Southwest Power Pool

Impact Study for Generation Interconnection Request GEN – 2004 – 016

SPP Coordinated Planning
(#GEN-2004-016)

August 2005

Summary

Black & Veatch performed the following Study at the request of the Southwest Power Pool (SPP) for Generation Interconnection request Gen-2004-016. 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.

Based on the results of the System Impact Study, the project was found to be able to interconnect without any negative effects. The study did not indicate any angular or voltage instability problems for the contingencies analyzed.

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.

The study noted that 25 MVAR of capacitors was needed to achieve a near zero reactive power exchange between the farm and the grid in a steady state condition. The use of the capacitor banks, sized at 25 MVAR will satisfy the second FERC requirement noted above. Based on this analysis this is a requirement for interconnection.

IMPACT STUDY FOR SPP GENERATION

QUEUE POSITION GEN-2004-016

SOUTHWEST POWER POOL (SPP)

August 18, 2005

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-2004-016 as part of the System Impact Study. The Interconnection Queue Position Gen-2004-016 is a wind farm of 150 MW capacity proposed to be located in Saline County, Kansas within the service territory of Kansas Gas and Electric Company (WERE). The wind farm would be interconnected to a new 230 kV three breaker ring bus on the Summit to E. McPherson 230 kV line owned by WERE.

Transient Stability studies were conducted with the full output of 150 MW (100%). The wind farm was considered to contain Gamesa G87-2.0 MW turbines in the study.

The 2009 peak load flow case and 2006 fall 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 Gamesa wind turbine models provided by the Customer.

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 25 MVAR capacitors would be needed in the summer peak load case.

Transient Stability studies were conducted with the Gen-2004-016 output at 150 MW (100%) for two scenarios, i.e., (i) summer peak load and (ii) light fall load. Twenty Four (24) 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-2004-016 generators would be disconnected for certain three phase faults near the wind farm.

The Interconnection Customer shall consider this additional risk implication of wind farm outages that the wind turbine under voltage control scheme may cause to the wind farm.

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-2004-016.

The Interconnection Queue Position Gen-2004-016 is a wind farm of 150 MW capacity proposed to be located in Saline County, Kansas within the service territory of Kansas Gas and Electric Company (WERE). The wind farm would be interconnected to a new 230 kV three breaker ring bus on Summit to East McPherson line owned by WERE. The system one line diagram of the area near the Queue Position Gen-2004-016 is shown below.

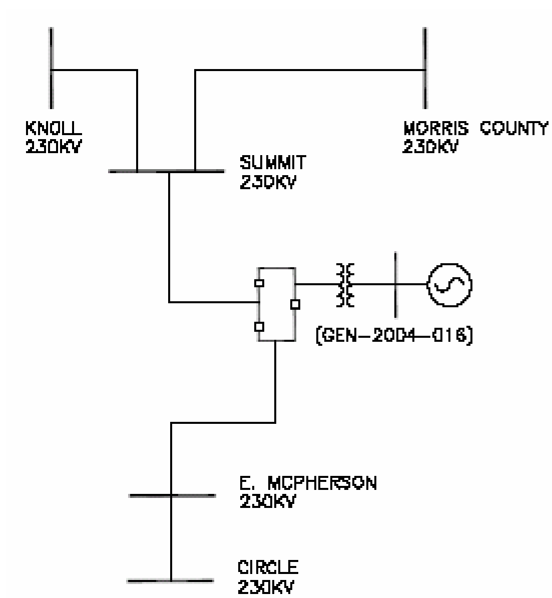

Figure 1 : System One Line Diagram near GEN-2004-016

Transient Stability studies were conducted with the full output of 150 MW (100%). The wind farm was considered to contain Gamesa G87-2.0 MW wind turbines in the study.

2. STABILITY STUDY CRITERIA

The 2009 summer peak and 2006 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-2004-016 output at 150 MW (100%) for two scenarios, i.e., (i) 2009 summer peak load and (ii) 2006 light fall load.

