Southwest Power Pool

Impact Study for Generation Interconnection Request GEN – 2002 – 022

SPP Coordinated Planning
(#GEN-2002-022)

August 2005

1 Summary

ABB performed the following Study at the request of the Southwest Power Pool (SPP) for Generation Interconnection request Gen-2002-022. 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, ABB 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.

IMPACT STUDIES FOR GENERATION INTERCONNECTION REQUEST GEN-2002-022

Prepared for: SOUTHWEST POWER POOL

Final Report

REPORT NO.: Consulting 2005-11070-1

August 5, 2005

Submitted by:

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Southwest Power Pool	**No. 2005-11070-1**		
Title: Interconnection Impact Studies for Generation Interconnection Request (GEN-2002-022)	**Dept.** ESC	**Date** August 5, 2005	**Pages** 33

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Reviewer: **William Quaintance**

Summary

Southwest Power Pool (SPP) has requested ABB to perform an interconnection impact study of a new 240 MW wind farm in Oldham County, Texas. The proposed plant will be connected to the Xcel Energy (SPS) transmission system at the Bushland Interchange. The wind farm developer requested that the studies be performed using two different types of wind turbine technologies: Gamesa G87 and the Bonus Mk II. The proposed wind farm has previously been studied assuming wind turbines from Mitsubishi, GE, and Vestas.

Based on the results of the stability analysis, it is concluded that the interconnection of the wind farm at 240 MW with either Gamesa G87 or Bonus Mk II turbines does not adversely impact the stability of the SPP system. The wind farm stays online for all the faults simulated. The present low-voltage ride-through capability of the Bonus Mk II and Gamesa models should suffice for the GEN-2002-022 wind farm to avoid unnecessary and nuisance tripping of generation following transmission faults.

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.

Rev. #	**Revision**	**Date**	**Author**	**Reviewed**	**Approved**
DISTRIBUTION: John E. Mills, Southwest Power Pool					

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2 INTRODUCTION

SPP has requested an interconnection impact study for interconnecting a 240 MW wind farm in Oldham County, Texas. The wind farm will be connected to the Xcel Energy (SPS) transmission system at the existing Bushland Interchange. The generation developer requested that the impact study be conducted using two types of wind turbine generators: Gamesa G87 and Bonus Mk II machines. The feasibility (power flow) study was not performed as a part of this study.

The objective of the impact study is to evaluate the impact on system stability after connecting the 240 MW wind farm to the interconnection point and its effect on the nearby transmission system and generating stations. The study is performed on two system scenarios: 2006 Winter Case and the 2009 Summer Case provided by SPP. The new wind farm is modeled accurately to represent the collector system (Figure 1.1) and the study is performed by using 2 equivalent machines of 160 MW and 80 MW on the two 34.5 kV feeders. Figure 1.1 shows the topology of the new generator interconnection.

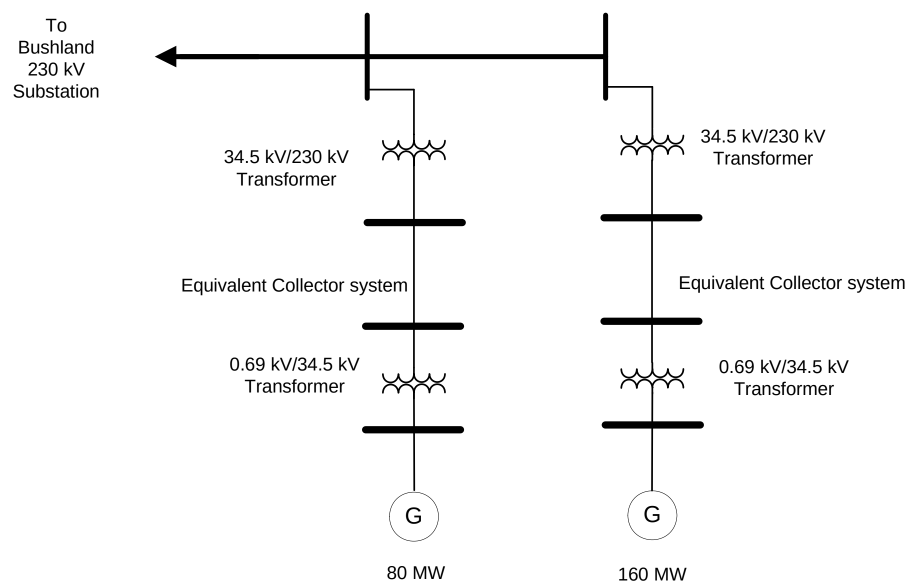

Figure 1.1: Proposed Interconnection of Wind Farm at Bushland 230 kV

3 STABILITY ANALYSIS

In this stability study, ABB investigated the stability of the system for faults in the vicinity of the proposed plant as defined by SPP. The faults involve three-phase and single-phase faults cleared by primary protection, reclosing with the fault still on, and then permanently clearing the fault with primary protection.

3.1 Stability Analysis Methodology

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 differences of the angular positions of synchronous machine rotors become constant following an aperiodic system disturbance."

Stability analysis was performed using PTI's PSS/E dynamics program V29. All the stability simulations were performed by modeling the new wind machines using the Gamesa G87 and the Bonus Mk II models.

Disturbances such as three-phase and single-phase line faults were simulated for the specified durations, including reclosing, and the synchronous machine rotor angles were monitored to make sure they maintained synchronism following the fault removal.

Single-phase line faults were simulated with the standard method of applying fault impedance to the positive sequence network to represent the effect of the negative and zero sequence networks on the positive sequence network. The fault impedance was computed to give a positive sequence voltage at the fault location of approximately 60% of pre-fault voltage, which is a typical value.

The ability of the wind generators to stay connected to the grid during the disturbances and during the fault recovery was also monitored. This is primarily determined by their low-voltage ride-through capabilities, or lack thereof, as represented in the models by low-voltage trip settings. Both the models of Gamesa G87 and Bonus Mk II units were equipped with over/under voltage relays and over/under frequency relays. All the faults that resulted in the tripping of the proposed wind farm were rerun with the tripping disabled to verify the stability of the farm.

3.2 Study Model Development

The study model consists of power flow cases and dynamics databases, developed as follows.

Collector System Development:

The developer provided a detailed layout of the wind farm collector system and wind turbine generators. While it is not practical to model 160, 1.5 MW generators in the case of Gamesa G87 and 105, 2.3 MW generators in the case of Bonus Mk II for the power systems stability analysis, the detailed data was used to calculate two equivalent machines of 160 MW and 80 MW on the two main feeders for the 240 MW plant (Figure 1.1). The detailed plant layout was modeled in PSS/E power flow, and short-circuit analysis was used to determine the Thevenin equivalent impedance of the wind farm at the low side of the substation transformers. This impedance was separated into three parts: an equivalent generator step-up transformer, equivalent source impedance, and the remainder representing an equivalent 34.5 kV collector system impedance[1]. An equivalent line charging capacitance is added to the equivalent collector impedance to give the same Mvar injection at the substation in the equivalent model as in the detailed model. This equivalent charging is 0.00813 and 0.01626 per unit at the 80 and 160 MW substations, respectively, for the Gamesa model, and 0.00753 and 0.01546 per unit for the Bonus model.

Appendix A shows the wind farm equivalent model data used for the load flow case development.

The load flow data for the equivalent machines is obtained from the iplan program for modeling the Gamesa G87 machines, and the data to model the Bonus Mk II equivalent machines were obtained from the package provided by SPP.

Power Flow Cases Development:

SPP provided two PSS/E power flow cases called "SPP_2006_Winter_stability.sav" representing the winter conditions of the SPP system for the year 2006 and the "SPP_2009_Summer_stability.sav" representing the summer conditions of the SPP system for the year 2009. The cases provided were updated to make them compatible with the dynamics database provided. The changes made to the cases are captured in idev files and are listed in Appendix A.3. These changes are necessary to prevent initial condition suspects and initialization errors during dynamic simulations.

