fault on the Mooreland – Iodine 138 kV line, near Mooreland.
FLT53PH	Three phase fault on the Mooreland – Morewood Switch 138 kV line, near Mooreland.
FLT61PH	Single phase fault on the Mooreland – Morewood Switch 138 kV line, near Mooreland.
FLT73PH	Three phase fault on the Red Hills – Elk City 138 kV line, near Elk City.
FLT81PH	Single phase fault on the Red Hills – Elk City 138

	kV line, near Elk City.
FLT93PH	Three phase fault on the Mooreland – Taloga 138 kV line, near Taloga.
FLT101PH	Single phase fault on the Mooreland – Taloga 138 kV line, near Taloga.
FLT113PH	Three phase fault on the Mooreland – Glass Mtn 138 kV, near Glass Mtn.
FLT121PH	Single phase fault on the Mooreland – Glass Mtn 138 kV, near Glass Mtn.
FLT133PH	Three phase fault on the Mooreland – Cederdale 138 kV line, near Mooreland.
FLT141PH	Single phase fault on the Mooreland – Cederdale 138 kV line, near Mooreland.
FLT153PH	Three phase fault on the Elk City – Clinton North 138 kV line, near Elk City.
FLT161PH	Single phase fault on the Elk City – Clinton North 138 kV line, near Elk City.
FLT173PH	Three phase fault on the Elk City – Clinton AFB, near Elk City.
FLT181PH	Single phase fault on the Elk City – Clinton AFB, near Elk City.
FLT193PH	Three phase fault on the Woodward – Gen-2001-037, near Woodward.
FLT201PH	Single phase fault on the Woodward – Gen-2001-037, near Woodward.
FLT213PH	Three phase fault on the Woodward – Iodine 138 kV line, near Woodward.
FLT221PH	Single phase fault on the Woodward – Iodine 138 kV line, near Woodward.

Table 1: Study Cases

In all of the simulations, the fault duration was considered to be 5 cycles. A single shot line re-close was considered in all of the above cases with a wait time of 20 cycles.

4. SIMULATION MODEL

The customer requested to use GE Wind turbines for the System Impact Study. The GE turbines are a three phase double fed induction generator. The following are the main electrical parameters of the GE 1.5 MW wind turbine.

Rated Power : 1.5 MW
Apparent Power : 1,670 kVA
Maximum Reactive Power Output : 490 kVAR
Maximum Reactive Power Consumption : 730 kVAR

The models of the Wind Farm equipment such as generators, transformers and cables were added to the base case for the purpose of this study. The equivalent generators of the wind farm were based on the number of collector circuits shown on the Customer provided single line diagram. Figure 2 shows the one line diagram of Gen-2005-008 modeled.

Table 2 provides the number of GE 1.5 MW wind generators modeled as equivalents at each collector buses of the wind farm.

Collector Bus	No. of generators aggregated
CKT_1	11
CKT_2A	11
CKT_2B	4
CKT_3	16
CKT_4	16
CKT_5B	12
CKT_5A	3
CKT_6A	2
CKT_6B	11
CKT_6C	6

Table 2 : Equivalent Generators with GE
1.5 MW Turbines

The following transmission line parameters were used in the model for the overhead and underground lines within the Wind Farm and also between the Wind Farm and the Switching Station:

Line resistance : 0.025 ohms per 1000 ft for 1250 kcmil 34.5 KV cable
0.1452 ohms per 1000 ft for 1000 kcmil 34.5 kV cable
0.0318 ohms per 1000 ft for 750 kcmil 34.5 kV cable
0.0633 ohms per 1000 ft for 350 kcmil 34.5 kV cable
0.1575 ohms per 1000 ft for 2/0 AWG 34.5 kV cable
0.43 ohms per mile for 556 kcmil ACSR 138 kV line

Line reactance : 0.0376 ohms per 1000 ft for 1250 kcmil 34.5 KV cable
0.0385 ohms per 1000 ft for 1000 kcmil 34.5 kV cable
0.0403 ohms per 1000 ft for 750 kcmil 34.5 kV cable

0.0453 ohms per 1000 ft for 350 kcmil 34.5 kV cable
0.0519 ohms per 1000 ft for 2/0 AWG 34.5 kV cable
0.2 ohms per mile for 556 kcmil ACSR 138 kV line

The Customer provided the wind turbine feeder conductor types, lengths and impedance values. Line charging is negligible for the length of cables considered in the study and so was not included.

