Impact Study for Generation Interconnection Request GEN – 2004 – 010

SPP Coordinated Planning
(#GEN-2004-010)

June 2005

Summary

Black & Veatch performed the following Study at the request of the Southwest Power Pool (SPP) for Generation Interconnection request Gen-2004-010. 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.

The Federal Energy Regulatory Commission finalized the grid-interconnection rule for large wind power facilities May 25, 2005. The final rule provides that wind generators must meet the following conditions, if the transmission service provider demonstrates they are needed. First, if needed, a large wind generating facility must remain operational during voltage disturbances on the grid. Second, large wind plants must, if needed, meet the same technical criteria for providing reactive power to the grid as required of conventional large generating facilities. Third, the final rule provides for supervisory control and data acquisition (SCADA), if needed, to ensure appropriate real-time communication and data exchanges between the wind power producer and the grid operator.

To this end SPP recommends that the Customer strongly consider these reliability requirements of the wind farm based on the FERC final rule. The study found that during 5 of the 18 faults studied the GE standard protection scheme allowed the wind farm to trip due to low voltage. With the GE Low Voltage Ride Through (LVRT) all faults studied with the exception of the Farm switching station to Rose Hill 345 kV line (FLT13PH) were found to stay connected to the grid. The use of the GE LVRT with the addition of 65 Mvar will satisfy the first and second FERC requirement noted above.

IMPACT STUDY FOR SPP GENERATION

QUEUE POSITION GEN-2004-010

SOUTHWEST POWER POOL (SPP)

June 2005

By

BLACK & VEATCH

Table of Contents

EXECUTIVE SUMMARY

A transient stability study has been performed for Southwest Power Pool (SPP) Interconnection Queue Position Gen-2004-010 as part of the System Impact Study. The Interconnection Queue Position Gen-2004-010 is a wind farm of 300 MW capacity proposed to be located near Beaumont, Kansas within the service territory of Kansas Gas and Electric Company (WERE). The wind farm would be interconnected to an existing 345 kV three breaker ring bus on the Rose Hill to Neosho 345 kV line by adding an additional breaker. A prior queued project Gen-2002-004 of 200 MW is already interconnected at the same ring bus.

Transient Stability studies were conducted with the full output of 300 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 load flow case together with the SPP MDWG 2004 stability model were used as the base case 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 65 MVAR capacitors would be needed in the summer peak load case.

Transient Stability studies were conducted with the Gen-2004-010 output at 300 MW (100%) for two scenarios, i.e., (i) summer peak load and (ii) light fall load. Eighteen (18) 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-2004-010 generators would be disconnected for certain three phase 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-2004-010 generators were found to stay connected to the grid for all the contingencies considered, except for a three phase fault scenario on the Wind Farm Switching Station – Rose Hill 345 kV line. Many generators within Gen-2004-010 wind farm were found to be tripped for this particular fault, which reduced the wind farm output to about 230 MW. Based on the FERC Final rule issue May 27, 2005 the Interconnection Customer shall review the requirements and this additional risk implication of wind farm outages that the wind turbine under voltage control scheme may cause to the wind farm. The Interconnection Customer shall include the addition of the 65 Mvar also identified in this study.

Based on the study results, the Customer shall also 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 WERE transmission facilities.

1. INTRODUCTION

This report discusses the results of a transient stability study performed for Southwest Power Pool (SPP) Interconnection Queue Position Gen-2004-010.

The Interconnection Queue Position Gen-2004-010 is a wind farm of 300 MW capacity proposed to be located near Beaumont, Kansas within the service territory of Kansas Gas and Electric Company (WERE). The wind farm would be interconnected to an existing 345 kV three breaker ring bus on the Rose Hill to Neosho 345 kV line by adding an additional breaker. A prior queued project Gen-2002-004 of 200 MW is already interconnected at the same ring bus. The system one line diagram of the area near the Queue Position Gen-2004-010 is shown in below.