The GEN 2002-019 wind farm comprising 162 MW of GE DFIG wind turbines was added to the base cases provided by SPP to build the pre-project cases. The resulting cases were used as the base cases for the GEN-2002-022 study.

Wind farm modeling:

The proposed wind farm is modeled in the load flow cases as two equivalent wind turbine generators having capacities of 80 MW and 160 MW. Each of the equivalent machines has a generator step-up transformer (GSU) modeled as a lumped equivalent as shown in Figure 1.1. Two substation transformers of required capacity are modeled as per the data provided by SPP. The wind turbine generator is modeled at unity power factor i.e., not to generate any reactive power. Transformer taps are adjusted as necessary to obtain a good voltage profile across the wind farm. Additional substation capacitors are placed on the 34.5 kV substation buses to maintain a near-unity power factor at the point of interconnection. For the Bonus design, 18 Mvar of capacitors were placed at the 80 MW substation and 31 Mvar at the 160 MW substation. For the Gamesa design, 22 and 35 Mvar were added at the two substations, respectively.

Stability Case Development

SPP provided the stability database in the form of a PSS/E dynamic raw data file "SPP_2006_Winter_stability.dyr" to model the winter stability dynamics database for 2006 and "SPP_2009_Summer_stability.dyr" to model the summer stability dynamics database for the year 2009.

[1] This separation of the Thevenin equivalent is purely aesthetic. For example, if the impedance of all the *individual* GSU transformers were to change, it would not be sufficient to simply change the impedance of the *equivalent* GSU transformer. One would need to change the individual GSU impedances in the detailed model and recalculate the Thevenin impedance. Subtracting out the new equivalent GSU impedance would leave a new and different equivalent collector system impedance. The only instance where one can expect the equivalent collector impedance to stay the same when changing the GSUs is if all wind generators were identically distant in impedance from the substation, which is rarely the case.

Along with the above-mentioned files, idev and batch files were also provided to compile and link user-written models. The provided files required the use of PSS/E version 29.

The latest PSS/E DFIG dynamic model was used to model the 2002-019 wind farm which is a 162 MW plant at a tap on the Grapevine to Nichols 230 kV line. The PSS/E DFIG model requires execution of an IPLAN program to create the GSU and to create the generator on the low side (0.575 kV). This IPLAN program also generates a dynamic data file (*.dyr) for the DFIG machines. The direct dispatch (100.0%) for MW generation and voltage control mode for Mvar generation were used. The under-voltage and frequency trip settings have been retained. The cases developed after the addition of the 2002-019 plant were used as the base cases for the study of the proposed wind farm (2002-022). The proposed wind farm was added to the base cases to develop the cases used for the study.

The dynamics database for the year 2006 and the 2006 winter load flow case were adjusted to overcome network non-convergence during the simulation of some of the faults (FLT-3_3PH, FLT-9_1PH, FLT-10_3PH, and FLT-12_3PH). The Miles City and Lamar DC lines were equivalenced, in the 2006 Winter case only, because they were causing problems for the simulations. This case was used as a base for the year 2006 for the addition of the new plant.

The Gamesa G87 type of wind turbine was added to the case by running the IPLAN program from the package provided by SPP. The dynamic data file (*.dyr) is appended to the pre-project dynamic database to develop the stability database with the new wind generation. The Bonus Mk II model data was also added to the pre-project database to create the databases with the new generation. Dynamic data for the equivalent 160 MW and 80 MW Gamesa and Bonus generator models are listed in Appendix B.

The dynamic model provided for the Bonus machines is very preliminary, evidenced by its version label of "V1.02 Alpha", and needs a lot of work. One problem found is that the model does not report to PSS/E its usage of model constants, states, and variables. As a result, if channels are added with default entries, the Bonus dynamic model and the channels will attempt to use the same array locations and write over each other's data. In addition, the DOCU report from the Bonus machine does not list all of the input constants. It is recommended that SPP require a fully working dynamic model before the Bonus machines can connect to the system.

Finally, four cases were developed by adding each type of generator model (Bonus Mk II and Gamesa G87) to the two pre-project cases established:

SPP_2006_Winter_stability-Gamesa-022.sav
SPP_2006_Winter_stability-Bonus-022.sav
SPP_2009_Summer_stability-Gamesa-022.sav
SPP_2009_Summer_stability-Bonusa-022.sav

Figures 2.1-2.4 illustrate the power flows for the region near the proposed wind farm for all the GEN-2002-022 cases developed.

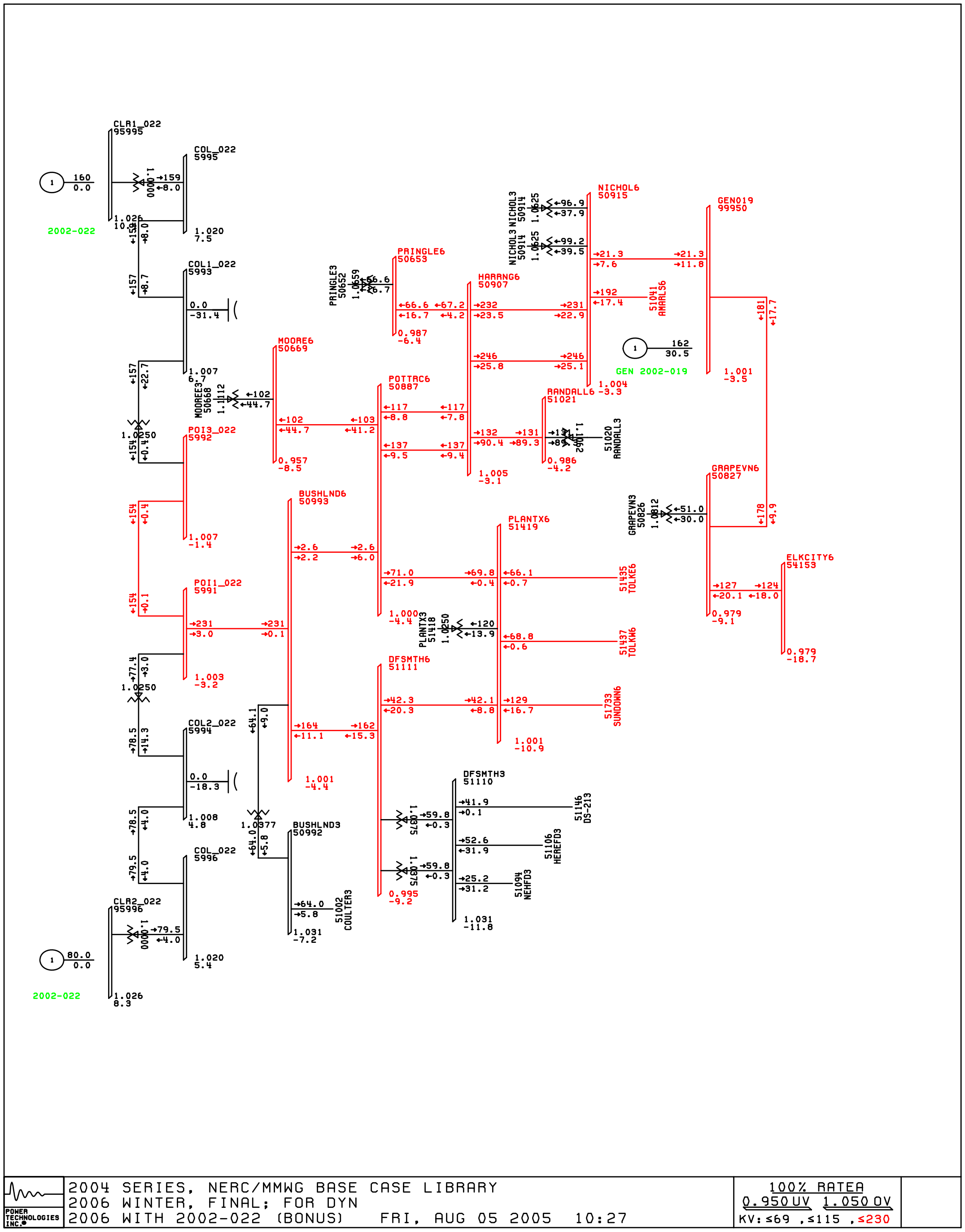

Figure 2.1: 2006 Winter case with 2002-022 (Bonus Mk II Model)