The Customer also provided the substation transformer impedance value and was 9% at 85 MVA.

The prior queued projects Gen-2001-014 (96 MW), Gen-2001-026 (74 MW); Gen-2001-037 (102.8 MW); Gen-2003-004, Gen-2004-023, and Gen-2005-003 (151.2 MW total); Gen-2003-005 (99 MW); Gen-2002-005 (120 MW); Gen-2003-022 (147 MW); Gen-2005-005 (18MW); and Gen-2005-006 (150MW) were also modeled. The wind farm models for the prior queued projects were provided by SPP.

A power flow analysis was conducted to estimate the amount of additional shunt capacitors that would be needed at the wind farm 34.5 kV collector buses so as to have zero reactive power exchange between wind farm and the grid. It was found that about 15 MVAR capacitors would be needed in the summer peak load case. These additional capacitors were included in the study.

Gen-2005-008 was modeled using the GE wind turbine model available in PSS/E. The effects of rotor current control and the turbine pitch control were also modeled. The GE data used in the study is as noted in Table 3.

Figure 2 also shows the 100% base case power flow for the project GEN-2005-008.

Description	Value
Stator resistance, Ra	0.00706 pu
Stator inductance, La	0.1714 pu
Mutual inductance, Lm	2.904 pu
Rotor resistance	0.005 pu
Rotor inductance	0.1563 pu
Drive train inertia	0.64 sec
Shaft damping	0.73 pu
Shaft stiffness	0.6286 pu
Generator rotor inertia	0.57 sec
Number of generator pole pairs	3
Gear box ratio	72.0

