SPP Southwest Power Pool

Impact Study for Generation Interconnection Request GEN – 2002 – 022

SPP Coordinated Planning
(#GEN-2002-022)

November 2004

Summary

Pursuant to the tariff and at the request of the Southwest Power Pool (SPP) ABB Inc. Electric Systems Consulting (ABB) performed the following Impact Study to satisfy the Impact Study Agreement executed by the requesting customer for SPP 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.

System Impact Study for Generation Interconnection Request GEN-2002-022

Issued: November 19, 2004

Prepared for Southwest Power Pool, Little Rock, AR

Report Number: 2004-10921-1

SUBMITTED BY:

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GEN-2002-022 Interconnection Study	No. 2004-10921-1		
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Reviewed by: W. Quaintance

Approved by:

Executive Summary

The main objective of this study is to assess the impact on local stability of interconnecting the proposed GEN-2002-022 wind farm located in Oldham County, Texas. This proposed wind farm would be interconnected to the Southwestern Public Service Company (SPS dba Xcel Energy) transmission system and will have a nominal rating of 240MW. The wind farm has previously been studied by Southwest Power Pool (SPP) using Mitsubishi wind turbines (rated 1.0 MW each, model MWT-1000a). On request of SPP and the wind farm developer, the proposed wind farm is now been studied using GE, Vestas, and Bonus wind turbine generators.

A comprehensive range of fault cases defined by SPP has been run in the study.

The following conclusions are reached from the studies:

GEN-2002-022 with GE wind turbine generators

- Overall, the post-fault recoveries show stable system performance for GEN-2002-022 with GE wind turbine generators.
- The wind turbines do not trip with the standard under-voltage ride-through settings

GEN-2002-022 with Vestas wind turbine generators

- GEN-2002-022 and GEN-2002-019 will trip due to low voltage in case of VESTAS Wind turbine Generators for faults near the wind farm. Undervoltage protection trip settings are major factor influencing the GEN-2002-022 tripping.
- With delayed undervoltage trip settings, voltage collapse was observed following loss of Bushland- Potter Co. 230kV line because the Vestas turbines do not provide dynamic voltage support.
- The voltage collapse situation can be mitigated by reducing the wind farm (GEN-2002-022) output to 220MW, installing a dedicated cross-tripping scheme, or installing a 25 Mvar SVC at the GEN-2002-022 34.5kV substation bus to provide dynamic VAR support. Since the SVC has to be installed on the 34.5kV substation bus, the cost will be considered as a direct assignment to the Customer.
- Depending on quick under-voltage trip settings is not sufficient to eliminate the voltage collapse problem.

GEN-2002-022 with Bonus Wind Turbine Generators

- As the GEN-2002-022 with Bonus Wind Turbine was modeled without undervoltage protection, no undervoltage tripping observed for simulated faults.

- Following loss of Bushland-Potter Co 230kV line GEN-2002-022 becomes unstable.

- Following loss of Bushland-Potter co 230kV line, instability can be averted by reducing the wind farm (GEN-2002-022) output to 230MW, installing a dedicated cross-tripping scheme, or installing a 25 Mvar SVC at the GEN-2002-022 34.5kV substation bus to provide dynamic VAR support. Since the SVC has to be installed on the 34.5kV substation bus, the cost will be considered as a direct assignment to the Customer.

A summary table for GEN-2002-022 stability results is presented below.

A full description of the study, and results, are given in the report.