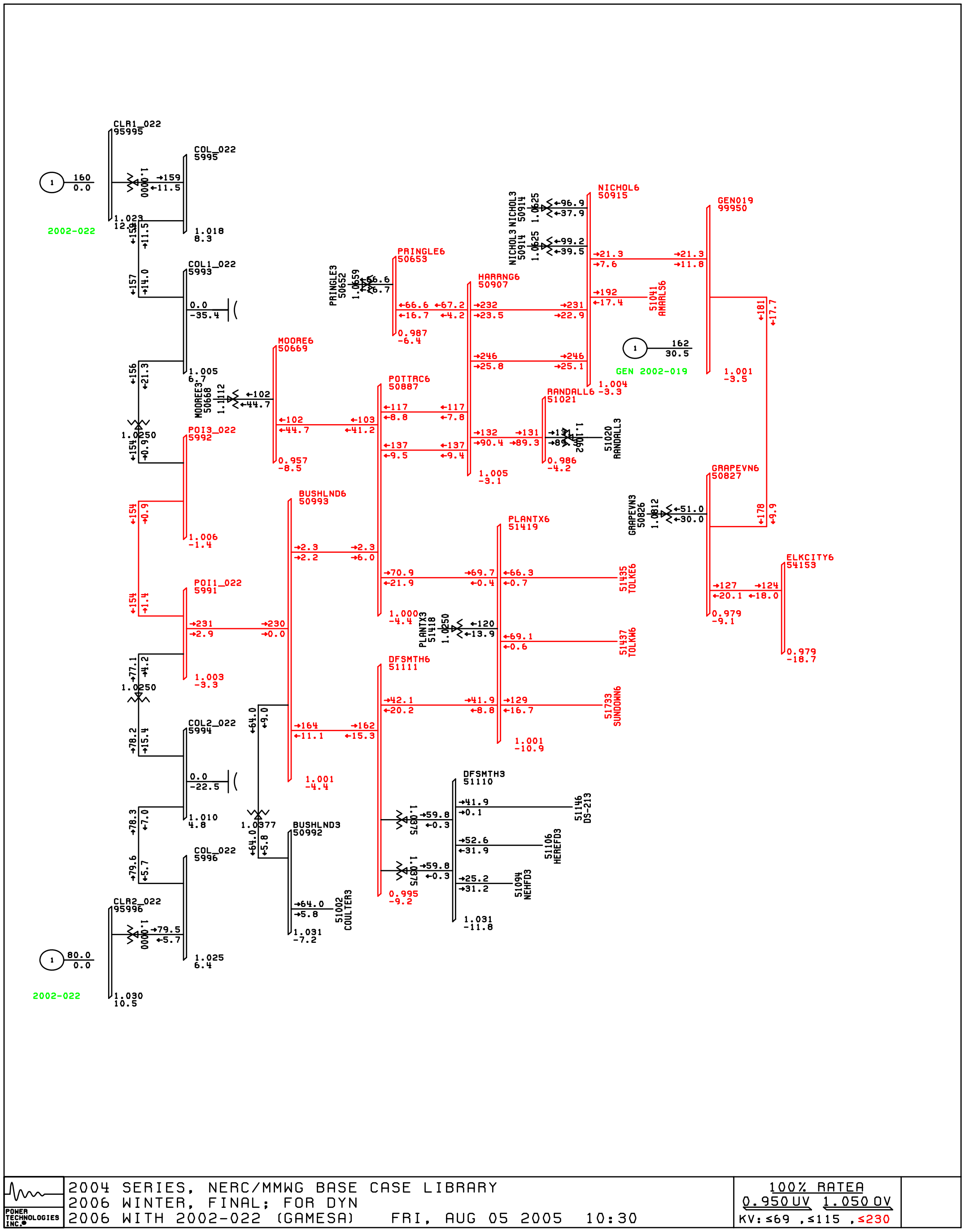

Figure 2.2: 2006 Winter case with 2002-022 (Gamesa G87 Model)

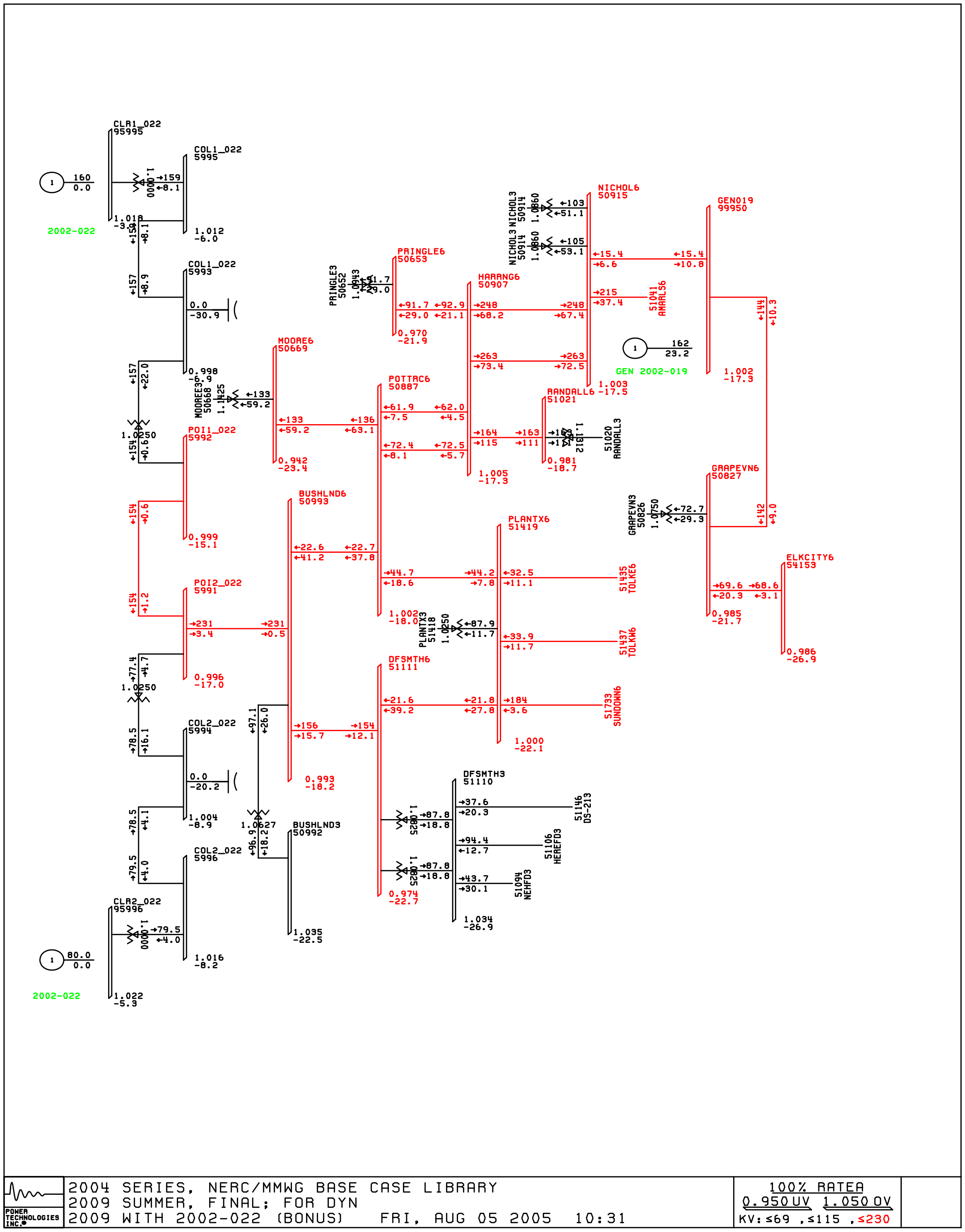

Figure 2.3: 2009 Summer case with 2002-022 (Bonus Mk II Model)