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

Fault Number	Fault Definition
FLT1_3PH	Three phase fault on Wind Farm Switching Station - Summit 230 kV line, near Summit, with one shot reclosing after 20 cycles.
FLT2_1PH	Single phase fault on Wind Farm Switching Station - Summit 230 kV line, near Summit, with one shot reclosing after 20 cycles.
FLT3_3PH	Three phase fault on Wind Farm Switching Station – E. McPherson 230 kV line near E. McPherson, with one shot reclosing after 20 cycles.
FLT4_1PH	Single phase fault on Wind Farm Switching Station – E. McPherson 230 kV line near E. McPherson, with one shot reclosing after 20 cycles.
FLT5_3PH	Three phase fault on Circle – Mullergren 230 kV line, near Circle, with one shot reclosing after 20 cycles.
FLT6_1PH	Single phase fault on Circle – Mullergren 230 kV line, near Circle, with one shot reclosing after 20 cycles.
FLT7_3PH	Three phase fault on Heizer – Mullergren 230 kV line near Heizer, with one shot reclosing after 20 cycles.

FLT8_1PH	Single phase fault on Heizer – Mullergren 230 kV line near Heizer, with one shot reclosing after 20 cycles.
FLT9_3PH	Three phase fault on Mullergren – Spearville 230 kV line near Spearville, with one shot reclosing after 30 cycles.
FLT10_1PH	Single phase fault on Mullergren – Spearville 230 kV line near Spearville, with one shot reclosing after 30 cycles.
FLT11_3PH	Three phase fault on Spearville – Holcome 230 kV line near Holcome, with one shot reclosing after 30 cycles.
FLT12_1PH	Single phase fault on Spearville – Holcome 230 kV line near Holcome, with one shot reclosing after 30 cycles.
FLT13_3PH	Three phase fault on Jeffrey Energy Center – Summit 345 kV line near Summit, with one shot reclosing after 30 cycles.
FLT14_1PH	Single phase fault on Jeffrey Energy Center – Summit 345 kV line near Summit, with one shot reclosing after 30 cycles.
FLT15_3PH	Three phase fault on Morris County – Summit 230 kV line near Summit, with one shot reclosing after 20 cycles.
FLT16_1PH	Single phase fault on Morris County – Summit 230 kV line near Summit, with one shot reclosing after 20 cycles.
FLT17_3PH	Three phase fault on Knoll – Redline 115 kV line near Knollr, with one shot reclosing after 15 cycles.
FLT18_1PH	Single phase fault on Knoll – Redline 115 kV line near Knollr, with one shot reclosing after 15 cycles.
FLT19_3PH	Three phase fault on Jeffrey Energy Center – Morris County 345 kV line near Morris County, with one shot reclosing after 30 cycles.
FLT20_1PH	Single phase fault on Jeffrey Energy Center – Morris County 345 kV line near Morris County, with one shot reclosing after 30 cycles.
FLT21_3PH	Three phase fault on Lang – Morris County 345 kV line near Lang, with one shot reclosing after 15 cycles.
FLT22_1PH	Single phase fault on Lang – Morris County 345 kV line near Lang, with one shot reclosing after 15 cycles.

FLT23_3PH	Three phase fault on Lang – Wichita 345 kV line near Wichita, with one shot reclosing after 15 cycles.
FLT24_1PH	Single phase fault on Lang – Wichita 345 kV line near Wichita, with one shot reclosing after 15 cycles.

Table 1: Study Cases

In all of the simulations, the fault duration was considered to be 5 cycles.

4. SIMULATION MODEL

The customer requested to use Gamesa G87-2.0 MW Wind turbines for the System Impact Study. These wind turbines are a three phase double fed induction generator. The following are the main electrical parameters of the Gamesa G87-2.0 MW wind turbine.

Rated Power : 2.0 MW
Voltage : 690 V ac
Rated Power Factor : 1.0

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-2004-016 modeled.

Table 2 provides the number of G87-2.0 MW wind generators modeled as equivalents at each collector buses of the wind farm.

Collector Bus	No. of generators aggregated
C15	2
C9	4
C4	4
C5	1
C8	3
C11	1
C21	1
C20	1
C26	5
C18	8
C32	1

C33	1
C45	5
C42	6
C36	1
C19	1
C54	1
C51	4
C55	1
C56	1
C59	3
C50	5
C62	1
C68	6
C71	4
C75	4

Table 2 : Equivalent Generators with Gamesa G87-2.0 MW Turbines

The following transmission line parameters, as provided by the Customer, were used in the model for the underground lines within the Wind Farm and also between the Wind Farm and the Switching Station:

Line resistance : 0.147 ohms per km for 750 kcmil 34.5 kv cable
0.156 ohms per km for 500 kcmil 34.5 kv cable
0.0917 ohms per km for 1000 kcmil 34.5 kV cable
0.734 ohms per km for 1/0 AWG 34.5 kV cable