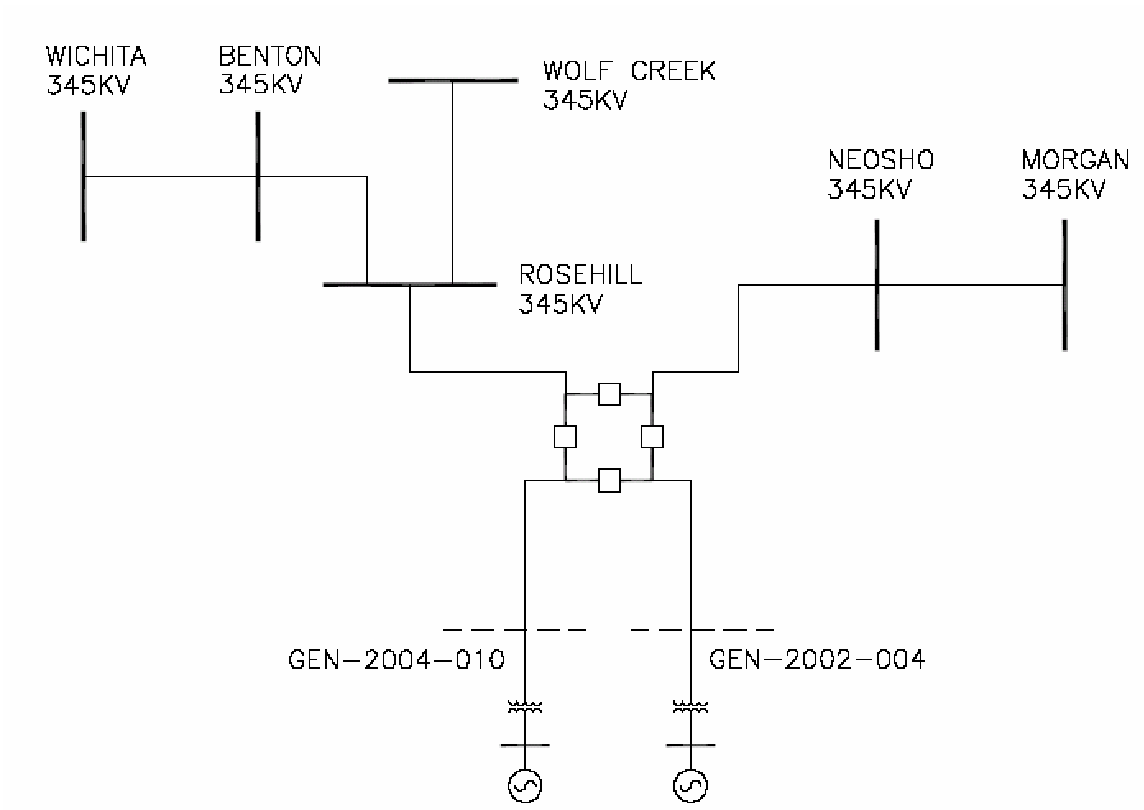

Figure 1: System One Line Diagram near GEN-2004-010

Transient Stability studies were conducted with the full output of 300 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 fall load flow cases together with the SPP MDWG 2004 stability model were used as the base case 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-2004-010 output at 300 MW (100%) for two scenarios, i.e., (i) 2009 summer peak load and (ii) 2009 light fall load.

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

Fault Number	Fault Definition
FLT13PH	Three phase fault at the midpoint of Rose Hill – Wind Farm Switching Station 345 kV line with one shot reclosing after 300 cycles.
FLT21PH	Single phase fault at the midpoint of Rose Hill – Wind Farm Switching Station 345 kV line with one shot reclosing after 300 cycles.
FLT33PH	Three phase fault on Wind Farm Switching Station – Neosho 345 kV line near Neosho, with one shot reclosing after 300 cycles.
FLT41PH	Single phase fault on Wind Farm Switching Station – Neosho 345 kV line near Neosho, with one shot reclosing after 300 cycles.
FLT53PH	Three phase fault at the mid point of Neosho – Morgan 345 kV line, with one shot reclosing after

	300 cycles.
FLT61PH	Single phase fault at the mid point of Neosho – Morgan 345 kV line, with one shot reclosing after 300 cycles.
FLT73PH	Three phase fault on Rose Hill – Wolf Creek 345 kV line near Rose Hill, with one shot reclosing after 300 cycles.
FLT81PH	Single phase fault on Rose Hill – Wolf Creek 345 kV line near Rose Hill, with one shot reclosing after 300 cycles.
FLT93PH	Three phase fault on Rose Hill – Benton 345 kV line near Benton, with one shot reclosing after 60 cycles.
FLT101PH	Single phase fault on Rose Hill – Benton 345 kV line near Benton, with one shot reclosing after 60 cycles.
FLT113PH	Three phase fault on Benton – Wichita 345 kV line near Wichita, with one shot reclosing after 60 cycles.
FLT121PH	Single phase fault on Benton – Wichita 345 kV line near Wichita, with one shot reclosing after 60 cycles.
FLT133PH	Three phase fault on Benton – Midian 138 kV line near Midian, with one shot reclosing after 25 cycles.
FLT141PH	Single phase fault on Benton – Midian 138 kV line near Midian, with one shot reclosing after 25 cycles.
FLT153PH	Three phase fault on Midian – Butler 138 kV line near Butler, with one shot reclosing after 25 cycles.
FLT161PH	Single phase fault on Midian – Butler 138 kV line near Butler, with one shot reclosing after 25 cycles.
FLT173PH	Three phase fault on Rose Hill – Weaver 138 kV line near Weaver, with one shot reclosing after 25 cycles.
FLT181PH	Single phase fault on Rose Hill – Weaver 138 kV line near Weaver, with one shot reclosing after 25 cycles.