Table 3 : GE 1.5 MW Wind Turbine Generator Parameters

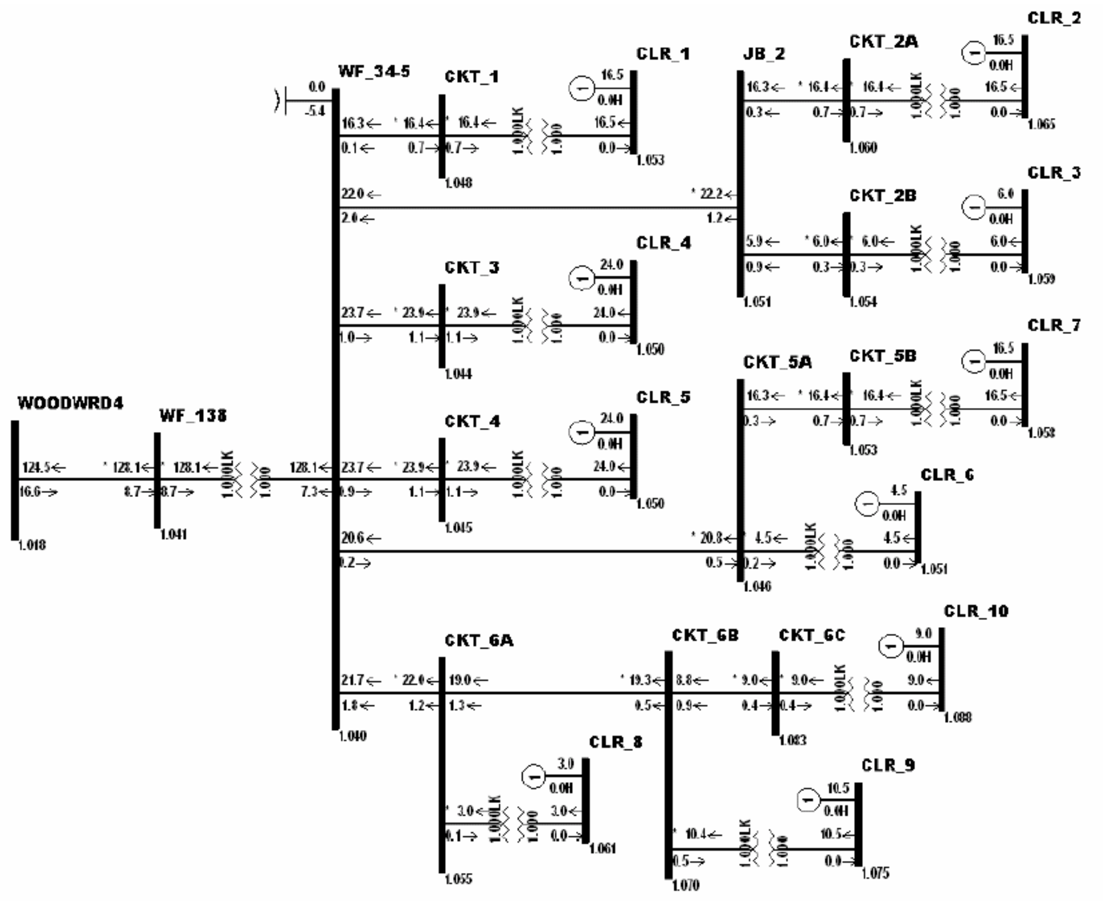

Figure 2 : Gen-2005-008 Power Flow Model

5. STUDY ASSUMPTIONS

The following assumptions were made in the Study:

1. The wind speed over the entire wind farm was assumed to be uniform and constant during the study period.
2. The turbine control models available within PSS/E such as CGECN2, TWIND1 and TGPTCH were used with their default values.
3. From the wind turbine data sheets the protection settings were used as and are shown in Table 4.
4. The other generators in the SPP control area were scaled down to accommodate the new generation as indicated in Table 5.

Protective Function	Protection Setting	Time Delay
Over Frequency	61.5 Hz	30 seconds
Over Frequency	62.5 Hz	0.02 seconds
Under Frequency	56.5 Hz	0.02 seconds
Under Frequency	57.5 Hz	10.0 seconds
Under Voltage	30%	0.02 seconds (for LVRT)
Under Voltage	70%	0.02 seconds (for standard) 0.1 seconds (for LVRT)
Under Voltage	75%	1.0 second
Under Voltage	85%	10.0 seconds
Over Voltage	110%	1.0 second
Over Voltage	115%	0.1 seconds
Over Voltage	130%	0.02 seconds

Table 4 : Protective Functions and Settings for GE 1.5 MW Turbines

Scenario	Generation within SPP	
	Summer	Winter
Without the Wind Farms	38,237 MW	25,336 MW
Gen-2005-008 at 100% output with the prior queued projects	38,107 MW	25,206 MW

Table 5 : SPP Dispatches

6. SIMULATION RESULTS

Initial simulation was carried out for 20 seconds without any disturbance to verify the numerical stability of the model and was confirmed to be stable.

Table 6 provides the summary of the stability studies with the standard protection package for Gen-2005-008.

Fault Number	**Summer Peak Load Level**	**Winter Peak Load Level**
FLT13PH	UV	UV
FLT21PH	- -	UV
FLT33PH	UV	UV
FLT41PH	- -	UV
FLT53PH	UV	UV
FLT61PH	- -	UV
FLT73PH	- -	- -
FLT81PH	- -	- -
FLT93PH	UV	UV
FLT101PH	- -	- -
FLT113PH	- -	- -
FLT121PH	- -	- -
FLT133PH	UV	UV
FLT141PH	- -	UV
FLT153PH	- -	- -
FLT161PH	- -	- -
FLT173PH	- -	- -
FLT181PH	- -	- -
FLT193PH	UV	UV
FLT201PH	- -	- -
FLT213PH	UV	UV
FLT221PH	- -	- -

UV : Tripped due to low voltage
OV : Tripped due to high voltage
UF : Tripped due to low frequency
OF : Tripped due to high frequency
S : Stability issues encountered
- - : Wind Farm did not trip

Table 6 : Stability Study Results Summary

Gen-2005-008 generators were found to be tripped for the following faults:

- FLT13PH and FLT21PH : Fault on Mooreland – Gen-2001-037 Wind Farm 138 kV line, near Mooreland.
- FLT33PH and FLT41PH : Fault on Mooreland – Iodine 138 kV line, near Mooreland.