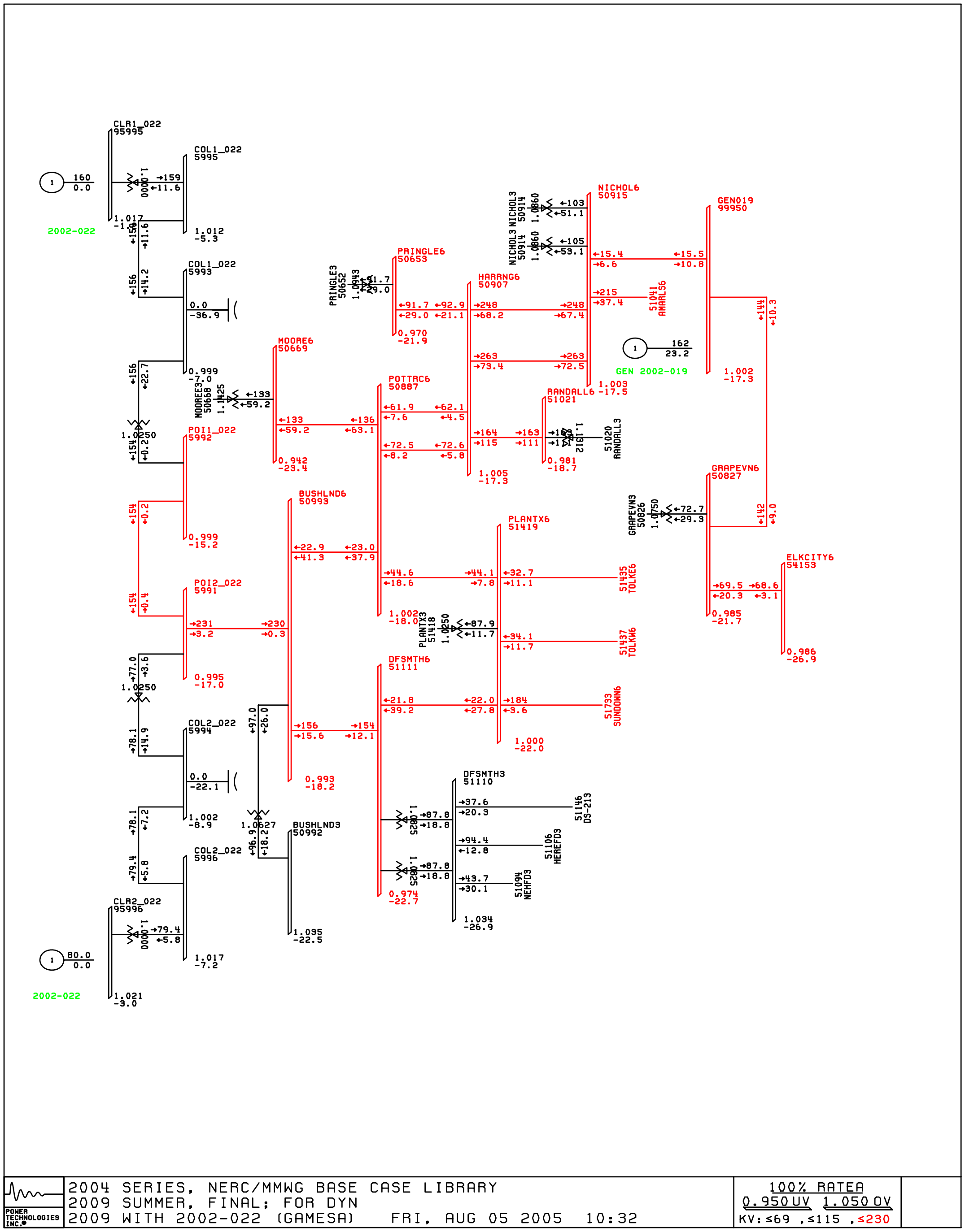

Figure 2.4: 2009 Summer case with 2002-022 (Gamesa G87 Model)

Low voltage ride through capability:
It is important to note that the PSS/E Gamesa model and the Bonus model include under / over-voltage and frequency trip relays in the model. The under voltage settings are the most critical. The following voltage settings were obtained from the model packages supplied by SPP.

Table 1. Gamesa G87 Voltage Trip Settings

Under / Over voltage settings (per unit)	Time Delay (seconds)
0.15	0.040
0.30	0.625
0.45	1.100
0.60	1.575
0.75	2.050
0.90	2.550
1.10	0.060

Table 2. Bonus Mk II Voltage Trip Settings

Under / Over voltage settings (per unit)	Time Delay (seconds)
0.15	0.625
0.90	3.000
1.10	1.000
1.20	0.200

Contingencies Tested

Ten three-phase and seven single-phase line faults were simulated on branches connected to Bushland Interchange and surrounding stations. An additional fault at Bushland on the line to Deaf Smith is also simulated along with the faults supplied by SPP. All transmission lines were assumed to have reclosing enabled. The complete fault descriptions are included in Table 3.

Table 3: Description of Faults with Wind Farm at 240MW

FAULT	FAULT DESCRIPTION
FLT1-3PH 3-phase Fault	**FAULT ON THE POTTER COUNTY (50887) – BUSHLAND (50993), 230KV LINE, NEAR POTTER.**
	a. Apply Fault at the Potter Bus (50887).
	b. Clear Fault after 5 cycles by removing the line from 50887 - 50993.
	c. Wait 20 cycles, and then re-close the line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT2-1PH 1-phase Fault	**FAULT ON THE POTTER COUNTY (50887) – BUSHLAND (50993), 230KV LINE, NEAR POTTER.**
	a. Apply Fault at the Potter Bus (50887).
	b. Clear Fault after 5 cycles by removing the line from 50887 - 50993.
	c. Wait 20 cycles, and then re-close the line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT3-3PH 3-phase Fault	**FAULT ON THE POTTER COUNTY (50888) – FINNEY SWITCH STATION (50858) 345KV LINE, NEAR FINNEY.**
	a. Apply fault at the Finney bus (50858).
	b. Clear fault after 5 cycles by removing the line from 50888 – 50858.
	c. Wait 30 cycles, and then re-close line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT4-3PH 3-phase Fault	**FAULT ON THE BUSHLAND (50992) – COULTER (51002) 115KV LINE, NEAR COULTER.**
	a. Apply fault at the Coulter bus (51002).
	b. Clear fault after 5 cycles by removing line from 50992 – 51002.
	c. Wait 20 cycles, and then re-close line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT5-1PH 1-phase Fault	**FAULT ON THE BUSHLAND (50992) – COULTER (51002) 115KV LINE, NEAR COULTER.**
	a. Apply fault at the Coulter bus (51002).
	b. Clear fault after 5 cycles by removing line from 50992 – 51002.
	c. Wait 20 cycles, and then re-close line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT6-3PH 3-phase Fault	**FAULT ON THE HARRINGTON (50907) – RANDALL INTERCHANGE (51021) 230KV LINE, NEAR RANDALL.**
	a. Apply fault at the Randall bus (51021).
	b. Clear fault after 5 cycles by removing the line from 50907 – 51021.
	c. Wait 20 cycles, and then re-close line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT7-1PH 1-phase Fault	**FAULT ON THE HARRINGTON (50907) – RANDALL INTERCHANGE (51021) 230KV LINE, NEAR RANDALL.**
	a. Apply fault at the Randall bus (51021).
	b. Clear fault after 5 cycles by removing the line from 50907 – 51021.
	c. Wait 20 cycles, and then re-close line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