Table 1: Study Cases

In all of the simulations, the fault duration was considered to be 5 cycles for the 345 kV line faults and 7 cycles for 138 kV line faults.

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 (a) to 2 (d) show the one line diagram of Gen-2004-010 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**
N5A7	7
N5B4	4
N4A7	7
N4B7	7
N4C1	1
W1A5	5
W1A7	7
N1B7	7
N1A4	4
N2A3	3
N3A7	7
N3B7	7
W2A4	4
W2B4	4
W2C4	4
W2D4	4
SE2A7	7
SE2B6	6
SE1C4	4
SE1B6	6

SE1A7	7
SW1A3	3
SW1B4	4
SW2A7	7
SW3A7	7
SW3B7	7
SW5A2	2
SW5B4	4
SW5C6	6
SW6A7	7
SW6B7	7
SW4A2	2
SW4B5	5
SW7A8	8
SW7B7	7
SW8A5	5
SW8B7	7

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 Switching Station:

Line resistance : 0.0445 ohms per 1000 ft for 397 kcmil ACSR line
0.0318 ohms per 1000 ft for 556 kcmil ACSR line
0.1281 ohms per 1000 ft for 1/0 AWG 34.5 kV cable
0.064 ohms per 1000 ft for 4/0 AWG 34.5 kV cable

Line reactance : 0.0824 ohms per 1000 ft for 397 kcmil ACSR line
0.0795 ohms per 1000 ft for 556 kcmil ACSR line
0.0507 ohms per 1000 ft for 1/0 AWG 34.5 kV cable
0.0466 ohms per 1000 ft for 4/0 AWG 34.5 kV cable

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 transformers' impedances and they were:

Transformer 1 : 8.5 % at 60 MVA
Transformer 2 : 8.5 % at 60 MVA
Transformer 3 : 8.5 % at 135 MVA

The prior queued projects Gen-2002-004 of 200 MW and Gen-2003-019 of 250 MW were also modeled in complete detail. The no. of aggregated equivalents of the wind generators for these prior queued projects was based on the no. of collector circuits. The wind farm data including circuit impedances was 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 65 MVAR capacitors would be needed in the summer peak load case. This additional capacitors were included in the study.

Gen-2004-010 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 (a) to 2(d) also show the 100% base case power flow for the project GEN-2004-010.