- FLT53PH and FLT61PH: Fault on Mooreland – Morewood Switch, near Mooreland.
- FLT93PH : Three phase fault on Mooreland – Taloga 138 kV line, near Taloga
- FLT133PH and FLT141PH : Fault on Mooreland – Cederdale 138 kV line, near Mooreland.
- FLT193PH : Three phase fault on Woodward – Gen-2001-037 138 kV line, near Woodward.
- FLT213PH : Three phase fault on Woodward – Iodine 138 kV line, near Woodward.

The voltages at the wind generator terminals were found to be lower than the permissible 0.7 p.u for more than 0.02 seconds for the above contingencies and hence the generators were found to be tripped by the under voltage relays as illustrated in Figure 3 for FLT13PH case. The Gen-2005-008 generators were found to stay connected to the grid for the remaining 10 contingencies.

With GE's Low Voltage Ride Through (LVRT) protection scheme, instead of the standard package, Gen-2005-008 generators were found to stay connected to the grid for all the contingencies considered. Figure 4 shows the system response with LVRT protection scheme for FLT13PH.

The simulation results of both peak and light load cases indicated that there was no stability problem associated with the project GEN-2005-008 and all the synchronous generators' rotor angles settled down to steady state values.

It was also noted that a few of the prior queued projects were found to be tripped for a few contingencies. Table 7 indicates the prior queued projects which were found to be tripped.

Fault Number	**Summer Peak Load Level**	**Winter Peak Load Level**
FLT13PH	Gen-2001-014, Gen-2001-037, Gen-2005-005	Gen-2001-014, Gen-2001-037, Gen-2005-005
FLT21PH	Gen-2001-037	Gen-2001-014, Gen-2001-037
FLT33PH	Gen-2001-014, Gen-2001-037, Gen-2005-005	Gen-2001-014, Gen-2001-037, Gen-2005-005
FLT41PH	Gen-2001-014, Gen-2001-037	Gen-2001-014, Gen-2001-037
FLT53PH	Gen-2001-014, Gen-2001-037, Gen-2005-005	Gen-2001-014, Gen-2001-037
FLT61PH	Gen-2001-037	Gen-2001-014,

		Gen-2001-037
FLT73PH	- -	- -
FLT81PH	- -	- -
FLT93PH	- -	Gen-2001-014, Gen-2001-037
FLT101PH	- -	- -
FLT113PH	- -	Gen-2001-037
FLT121PH	- -	- -
FLT133PH	Gen-2001-014, Gen-2001-037, Gen-2005-005	Gen-2001-014, Gen-2001-037, Gen-2005-005
FLT141PH	Gen-2001-037	Gen-2001-014, Gen-2001-037
FLT153PH	- -	Gen-2002-005
FLT161PH	- -	- -
FLT173PH	- -	Gen-2002-005
FLT181PH	- -	- -
FLT193PH	Gen-2001-014, Gen-2001-037	Gen-2001-014, Gen-2001-037
FLT201PH	- -	- -
FLT213PH	Gen-2001-014, Gen-2001-037	Gen-2001-014, Gen-2001-037
FLT221PH	- -	- -

Table 7 : The prior queued projects which tripped

7. SUMMARY

A transient stability analysis was conducted for the SPP Interconnection Generation Queue Position Gen-2005-008 with its output at 130.5 MW consisting of GE 1.5 MW wind turbines. The study was conducted for two different power flow scenarios, i.e., one for summer peak load and the other for winter peak load. The study has not indicated any angular or voltage instability problem for the contingencies analyzed in both the scenarios.

However, the study has indicated that all Gen-2005-008 generators would be disconnected for certain faults near the wind farm by the standard wind turbine generator under voltage protection scheme.

With GE's Low Voltage Ride Through (LVRT) protection scheme, instead of the standard package, Gen-2005-008 generators were found to stay connected to the grid for all the contingencies considered.

Based on the study results, the Customer shall discuss with GE, the turbine manufacturer, the LVRT control and protection packages available for the GE 1.5 MW wind turbines which would enable the turbine generators to ride through low voltages during grid faults.