FAULT	FAULT DESCRIPTION
FLT8-3PH 3-phase Fault	**FAULT ON THE BUSHLAND (50993) – DEAF SMITH (51111) 230KV LINE, NEAR DEAF SMITH.**
	a. Apply fault at the Deaf Smith bus (51111).
	b. Clear fault after 5 cycles by removing the line from 50993 - 51111.
	c. Wait 20 cycles, and then re-close the line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove the fault.
FLT9-1PH 1-phase Fault	**FAULT ON THE BUSHLAND (50993) – DEAF SMITH (51111) 230KV LINE, NEAR DEAF SMITH.**
	a. Apply fault at the Deaf Smith bus (51111).
	b. Clear fault after 5 cycles by removing the line from 50993 - 51111.
	c. Wait 20 cycles, and then re-close the line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove the fault.
FLT10-3PH 3-phase Fault	**FAULT ON THE GRAPEVINE (50827) – ELK CITY (54153) 230KV LINE, NEAR ELK CITY.**
	a. Apply fault at the Elk City bus (54153).
	b. Clear fault after 5 cycles by removing line from 54153 - 50827.
	c. Wait 20 cycles, and then re-close line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT11-1PH 1-phase Fault	**FAULT ON THE GRAPEVINE (50827) – ELK CITY (54153) 230KV LINE, NEAR ELK CITY.**
	a. Apply fault at the Elk City bus (54153).
	b. Clear fault after 5 cycles by removing line from 54153 - 50827.
	c. Wait 20 cycles, and then re-close line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT12-3PH 3-phase Fault	**FAULT ON THE WOLFFORTH INTERCHANGE (51762) – TERRY COUNTY (51830) 115KV LINE, NEAR TERRY COUNTY.**
	a. Apply fault at the Terry County bus (51830).
	b. Clear fault after 5 cycles by removing line from 51762 -51830.
	c. Wait 20 cycles, and then re-close line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT13-1PH 1-phase Fault	**FAULT ON THE WOLFFORTH INTERCHANGE (51762) – TERRY COUNTY (51830) 115KV LINE, NEAR TERRY COUNTY.**
	a. Apply fault at the Terry County bus (51830).
	b. Clear fault after 5 cycles by removing line from 51762 -51830.
	c. Wait 20 cycles, and then re-close line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT14-3PH 3-phase Fault	**FAULT ON THE POTTER COUNTY (50887) – BUSHLAND (50993) 230KV LINE, NEAR BUSHLAND.**
	a. Apply fault at the Bushland bus (50993).
	b. Clear fault after 5 cycles by removing the line from 50887 - 50993.
	c. Wait 20 cycles, and then re-close the line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove the fault.
FLT15-1PH 1-phase Fault	**FAULT ON THE POTTER COUNTY (50887) – BUSHLAND (50993) 230KV LINE, NEAR BUSHLAND.**
	a. Apply fault at the Bushland bus (50993).
	b. Clear fault after 5 cycles by removing the line from 50887 - 50993.
	c. Wait 20 cycles, and then re-close the line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove the fault.

FAULT	FAULT DESCRIPTION
FLT16-3PH 3-phase Fault	**FAULT ON THE BUSHLAND (50993) 230/115KV TRANSFORMER**
	a. Apply fault at the Bushland (50993) 230/115 transformer.
	b. Clear fault after 5 cycles by removing the 230/115 kV transformer.
	c. Wait 20 cycles, and then re-close the 230/115 kV transformer (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove the fault.
FLT17-3PH 3-phase Fault	**FAULT ON THE BUSHLAND (50993) – DEAF SMITH (51111) 230KV LINE, NEAR BUSHLAND.**
	a. Apply fault at the Bushland bus (50993).
	b. Clear fault after 5 cycles by removing the line from 50993 - 51111.
	c. Wait 20 cycles, and then re-close the line in (b) into the fault.
	d. Leave fault on for 5 cycles, then trip the line in (b) and remove the fault.

3.3 Stability Results

Results for all the disturbances simulated are summarized in Tables 4 and 5. The results indicate that the system and all generators are stable following all the faults. In addition, the new wind farm at Bushland does not trip for any of the faults simulated due to its *undervoltage* trip settings (See Table 1 and Table 2 in the previous section) incorporated as per the information provided by the developer.

The frequency tripping of the Gen-2002-022 wind generators during a 3-phase fault at Bushland (fault 14) was observed when the machines were modeled using Gamesa G87 on the 2009 summer case. PSS/E is not capable of calculating accurate frequencies during three-phase bolted fault conditions and the wind farm in reality would probably not trip on under-frequency. Fault 14 was repeated with the frequency tripping disabled to verify wind farm stability, and the system remained stable following the fault.

In the case of Gamesa and Bonus Models, the low voltage ride through capability settings enable the new wind farm to be online following the 3-phase and single phase faults.

Currently the PSS/E model does not consider cumulative low-voltage time caused by one or more reclosings. However, cumulative fault time in a short time span may indeed be important in determining true low-voltage ride-through capability. To study this phenomenon in detail, a three-phase electromagnetic transient study may be needed, along with more information from the wind turbine manufacturer. This issue is relevant to all wind turbines close to transmission lines with reclosing.

Simulation plots for all fault cases are shown in Appendix E.

All the faults simulated on the 2006 and 2009 cases with the Gamesa models and also with Bonus models were stable.

Table 4: Summary of Fault Results with Gamesa G87 Turbines

FAULT	FAULT DEFINITION	2006 Winter	2009 Summer
FLT1-3PH	FAULT ON THE POTTER COUNTY (50887) - BUSHLAND (50993), 230KV LINE, NEAR POTTER.	STABLE	STABLE
FLT2-1PH	FAULT ON THE POTTER COUNTY (50887) - BUSHLAND (50993), 230KV LINE, NEAR POTTER.	STABLE	STABLE
FLT3-3PH	FAULT ON THE POTTER COUNTY (50888) - FINNEY SWITCH STATION (50858) 345KV LINE, NEAR FINNEY.	STABLE	STABLE
FLT4-3PH	FAULT ON THE BUSHLAND (50992) - COULTER (51002) 115KV LINE, NEAR COULTER.	STABLE	STABLE
FLT5-1PH	FAULT ON THE BUSHLAND (50992) - COULTER (51002) 115KV LINE, NEAR COULTER.	STABLE	STABLE
FLT6-3PH	FAULT ON THE HARRINGTON (50907) - RANDALL INTERCHANGE (51021) 230KV LINE, NEAR RANDALL.	STABLE	STABLE
FLT7-1PH	FAULT ON THE HARRINGTON (50907) - RANDALL INTERCHANGE (51021) 230KV LINE, NEAR RANDALL.	STABLE	STABLE
FLT8-3PH	FAULT ON THE BUSHLAND (50993) - DEAF SMITH (51111) 230KV LINE, NEAR DEAF SMITH.	STABLE	STABLE
FLT9-1PH	FAULT ON THE BUSHLAND (50993) - DEAF SMITH (51111) 230KV LINE, NEAR DEAF SMITH.	STABLE	STABLE
FLT10-3PH	FAULT ON THE GRAPEVINE (50827) - ELK CITY (54153) 230KV LINE, NEAR ELK CITY.	STABLE	STABLE
FLT11-1PH	FAULT ON THE GRAPEVINE (50827) - ELK CITY (54153) 230KV LINE, NEAR ELK CITY.	STABLE	STABLE
FLT12-3PH	FAULT ON THE WOLFFORTH INTERCHANGE (51762) - TERRY COUNTY (51830) 115KV LINE, NEAR TERRY COUNTY.	STABLE	STABLE
FLT13-1PH	FAULT ON THE WOLFFORTH INTERCHANGE (51762) - TERRY COUNTY (51830) 115KV LINE, NEAR TERRY COUNTY.	STABLE	STABLE
FLT14-3PH	FAULT ON THE POTTER COUNTY (50887) - BUSHLAND (50993) 230KV LINE, NEAR BUSHLAND.	STABLE	STABLE , GEN-2002-022 Tripped
FLT14-3PH-NT	FAULT ON THE POTTER COUNTY (50887) - BUSHLAND (50993) 230KV LINE, NEAR BUSHLAND., TRIPPING DISABLED.	STABLE	STABLE
FLT15-1PH	FAULT ON THE POTTER COUNTY (50887) - BUSHLAND (50993) 230KV LINE, NEAR BUSHLAND.	STABLE	STABLE
FLT16-3PH	FAULT ON THE BUSHLAND (50993) 230/115KV TRANSFORMER	STABLE	STABLE
FLT17-3PH	FAULT ON THE BUSHLAND (50993) - DEAF SMITH (51111) 230KV LINE, NEAR BUSHLAND.	STABLE	STABLE