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

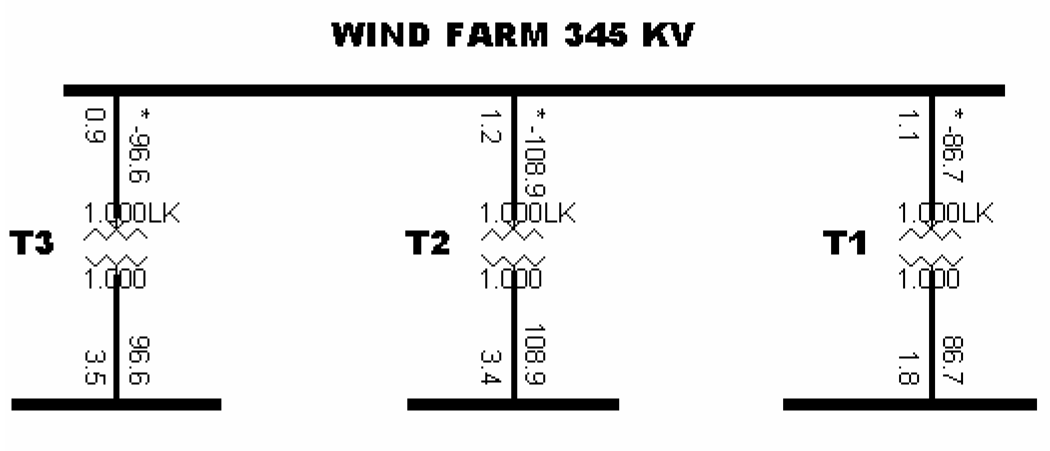

Figure 2 (a) : Gen-2004-010 Switching Station

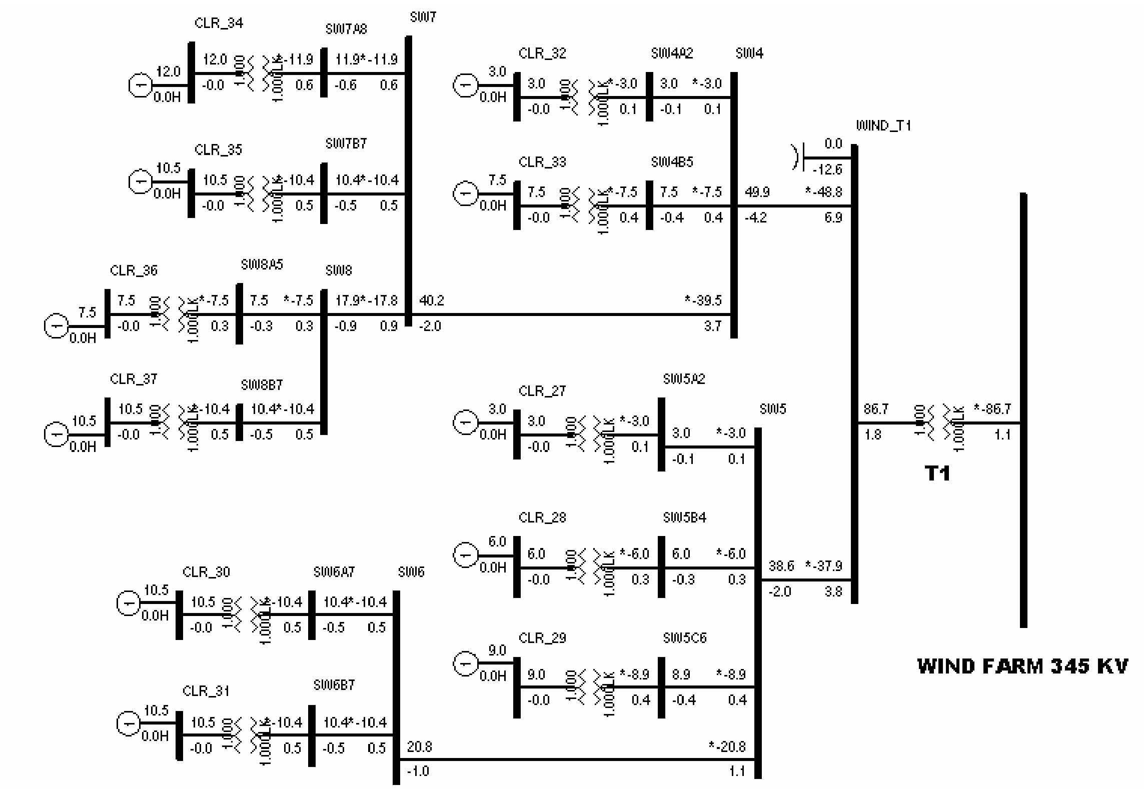

Figure 2 (b): T1 Collector Circuit

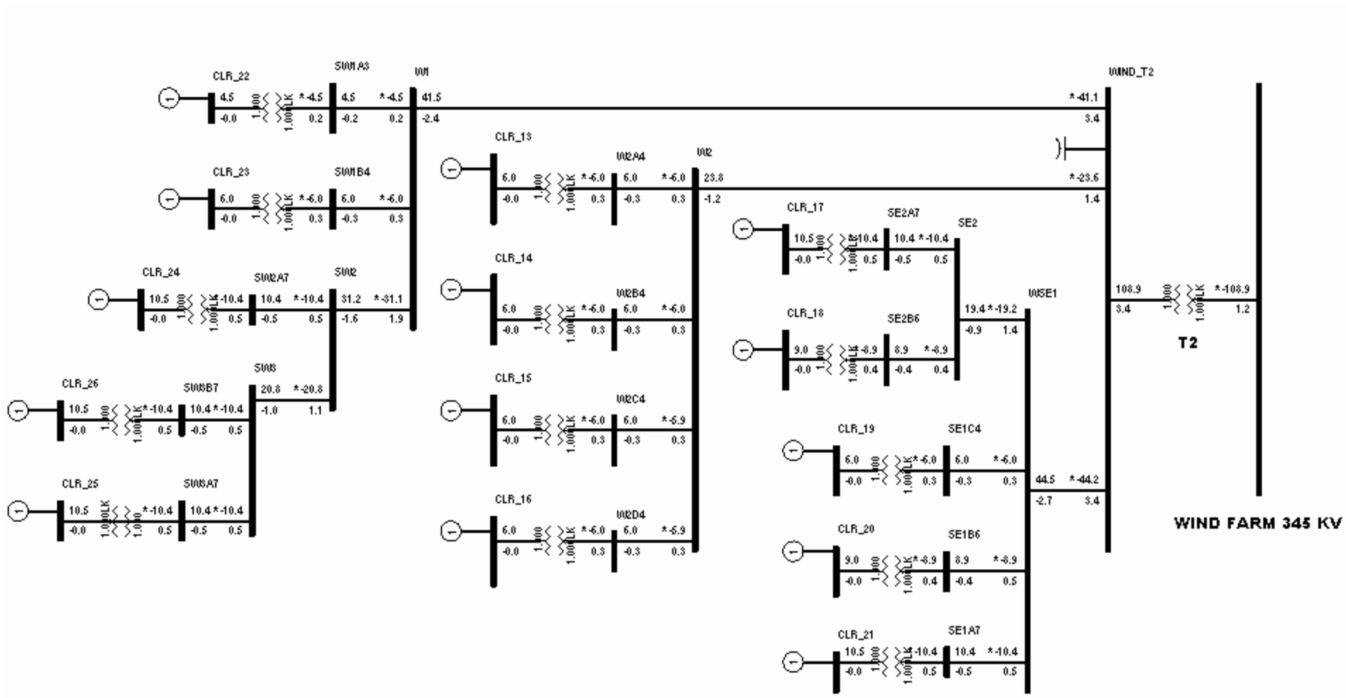

Figure 2(c): T2 Collector Circuit

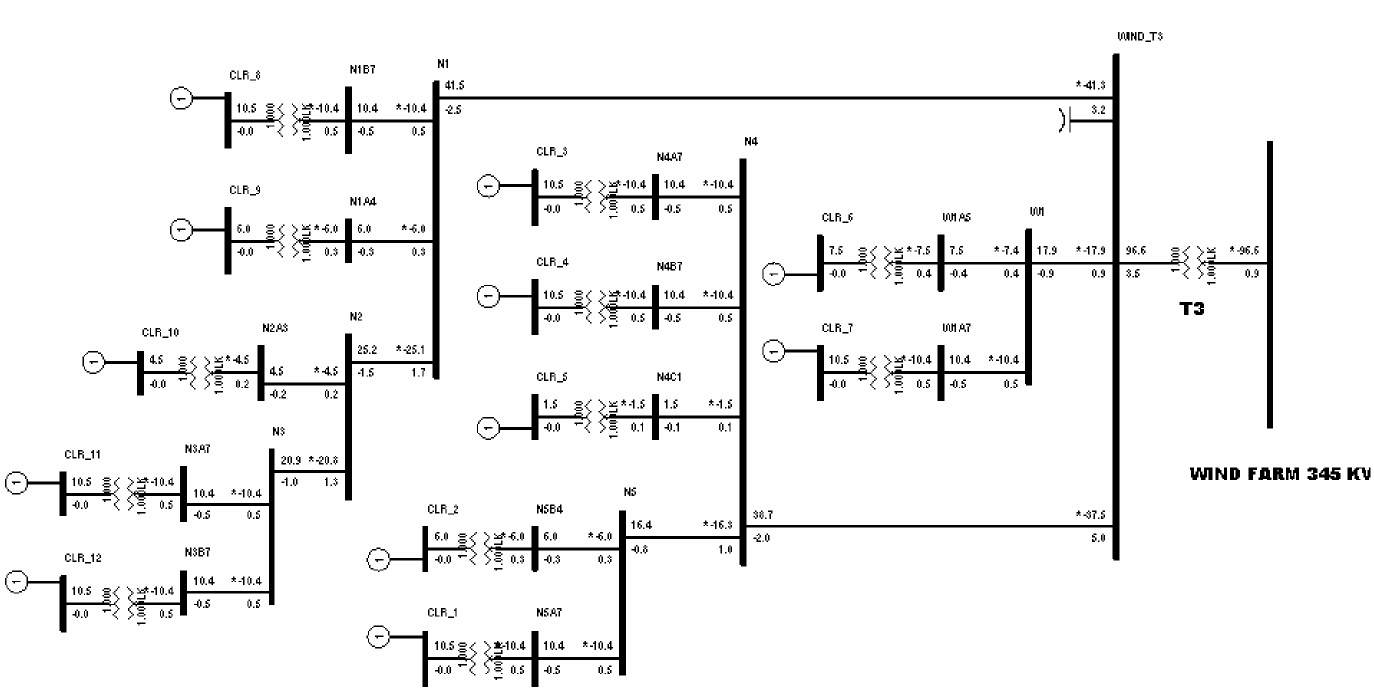

Figure 2 (d): T3 Collector Circuit

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. Out of total of 750 MW from the three projects that were modeled, 590 MW was dispatched across the SPP footprint and 160 MW was dispatched to area 544.

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	70%	0.02 seconds
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	Fall
Without the Wind Farms	38,027 MW	24,929 MW
Gen-2004-010 at 100% output with the prior queued projects	37,277 MW	24,179 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-2004-010.