Line reactance : 0.21 ohms per km for 750 kcmil 34.5 kv cable
0.29 ohms per km for 500 kcmil 34.5 kv cable
0.21 ohms per km for 1000 kcmil 34.5 kV cable
0.32 ohms per km for 1/0 AWG 34.5 kV cable

Line capacitance : 0.288 µF per km for 750 kcmil 34.5 kv cable
0.235 µF per km for 500 kcmil 34.5 kv cable
0.315 µF per km for 1000 kcmil 34.5 kV cable
0.1424 µF per km for 1/0 AWG 34.5 kV cable

The Customer also provided the following substation transformer's impedance:

Transformer Impedance : 9.6 % at 95 MVA

The prior queued projects Gen-2002-004 of 200 MW, Gen-2002-026 of 121 MW, Gen-2003-019 of 250 MW, Gen-2004-010 of 300 MW and Gen-2004-014 of 154.5 MW were also included in the study model.

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 25 MVAR capacitors would be needed in the summer peak load case. This additional capacitors were included in the study.

Gen-2004-016 was modeled using the Gamesa G87-2.0 MW wind turbine model in PSS/E using the dynamic models supplied by the Customer. The data used in the study is as noted in Table 3.

Figure 2 shows the 100% base case power flow for the project GEN-2004-016.

Description	Value
Stator resistance, Ra	0.0102 pu
Stator inductance, La	0.1428 pu
Mutual inductance, Lm_D	7.2114 pu
Mutual inductance, Lm_Y	6.9453 pu
Rotor resistance	0.0101 pu
Rotor inductance	0.175 pu