Disclaimer

If any previously queued projects that were included in this study drop out, then this System Impact Study may have to be revised to determine the impacts of this Interconnection Customer's project on SPS transmission facilities. Since this is also a preliminary System Impact Study, not all previously queued projects were assumed to be in service in this System Impact Study. If any of those projects are constructed, then this System Impact Study may have to be revised to determine the impacts of this Interconnection Customer's project on SPS transmission facilities. In accordance with FERC and SPP procedures, the study cost for restudy shall be borne by the Interconnection Customer.

Figure 3 : System Responses with 100% output of Gen-2005-008

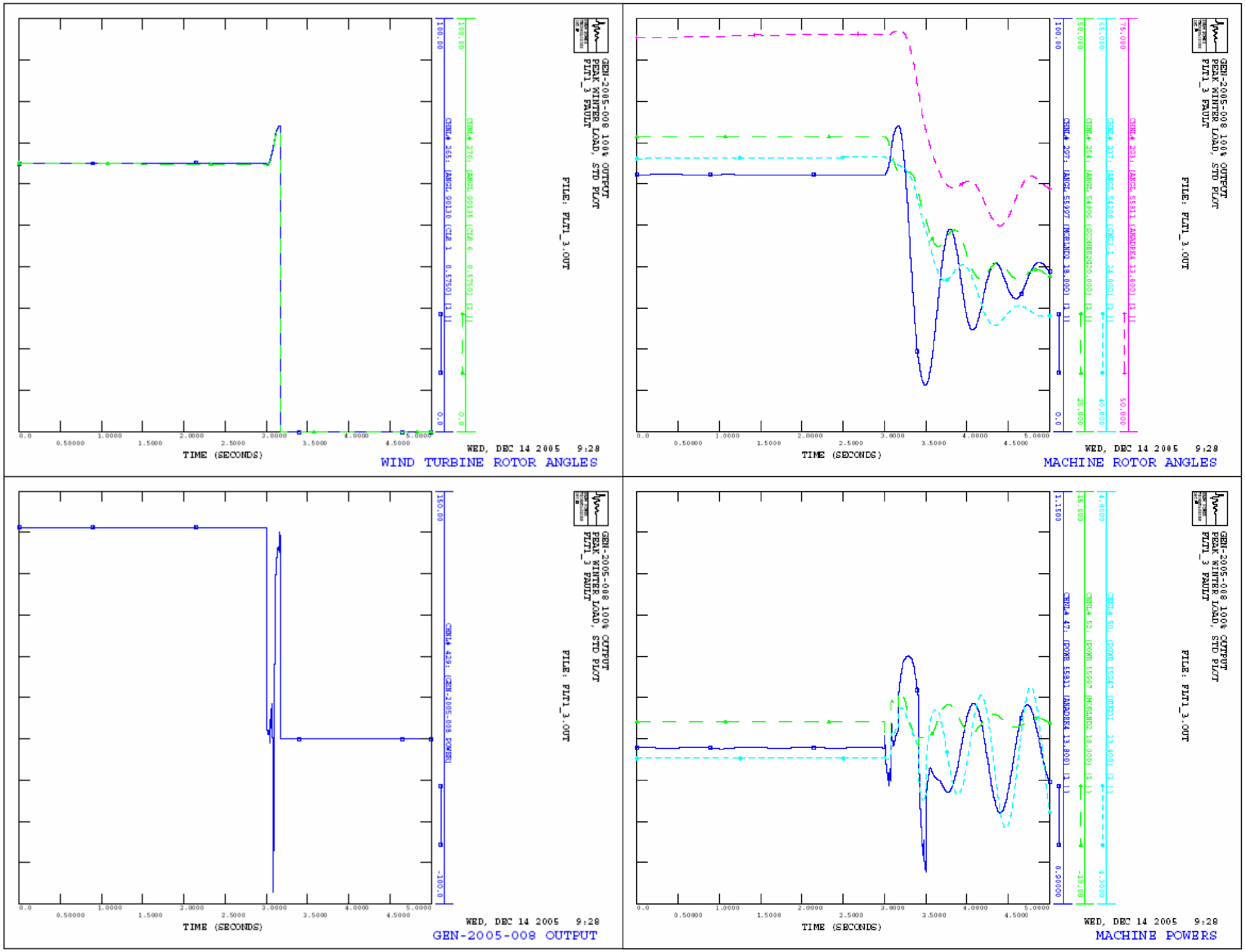

Figure 3 : System Responses with 100% output of Gen-2005-008 (Cont'd)