Fault Number	**Summer Peak Load Level**	**Fall Light Load Level**
FLT13PH	UV	UV
FLT21PH	- -	- -
FLT33PH	UV	UV
FLT41PH	- -	- -
FLT53PH	- -	- -
FLT61PH	- -	- -
FLT73PH	UV	UV
FLT81PH	- -	- -
FLT93PH	UV	UV
FLT101PH	- -	- -
FLT113PH	UV	UV
FLT121PH	- -	- -
FLT133PH	- -	- -
FLT141PH	- -	- -
FLT153PH	- -	- -
FLT161PH	- -	- -
FLT173PH	- -	- -
FLT181PH	- -	- -

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-2004-010 generators were found to be tripped for the following faults:

- FLT13PH : Three phase fault on Wind Farm Switching Station – Rose Hill 345 kV line at midpoint.

- FLT33PH : Three phase fault on Wind Farm Switching Station – Neosho 345 kV line, near Neosho.
- FLT73PH : Three phase fault on Rose Hill – Wolf Creek 345 kV line, near Rose Hill.
- FLT93PH : Three phase fault on Rose Hill – Benton 345 kV line, near Benton.
- FLT113PH : Three phase fault on Benton – Wichita 345 kV line, near Wichita.

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-2004-010 generators were found to stay connected to the grid for the remaining 13 contingencies.

With GE's Low Voltage Ride Through (LVRT) protection scheme, instead of the standard package, Gen-2004-010 generators were found to stay connected to the grid for all the contingencies considered, except for a three phase fault scenario on the Wind Farm Switching Station – Rose Hill 345 kV line (FLT13PH). Many generators within Gen-2004-010 wind farm were found to be tripped for this particular fault, which reduced the wind farm output to about 230 MW, as illustrated in Figure 4.

The simulation results of both peak and light load cases indicated that there was no stability problem associated with the project GEN-2004-010 and all the synchronous generators' rotor angles settled down to steady state values.

7. SUMMARY

A transient stability analysis was conducted for the SPP Interconnection Generation Queue Position Gen-2004-010 with its output at 300 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 light fall 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-2004-010 generators would be disconnected for certain three phase 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-2004-010 generators were found to stay connected to the grid for all the contingencies considered, except for a three phase fault scenario on the Wind Farm Switching Station – Rose Hill 345 kV line. Many generators within Gen-2004-010 wind farm were found to be tripped for this particular fault, which reduced the wind farm output to about 230 MW. Based on the FERC Final rule issue May 27, 2005 the

Interconnection Customer shall review the requirements and this additional risk implication of wind farm outages that the wind turbine under voltage control scheme may cause to the wind farm. The Interconnection Customer shall include the addition of the 65 Mvar also identified in this study.

Based on the study results, the Customer shall also 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.

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 WERE 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 WERE 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-2004-010