Table 5: Summary of Fault Results with Bonus Mk II Wind Turbines

FAULT	FAULT DEFINITION	2006 Winter	2009 Summer
FLT1-3PH	FAULT ON THE POTTER COUNTY (50887) - BUSHLAND (50993), 230KV LINE, NEAR POTTER.	STABLE	STABLE
FLT2-1PH	FAULT ON THE POTTER COUNTY (50887) - BUSHLAND (50993), 230KV LINE, NEAR POTTER.	STABLE	STABLE
FLT3-3PH	FAULT ON THE POTTER COUNTY (50888) - FINNEY SWITCH STATION (50858) 345KV LINE, NEAR FINNEY.	STABLE	STABLE
FLT4-3PH	FAULT ON THE BUSHLAND (50992) - COULTER (51002) 115KV LINE, NEAR COULTER.	STABLE	STABLE
FLT5-1PH	FAULT ON THE BUSHLAND (50992) - COULTER (51002) 115KV LINE, NEAR COULTER.	STABLE	STABLE
FLT6-3PH	FAULT ON THE HARRINGTON (50907) - RANDALL INTERCHANGE (51021) 230KV LINE, NEAR RANDALL.	STABLE	STABLE
FLT7-1PH	FAULT ON THE HARRINGTON (50907) - RANDALL INTERCHANGE (51021) 230KV LINE, NEAR RANDALL.	STABLE	STABLE
FLT8-3PH	FAULT ON THE BUSHLAND (50993) - DEAF SMITH (51111) 230KV LINE, NEAR DEAF SMITH.	STABLE	STABLE
FLT9-1PH	FAULT ON THE BUSHLAND (50993) - DEAF SMITH (51111) 230KV LINE, NEAR DEAF SMITH.	STABLE	STABLE
FLT10-3PH	FAULT ON THE GRAPEVINE (50827) - ELK CITY (54153) 230KV LINE, NEAR ELK CITY.	STABLE	STABLE
FLT11-1PH	FAULT ON THE GRAPEVINE (50827) - ELK CITY (54153) 230KV LINE, NEAR ELK CITY.	STABLE	STABLE
FLT12-3PH	FAULT ON THE WOLFFORTH INTERCHANGE (51762) - TERRY COUNTY (51830) 115KV LINE, NEAR TERRY COUNTY.	STABLE	STABLE
FLT13-1PH	FAULT ON THE WOLFFORTH INTERCHANGE (51762) - TERRY COUNTY (51830) 115KV LINE, NEAR TERRY COUNTY.	STABLE	STABLE
FLT14-3PH	FAULT ON THE POTTER COUNTY (50887) - BUSHLAND (50993) 230KV LINE, NEAR BUSHLAND.	STABLE	STABLE
FLT15-1PH	FAULT ON THE POTTER COUNTY (50887) - BUSHLAND (50993) 230KV LINE, NEAR BUSHLAND.	STABLE	STABLE
FLT16-3PH	FAULT ON THE BUSHLAND (50993) 230/115KV TRANSFORMER	STABLE	STABLE
FLT17-3PH	FAULT ON THE BUSHLAND (50993) - DEAF SMITH (51111) 230KV LINE, NEAR BUSHLAND.	STABLE	STABLE

Comparison of Bonus and Gamesa Parameters:

Figure 2.5 shows the plots for electrical output, var output and the terminal voltage of the 160 MW equivalent machine modeled using Bonus and Gamesa on the 2006 Winter stability case during the simulation of FLT8-3PH.

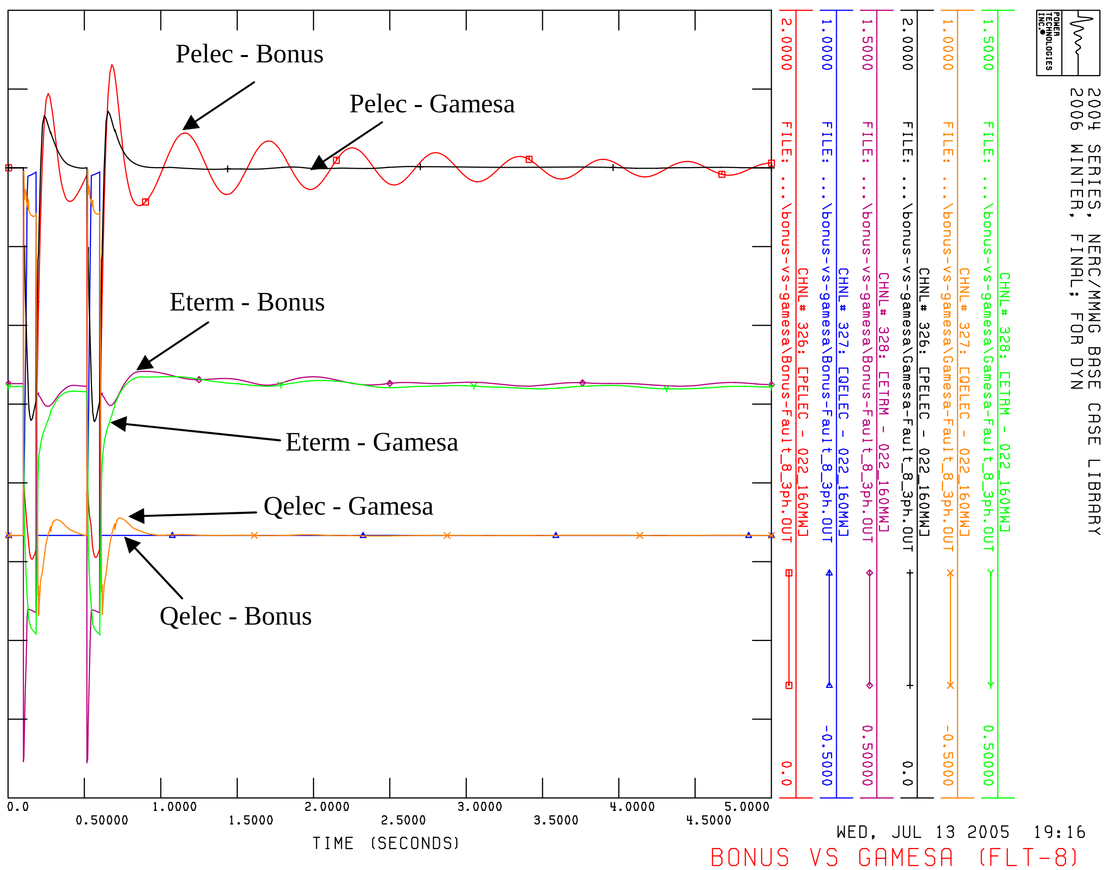

Figure 2.5: Comparison of Bonus Mk II and Gamesa G87 Response

4 STUDY CONCLUSIONS

Based on the results of the stability analysis, it is concluded that the interconnection of the wind farm at 240 MW does not adversely impact the stability of the SPP system. The wind farm (Bonus and Gamesa models) stays online for all the faults simulated. The present low-voltage ride-through capability of the Bonus Mk II and Gamesa models should keep the GEN-2002-022 wind farm on line during most system events, which will avoid unnecessary and nuisance tripping of generation following transmission faults.