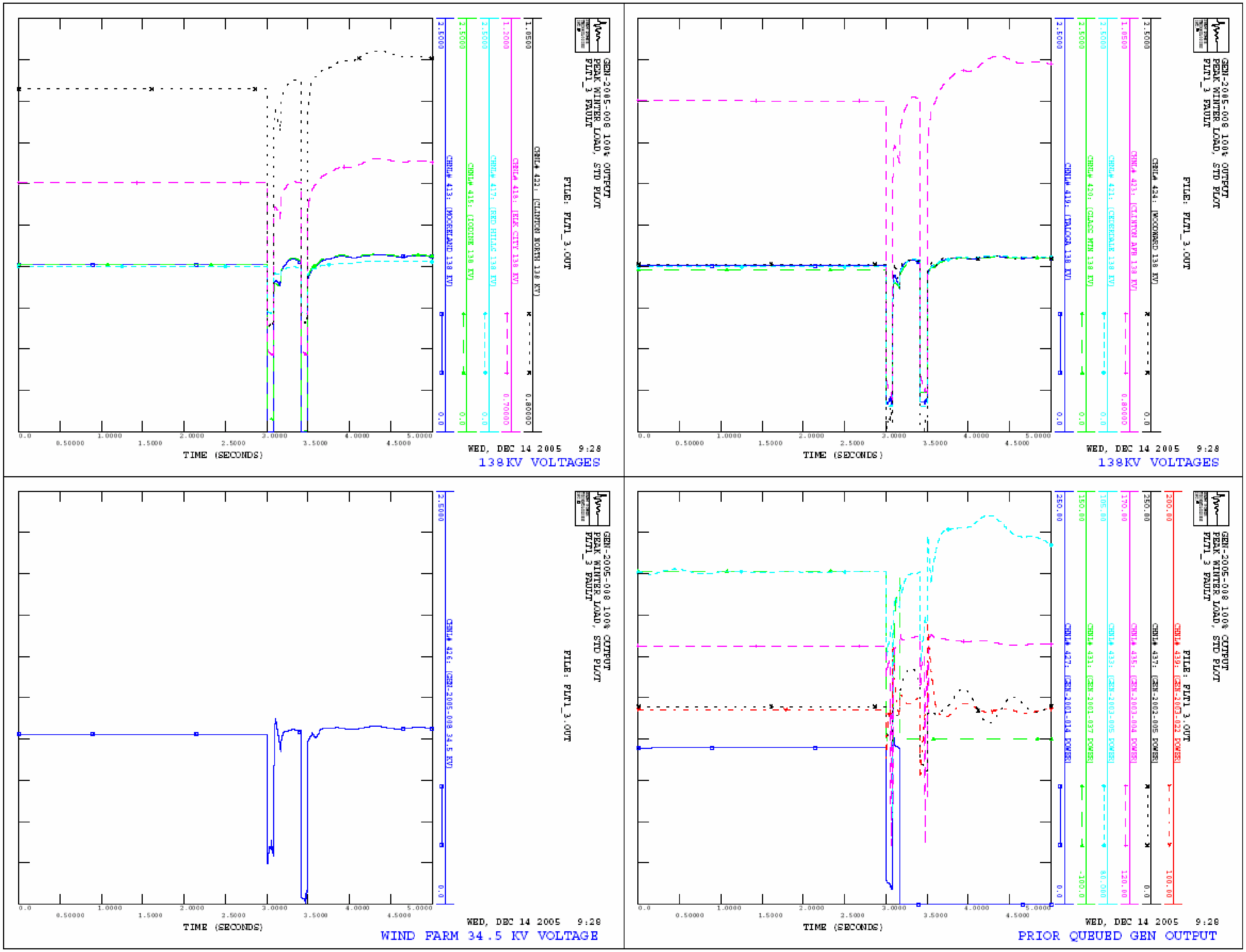

Figure 4 : System Responses with the Low Voltage Ride Through Protection