Table 3 : Gamesa G87-2.0 MW Wind Turbine Generator Parameters

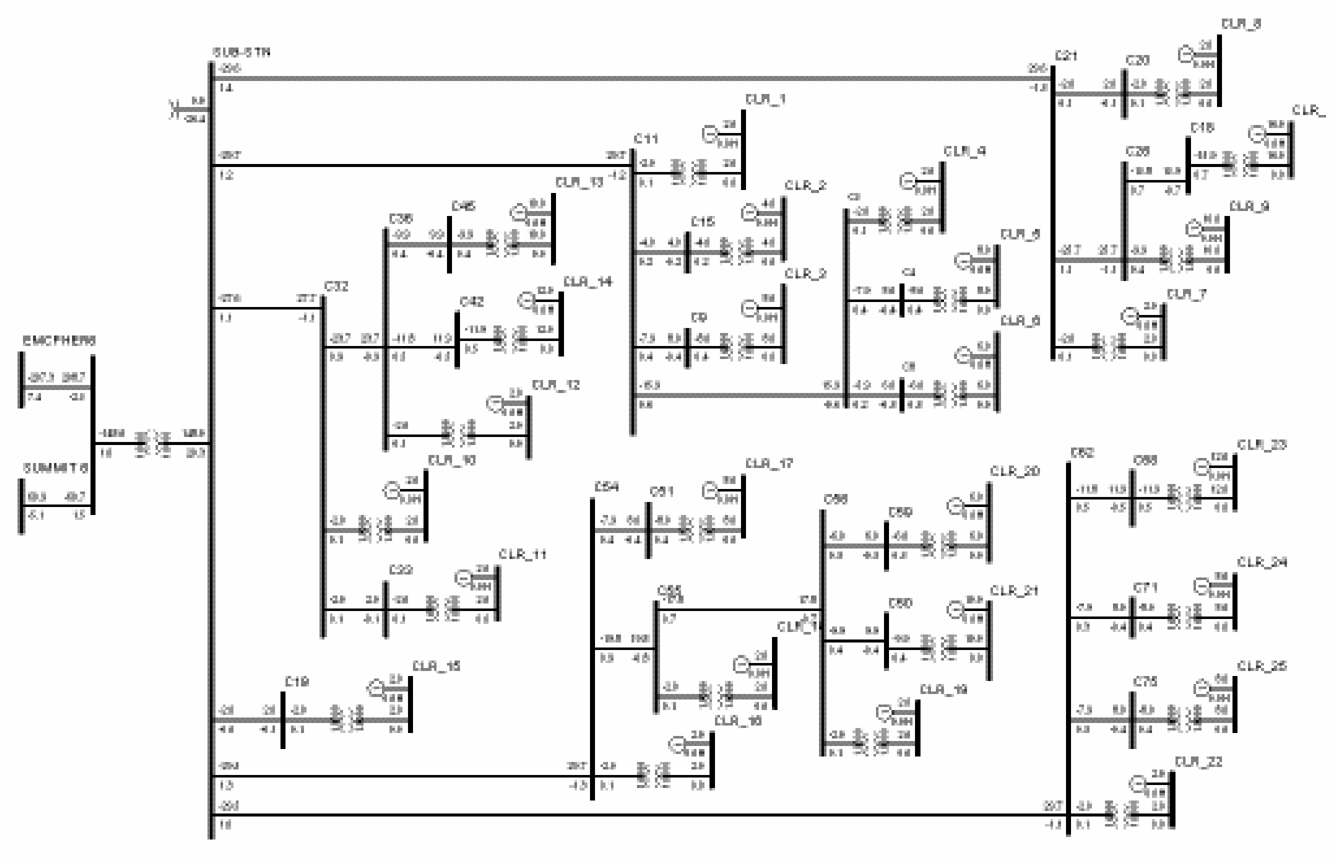

Figure 2 : 100% Power Flow Base Case for GEN-2004-016

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 dynamic models used for the Gamesa wind turbines were supplied by the Customer.
3. The protection settings considered for Gamesa wind turbines were supplied by the Customer as and are shown in Table 4.
4. The protection settings for the prior queued projects were considered to be the standard package offered by the respective manufacturers.
5. 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	62.0 Hz	0 seconds
Under Frequency	57.0 Hz	0 seconds
Under Voltage	15%	0.04 seconds
Under Voltage	30%	0.625 seconds
Under Voltage	45%	1.1 seconds
Under Voltage	60%	1.575 seconds
Under Voltage	75%	2.05 seconds
Under Voltage	90%	2.55 seconds
Over Voltage	110%	0.06 second

Table 4 : Protective Functions and Settings for Gamesa G87-2.0 MW Turbines

Scenario	Generation within SPP	
	Summer	Fall
Without the Wind Farms	38,027 MW	25,173 MW
Gen-2004-016 at 100% output with the prior queued projects	36,883 MW	24,030 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 for Gen-2004-016.

Fault Number	Summer Peak Load Level	Fall Light Load Level
FLT1_3PH	PQ	UV,PQ
FLT2_1PH	- -	PQ
FLT3_3PH	- -	
FLT4_1PH	- -	- -
FLT5_3PH	- -	- -
FLT6_1PH	- -	- -
FLT7_3PH	- -	
FLT8_1PH	- -	- -

FLT9_3PH	- -	
FLT10_1PH	- -	- -
FLT11_3PH	- -	
FLT12_1PH	- -	- -
FLT13_3PH	PQ	PQ
FLT14_1PH	- -	- -
FLT15_3PH	PQ	UV,PQ
FLT16_1PH	- -	- -
FLT17_3PH	- -	PQ
FLT18_1PH	- -	- -
FLT19_3PH	- -	PQ
FLT20_1PH	- -	- -
FLT21_3PH	- -	- -
FLT22_1PH	- -	- -
FLT23_3PH	- -	- -
FLT24_1PH	- -	- -

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
PQ : Prior queued project Gen-2003-019 tripped

Table 6 : Stability Study Results Summary

Gen-2004-016 generators were found to be tripped for the following faults:

- FLT1_3PH : Three phase fault on Wind Farm Switching Station – Summit 230 kV line, near Summit.
- FLT15_3PH : Three phase fault on Morris County – Summit 230 kV line, near Summit.

The voltages at the wind generator terminals were found to be lower than the permissible levels for the above contingencies and hence the generators were found to be tripped by the under voltage relays. The Gen-2004-016 generators were found to stay connected to the grid for the remaining contingencies.

The prior queued project Gen-2003-019 was found to be tripped for a number of cases as indicated in Table 6. Manufacturer's standard protection package was considered in the study for Gen-2003-019 wind turbine generators which did not have "Low Voltage Ride Through" facility. SPP Generation Interconnection Study Report "Impact Study for

Generation Interconnection Request Gen-2003-019" has recommended special protection package AG04 for the Gen-2003-019 wind turbine generators.

Figure 3 shows the system response for FLT2_1PH case.