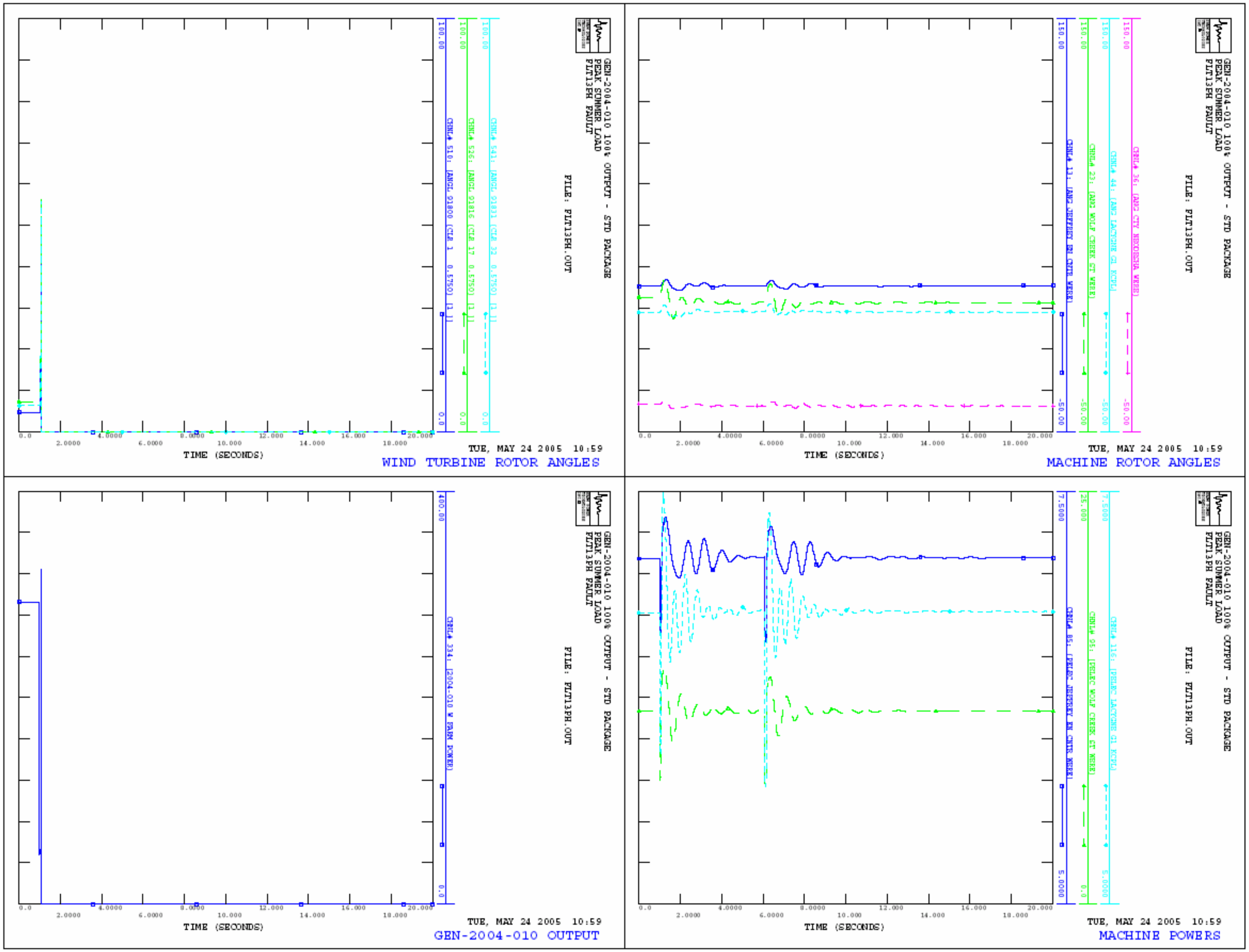

Figure 3 : System Responses with 100% output of Gen-2004-010 (Cont'd)