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.

APPENDIX A – COLLECTOR SYSTEM

Appendix A.1. Collector System for the Gamesa Machines

Substation Main Transformers data:

Unit 1
100,000/133,300/166,600 kVA
230/34.5/13.8 kV
825/200/110 kV BIL
9.0% @100 MVA base

Unit 2
50,000/666,667/83,333
230/34.5/13.8 kV
825/200/110 kV BIL
9.0% @ 50 MVA

Collector system Equivalent 1:

R = 0.00982
X = 0.01730
B = 0.01626

Collector system Equivalent 2:

R = 0.02160
X = 0.03660
B = 0.00813

GSU Equivalent 1:

2000 kVA times 80 turbines equals 160 MVA
34.5/0.690 kV
150/30 kV BIL
7.5 % @ 160 MVA

GSU Equivalent 2:

2000 kVA times 40 turbines equals 80 MVA
34.5/0.690 kV
150/30 kV BIL
7.5 % @ 80 MVA

Appendix A.2. Collector System for the Bonus Machines

Substation Main Transformers data:

Unit 1
100,000/133,300/166,600 kVA
230/34.5/13.8 kV
825/200/110 kV BIL
9.0% @100 MVA base

Unit 2
50,000/666,667/83,333
230/34.5/13.8 kV
825/200/110 kV BIL
9.0% @ 50 MVA

Collector system Equivalent 1:

R = 0.00926
X = 0.00945
B = 0.01546

Collector system Equivalent 2:

R = 0.01566
X = 0.01281
B = 0.00753

GSU Equivalent 1:

2600 kVA times 70 turbines equals 182 MVA
34.5/0.690
150/30 kV BIL
6.0% @ 182 MVA

GSU Equivalent 2:

2600 kVA times 35 turbines equals 91 MVA
34.5/0.690
150/30 kV BIL
6.0% @ 91 MVA

Appendix A.3. Load Flow Case Changes:

1. 2006 Winter stability case:

```
DSCN
16745
15621
15622
52500

RDCH
1
66569,,,1
59995,,,1
59996,,,1
59998,,,1
56758,,,2

0
37607,'W ',,,,,,,,,0.2300,,
23618,1,124.0,
32287,4,98.0,
34899,6,100.0,
42630,1,168.0,
63007,2,177.0,
73574,'1 ',,,,,,,,,,,,,0,

Q

Fdns,opt
1,1,1
0

@END
```

2. 2009 Summer stability case:

```
DSCN
67621


RDCH
1
16745,,,1
66569,,,1
59995,,,1
59996,,,1
59998,,,1

0
34899,6,100,
52632,1,234,
54910,1,49,
54911,1,49,
```

```
59800,8,18,
59802,6,19,
63806,4,865,
64496,3,15,
64499,1,18,
72869,1,1310,
54206,1,78.0,
54204,1,455.0,

60173,-67564,'1 ',   0.00176,   0.03004,   2.75280, 2251.7,3691.9, ,  0.00000,  0.00000,  0.00000, -
2.25000,1,   0.00, 667,1.0000

Q

FDNS,OPT
1,1,1,,,
0

rdch
1
0
0
72869,1,1310,

q

fdns,opt
1,1,1
0
```

APPENDIX B – STABILITY MODEL PARAMETERS

PSS/E Dynamic Data for Equivalent Gamesa 160 MW Generator

```
PLANT MODELS

 REPORT FOR ALL MODELS                             BUS 95995 [CLR1_0220.6900] MODELS


 ** G8XDFG **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S       VAR        ICON
            95995     CLR1_022 0.6900 1  235057-235063  89108-89112   16289-16316    8107

     Ra        La       Lm_D       Lm_Y        R1         L1
   0.0102    0.1428    7.2114    6.9453    0.0101    0.1750

     cosfi
   1.0000



 ** G8XCNT for G8XDFG **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S       VAR        ICON
                       95995     CLR1_022 0.6900 1       0-0      89118-89123   16345-16355    8109-8111

      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E      TUE, JUL 12 2005  12:00
 2004 SERIES, NERC/MMWG BASE CASE LIBRARY
 2009 SUMMER, FINAL; FOR DYN

 CONEC MODELS

 REPORT FOR ALL MODELS                             BUS 95995 [CLR1_0220.6900] MODELS


                 *** CALL GTWIND(  8117,235078,     0, 16370) ***


  ** GTWIND ** BUS X-- NAME --X BASEKV MC    C O N S       V A R S       ICONS
            95995 CLR1_022.690        1  235078-235084  16370-16372    8117-8118

     VWB     T1G      TG    MAXG     T1R     T2R    MAXR
  17.0009999.000   5.000  30.0009999.0009999.000  30.000

               Wind generator Bus #  95995
               Wind Generator ID       1


 ** G8XAER for DFIG **      BUS X-- NAME --X BASEKV MC    C O N S       STATE         VAR        ICON
                       95995     CLR1_022 0.6900 1  235091-235096   89131-89131   16377-16380    8122-8124

     VWinit      Lambda_Max      Lambda_Min   PITCH_MAX    PITCH_MIN      Ta
      17.0000      19.5000       0.0000      50.0000       0.0000       0.5000


               Wind Generator Bus #  95995
               Wind Generator ID       1


 ** G8XPTC for G8XDFG **  BUS X-- NAME --X BASEKV MC    C O N S        STATE         VAR        ICON
                       95995     CLR1_022 0.6900 1       0-0       89137-89141   16392-16402    8128-8130
                  Wind Generator Bus #  95995
                  Wind Generator ID       1

      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E      TUE, JUL 12 2005  12:00
 2004 SERIES, NERC/MMWG BASE CASE LIBRARY
 2009 SUMMER, FINAL; FOR DYN

 CONET MODELS

 REPORT FOR ALL MODELS                             BUS 95995 [CLR1_0220.6900] MODELS


               *** CALL G_VTRP(  8166,235125,     0, 16410) ***

                BUS   NAME  BSKV        GENR BUS   NAME  BSKV
              95995 CLR1_022.690           95995 CLR1_022.690

                    I C O N S      C O N S       V A R
                    8166-8170   235125-235128   16410
```

```
       VLO       VUP      PICKUP     TB
       0.150     5.000     0.040     0.050


 *** CALL G_VTRP(  8171,235129,     0, 16411) ***

  BUS   NAME  BSKV         GENR BUS   NAME  BSKV
95995 CLR1_022.690            95995 CLR1_022.690

     I C O N S      C O N S      V A R
     8171-8175   235129-235132   16411

       VLO       VUP      PICKUP     TB
       0.300     5.000     0.625     0.050


 *** CALL G_VTRP(  8176,235133,     0, 16412) ***

  BUS   NAME  BSKV         GENR BUS   NAME  BSKV
95995 CLR1_022.690            95995 CLR1_022.690

     I C O N S      C O N S      V A R
     8176-8180   235133-235136   16412

       VLO       VUP      PICKUP     TB
       0.450     5.000     1.100     0.050


 *** CALL G_VTRP(  8181,235137,     0, 16413) ***

  BUS   NAME  BSKV         GENR BUS   NAME  BSKV
95995 CLR1_022.690            95995 CLR1_022.690

     I C O N S      C O N S      V A R
     8181-8185   235137-235140   16413

       VLO       VUP      PICKUP     TB
       0.600     5.000     1.575     0.050


 *** CALL G_VTRP(  8186,235141,     0, 16414) ***

  BUS   NAME  BSKV         GENR BUS   NAME  BSKV
95995 CLR1_022.690            95995 CLR1_022.690

     I C O N S      C O N S      V A R
     8186-8190   235141-235144   16414

       VLO       VUP      PICKUP     TB
       0.750     5.000     2.050     0.050


 *** CALL G_VTRP(  8191,235145,     0, 16415) ***

  BUS   NAME  BSKV         GENR BUS   NAME  BSKV
95995 CLR1_022.690            95995 CLR1_022.690

     I C O N S      C O N S      V A R
     8191-8195   235145-235148   16415

       VLO       VUP      PICKUP     TB
       0.900     5.000     2.550     0.050


 *** CALL G_VTRP(  8196,235149,     0, 16416) ***

  BUS   NAME  BSKV         GENR BUS   NAME  BSKV
95995 CLR1_022.690            95995 CLR1_022.690

     I C O N S      C O N S      V A R
     8196-8200   235149-235152   16416

       VLO       VUP      PICKUP     TB
       0.000     1.100     0.060     0.050


 *** CALL G_FRTP(  8207,235157,     0, 16418) ***

  BUS    NAME     BSKV      GEN BUS    NAME    BSKV   ID
95995  CLR1_022  .690       95995  CLR1_022  .690    1
```

```
                 I C O N S      C O N S       V A R
                 8207-8212   235157-235160   16418

                   FLO       FUP      PICKUP     TB
                  57.000    62.000     0.000     0.050
```