The simulation results of both peak and light load cases indicated that there was no stability problem associated with the project GEN-2004-016 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-2004-016 with its output at 150 MW consisting of Gamesa G87-2.0 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-2004-016 generators would be disconnected for three phase fault near Summit 230 kV bus.

The Interconnection Customer shall consider this additional risk implication of wind farm outages that the wind turbine under voltage control scheme may cause to the wind farm.

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. 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-2004-016

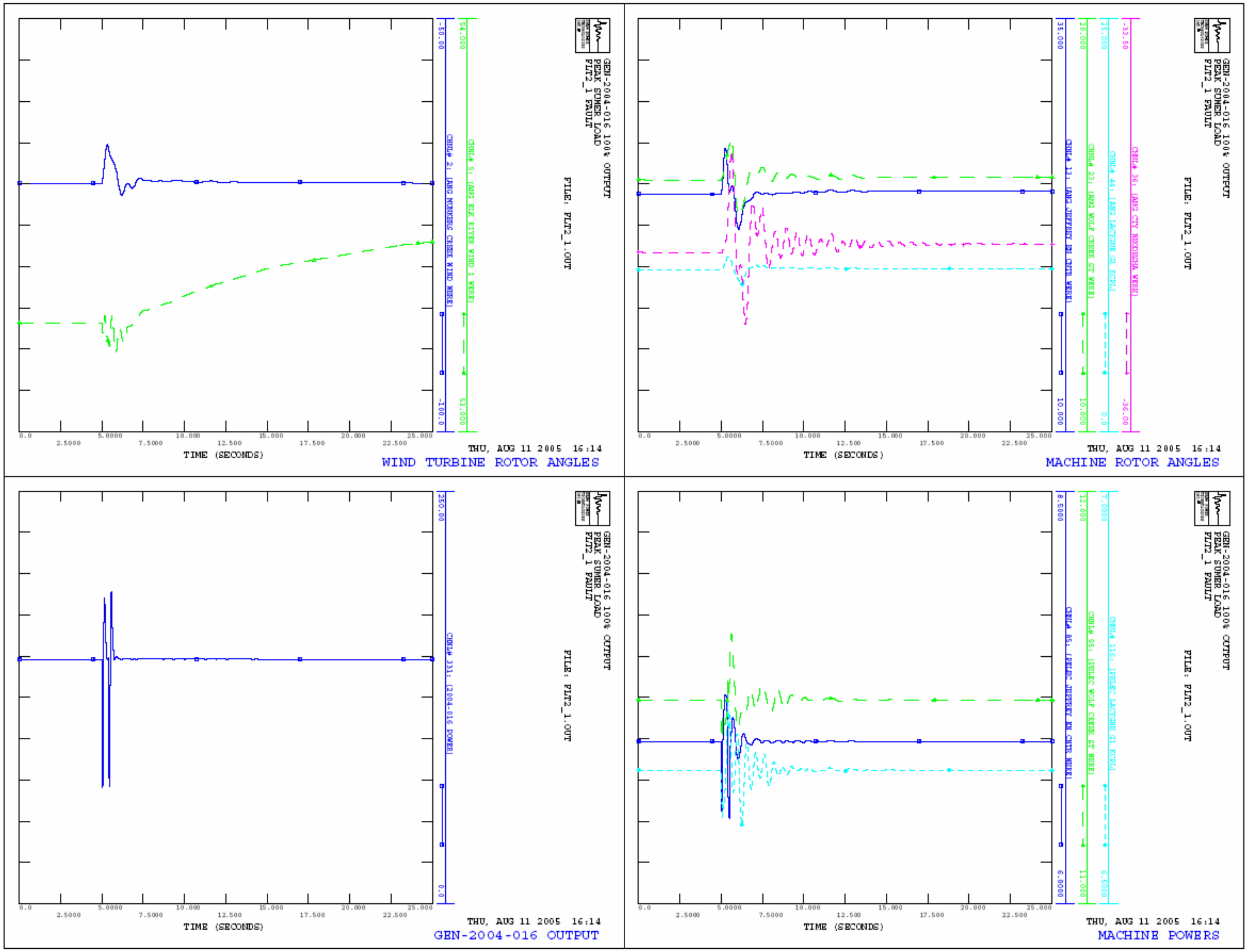

Figure 3 : System Responses with 100% output of Gen-2004-016 (Cont'd)