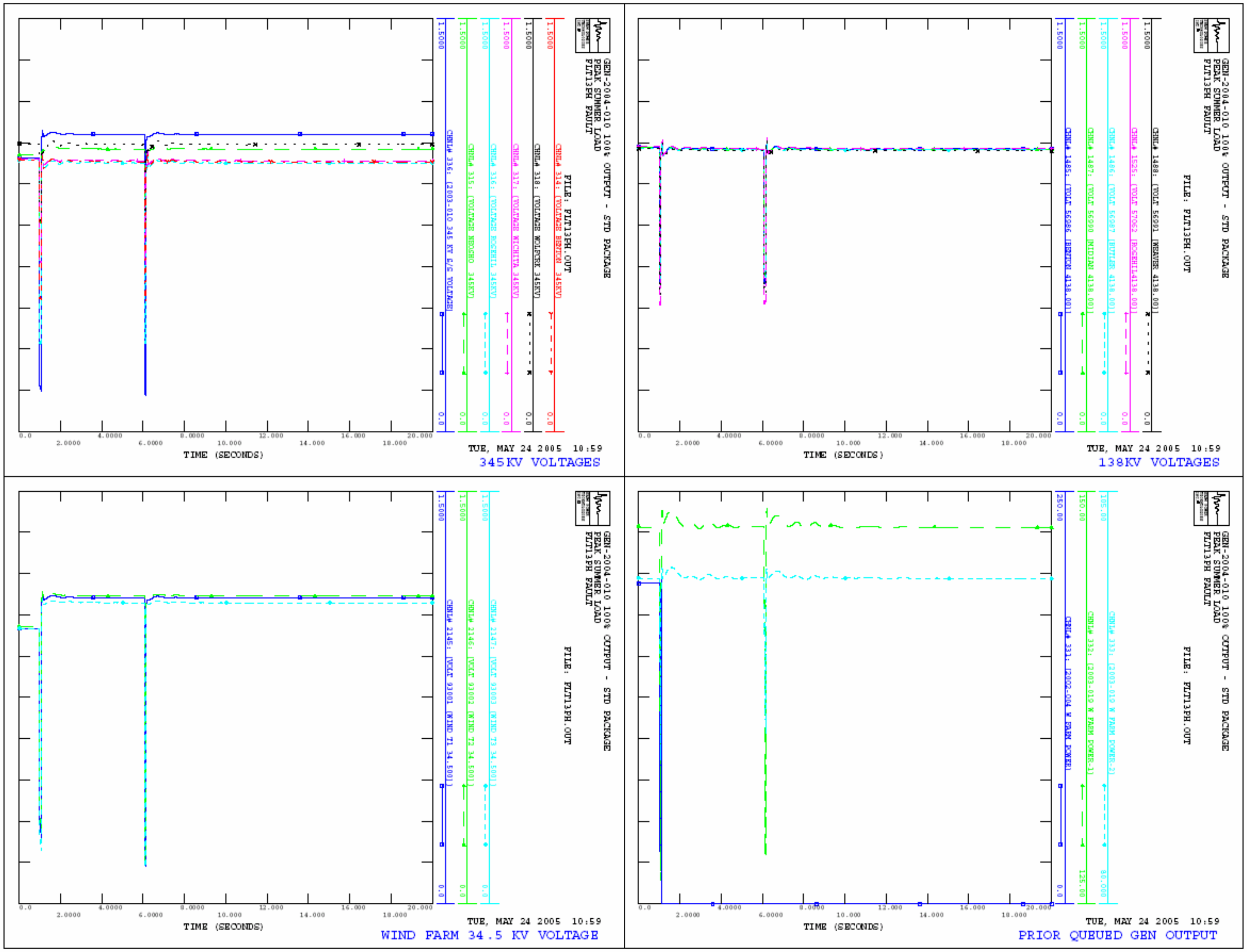

Figure 4 : System Responses with the Low Voltage Ride Through

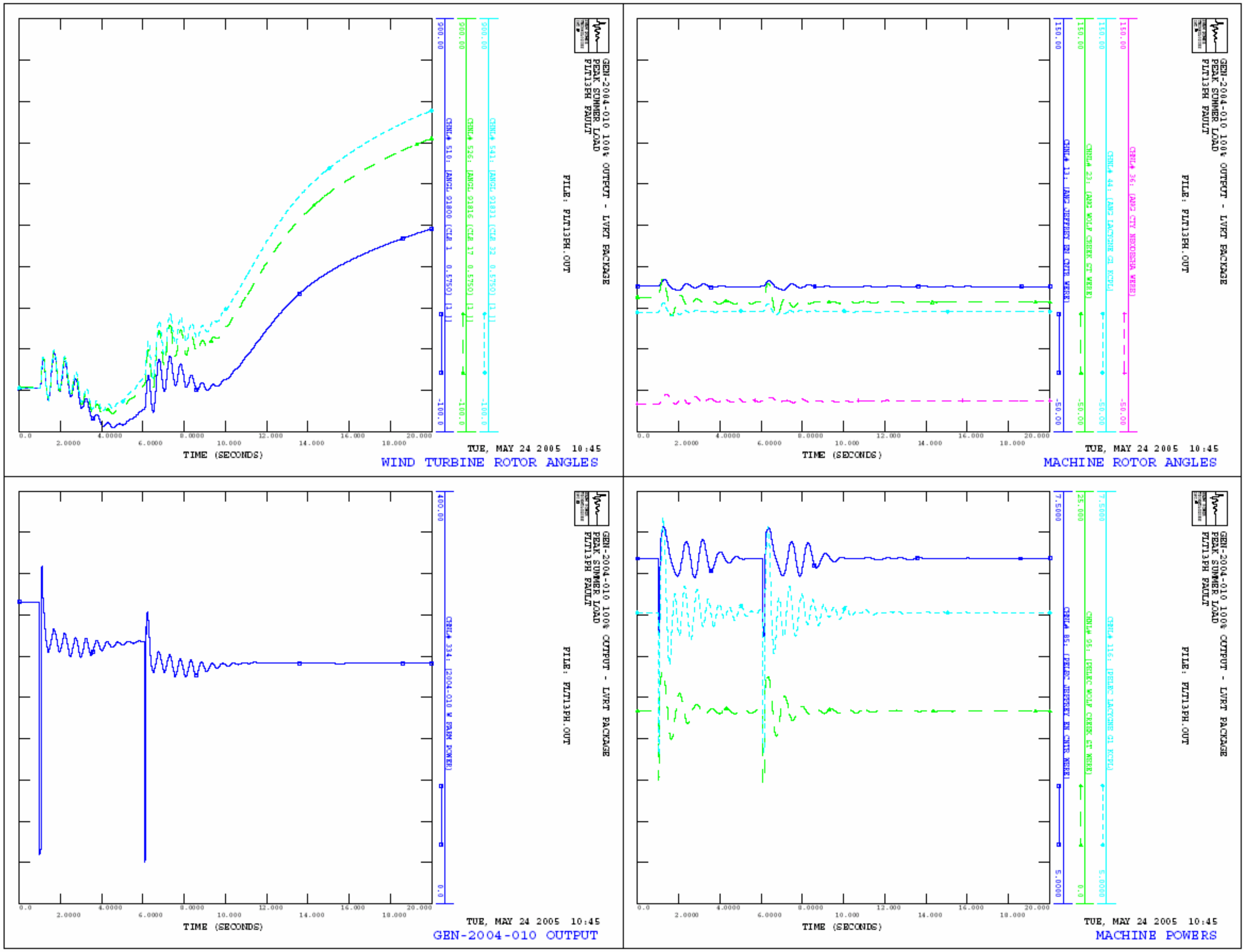

Figure 4 : System Responses with the Low Voltage Ride Through Protection (Cont'd)