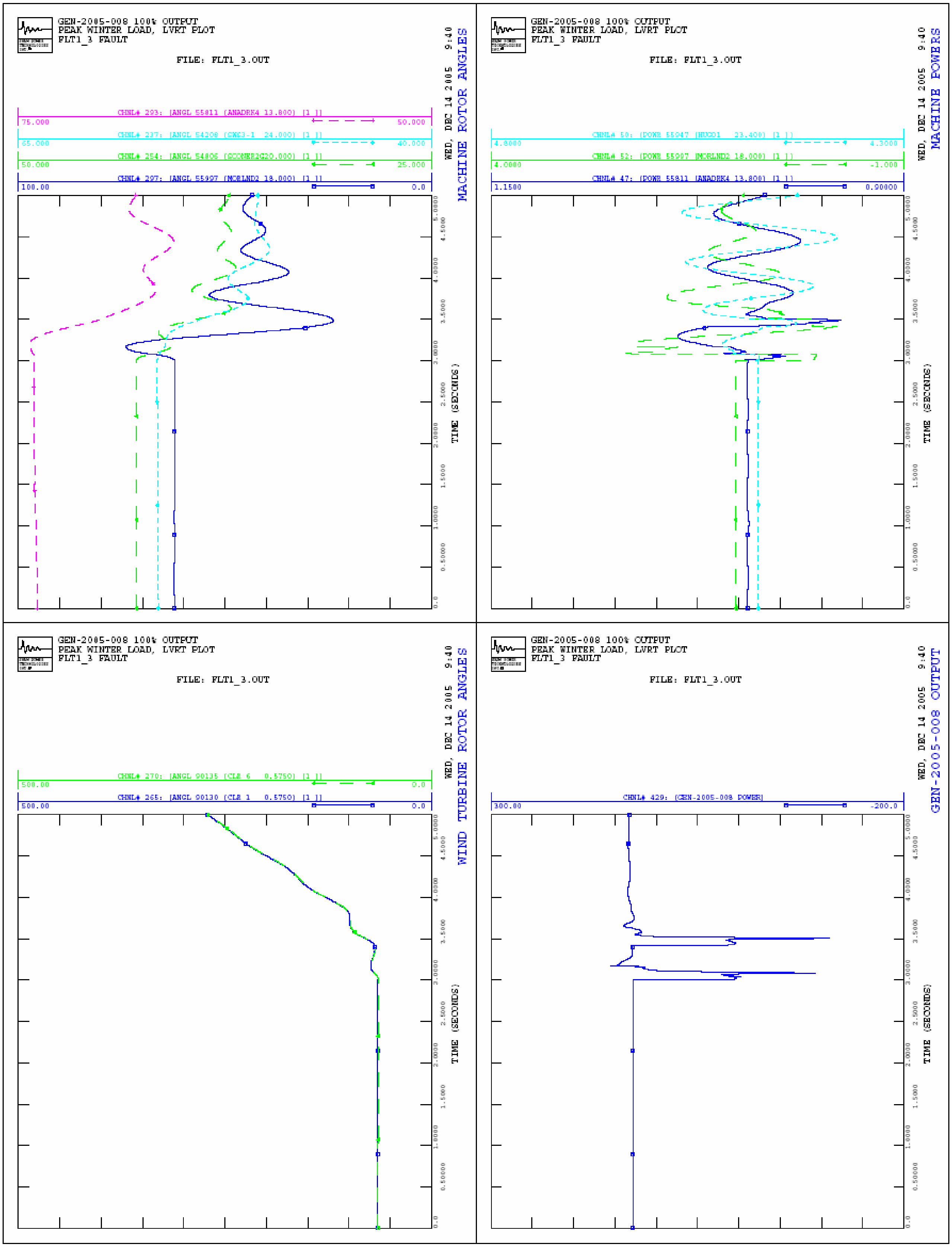

Figure 4 : System Responses with the Low Voltage Ride Through Protection (Cont'd)