PSS/E Dynamic Data for Equivalent Gamesa 80 MW Generator

```
PLANT MODELS

REPORT FOR ALL MODELS                        BUS 95996 [CLR2_0220.6900] MODELS


** G8XDFG **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S       VAR        ICON
            95996     CLR2_022 0.6900 1  235064-235070  89113-89117   16317-16344    8108

    Ra        La       Lm_D       Lm_Y        R1          L1
  0.0102    0.1428    7.2114    6.9453    0.0101    0.1750

    cosfi
  1.0000



** G8XCNT for G8XDFG **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S       VAR        ICON
                       95996     CLR2_022 0.6900 1       0-0       89124-89129   16356-16366    8112-8114

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E      TUE, JUL 12 2005  12:01
2004 SERIES, NERC/MMWG BASE CASE LIBRARY
2009 SUMMER, FINAL; FOR DYN

CONEC MODELS

REPORT FOR ALL MODELS                        BUS 95996 [CLR2_0220.6900] MODELS


                *** CALL GTWIND(  8115,235071,     0, 16367) ***


 ** GTWIND ** BUS X-- NAME --X BASEKV MC    C O N S       V A R S       ICONS
            95996 CLR2_022.690        1  235071-235077  16367-16369    8115-8116

    VWB     T1G      TG    MAXG     T1R     T2R    MAXR
 17.0009999.000   5.000  30.0009999.0009999.000  30.000

              Wind generator Bus #  95996
              Wind Generator ID        1


** G8XAER for DFIG **      BUS X-- NAME --X BASEKV MC    C O N S       STATE         VAR        ICON
                       95996     CLR2_022 0.6900 1  235085-235090   89130-89130   16373-16376    8119-8121

    VWinit      Lambda_Max      Lambda_Min   PITCH_MAX    PITCH_MIN      Ta
     17.0000      19.5000       0.0000      50.0000       0.0000       0.5000


              Wind Generator Bus #  95996
              Wind Generator ID        1


** G8XPTC for G8XDFG **  BUS X-- NAME --X BASEKV MC    C O N S        STATE         VAR        ICON
                       95996     CLR2_022 0.6900 1       0-0        89132-89136   16381-16391    8125-8127
                 Wind Generator Bus #  95996
                 Wind Generator ID        1

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E      TUE, JUL 12 2005  12:01
2004 SERIES, NERC/MMWG BASE CASE LIBRARY
2009 SUMMER, FINAL; FOR DYN

CONET MODELS

REPORT FOR ALL MODELS                        BUS 95996 [CLR2_0220.6900] MODELS


              *** CALL G_VTRP(  8131,235097,     0, 16403) ***
```

```
  BUS   NAME  BSKV        GENR BUS   NAME  BSKV
95996 CLR2_022.690           95996 CLR2_022.690

     I C O N S      C O N S      V A R
     8131-8135   235097-235100   16403

       VLO       VUP      PICKUP     TB
       0.150     5.000     0.040     0.050


 *** CALL G_VTRP(  8136,235101,     0, 16404) ***

  BUS   NAME  BSKV        GENR BUS   NAME  BSKV
95996 CLR2_022.690           95996 CLR2_022.690

     I C O N S      C O N S      V A R
     8136-8140   235101-235104   16404

       VLO       VUP      PICKUP     TB
       0.300     5.000     0.625     0.050


 *** CALL G_VTRP(  8141,235105,     0, 16405) ***

  BUS   NAME  BSKV        GENR BUS   NAME  BSKV
95996 CLR2_022.690           95996 CLR2_022.690

     I C O N S      C O N S      V A R
     8141-8145   235105-235108   16405

       VLO       VUP      PICKUP     TB
       0.450     5.000     1.100     0.050


 *** CALL G_VTRP(  8146,235109,     0, 16406) ***

  BUS   NAME  BSKV        GENR BUS   NAME  BSKV
95996 CLR2_022.690           95996 CLR2_022.690

     I C O N S      C O N S      V A R
     8146-8150   235109-235112   16406

       VLO       VUP      PICKUP     TB
       0.600     5.000     1.575     0.050


 *** CALL G_VTRP(  8151,235113,     0, 16407) ***

  BUS   NAME  BSKV        GENR BUS   NAME  BSKV
95996 CLR2_022.690           95996 CLR2_022.690

     I C O N S      C O N S      V A R
     8151-8155   235113-235116   16407

       VLO       VUP      PICKUP     TB
       0.750     5.000     2.050     0.050


 *** CALL G_VTRP(  8156,235117,     0, 16408) ***

  BUS   NAME  BSKV        GENR BUS   NAME  BSKV
95996 CLR2_022.690           95996 CLR2_022.690

     I C O N S      C O N S      V A R
     8156-8160   235117-235120   16408

       VLO       VUP      PICKUP     TB
       0.900     5.000     2.550     0.050


 *** CALL G_VTRP(  8161,235121,     0, 16409) ***

  BUS   NAME  BSKV        GENR BUS   NAME  BSKV
95996 CLR2_022.690           95996 CLR2_022.690

     I C O N S      C O N S      V A R
     8161-8165   235121-235124   16409

       VLO       VUP      PICKUP     TB
       0.000     1.100     0.060     0.050
```

```
*** CALL G_FRTP(  8201,235153,     0, 16417) ***

  BUS    NAME    BSKV      GEN BUS    NAME    BSKV   ID
95996  CLR2_022  .690       95996  CLR2_022  .690    1

     I C O N S      C O N S      V A R
     8201-8206   235153-235156   16417

      FLO       FUP      PICKUP     TB
     57.000    62.000     0.000     0.050
```

PSS/E Dynamic Data for Equivalent Bonus 160 MW Generator

```
PLANT MODELS

 REPORT FOR ALL MODELS                        BUS 95995 [CLR1_0220.6900] MODELS


  ** SWP2M3 **  BUS MACH      C O N S     S T A T E S      V A R S    I C O N S
              95995   1    *****-*****   86829-86836   16189-16209    8106- 8112

      Mbase     Rsource     Xsource     |Vterm|       P_lf        Q_lf
    160.000    0.000000    0.200000    1.025876    1.000000    0.000001
```

PSS/E Dynamic Data for Equivalent Bonus 80 MW Generator

```
 PLANT MODELS

 REPORT FOR ALL MODELS                        BUS 95996 [CLR2_0220.6900] MODELS


  ** SWP2M3 **  BUS MACH      C O N S     S T A T E S      V A R S    I C O N S
              95996   1    *****-*****   86837-86844   16210-16230    8113- 8119

      Mbase     Rsource     Xsource     |Vterm|       P_lf        Q_lf
     80.000    0.000000    0.200000    1.025684    0.999999    0.000001
```

APPENDIX C – STABILITY PLOTS