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SUMMARY TABLE FOR GEN-2002-022 STABILITY RESULTS

FAULT	FAULT DEFINITION	RESULTS					
		GE		VESTAS		BONUS	
		SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10
FLT_1_3PH	3 Phase Fault at Potter Co. (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault	Stable	Stable	Stable, GEN-2002-019 and GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-019 and GEN-2002-022 tripped for Undervoltage (below 0.75PU)	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**
FLT_1_3PH-nt	Same as FLT_1_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Not required	Not required	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**	Not required	Not required
FLT_1_3PH-nt-reduced output	Same as FLT_1_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022, with GEN-2002-022 at reduced output	Not required	Not required	Stable (GEN-2002-022 @ 220MW)	Stable (GEN-2002-022 @ 220MW)	Stable (GEN-2002-022 @ 230MW)	Stable (GEN-2002-022 @ 230MW)
FLT_2_1PH	SLG Fault at Potter (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault	Stable	Stable	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**
FLT_2_1PH-nt-reduced output	Same as FLT_2_1PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022, with GEN-2002-022 at reduced output	Not required	Not required	Stable (GEN-2002-022 @ 220MW)	Stable (GEN-2002-022 @ 220MW)	Stable (GEN-2002-022 @ 230MW)	Stable (GEN-2002-022 @ 230MW)
FLT_3_3PH	3 Phase Fault at Finney (#50858) 345kV Trip Potter-Finney 230kV line after 4cy and Clear the fault	Stable	Stable	Stable	Stable	Stable	Stable
FLT_4_3PH	3 Phase Fault at Coulter (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable

FAULT	FAULT DEFINITION	RESULTS					
		GE		VESTAS		BONUS	
		SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10
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FLT_6_3PH	3 Phase Fault at Randall (#51021) 230kV Trip Harrington-Randall 230kV line after 5cy Reclose Harrington-Randall 230kV line on fault after 20cy Trip Harrington-Randall 230kV line after 5cy and clear the fault	Stable	Stable	Stable, GEN-2002-019 and GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-019 and GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable	Stable
FLT_6_3PH-nt	Same as FLT_6_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Not required	Not required	Stable	Stable	Stable	Stable
FLT_7_1PH	SLG Fault at Randall (#51021) 230kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 230kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable
FLT_8_3PH	3 Phase Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable	Stable	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable	Stable	Stable
FLT_8_3PH-nt	Same as FLT_8_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Not required	Not required	Stable	Stable	Not required	Not required

FAULT	FAULT DEFINITION	RESULTS					
		GE		VESTAS		BONUS	
		SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10
FLT_9_1PH	SLG Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable
FLT_10_3PH	3 Phase fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable
FLT_11_1PH	SLG fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable
FLT_12_1PH	3 Phase Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable
FLT_13_1PH	SLG Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable

FAULT	FAULT DEFINITION	RESULTS					
		GE		VESTAS		BONUS	
		SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10
FLT_14_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Potter Co 230kV line after 5cy Reclose Bushland-Potter Co 230kV line on fault after 20cy Trip Bushland-Potter Co 230kV line after 5cy and clear the fault	Stable	Stable	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**
FLT_14_3PH-nt	Same as FLT_14_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Not required	Not required	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**	Not required	Not required
FLT_14_3PH-nt-reduced output	Same as FLT_14_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022, with GEN-2002-022 at reduced output	Not required	Not required	Stable (GEN-2002-022 @ 220MW)	Stable (GEN-2002-022 @ 220MW)	Stable (GEN-2002-022 @ 230MW)	Stable (GEN-2002-022 @ 230MW)
FLT_15_1PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable	Stable	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable	Stable
FLT_15_3PH-nt	Same as FLT_15_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Not required	Not required	Stable	Stable	Not required	Not required
FLT_16_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland 230/115kV transformer after 5cy Reclose Bushland 230/115kV transformer on fault after 20cy Trip Bushland 230/115kV transformer after 5cy and clear the fault	Stable	Stable	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable	Stable
FLT_16_3PH-nt	Same as FLT_16_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Not required	Not required	Stable	Stable	Not required	Not required

TABLE OF CONTENTS

1 INTRODUCTION

A study has been made of a 230 kV interconnection to the proposed wind farm located in Oldham County, Texas. This proposed wind farm would be interconnected to the Xcel Energy (SPS) transmission system, and will have a nominal rating of 240 MW. The wind farm has previously been studied by SPP using Mitsubishi wind turbines (rated 1.0 MW each, model MWT-1000a). On request of SPP and the wind farm developer the proposed wind farm (GEN-2002-022) is studied for three options:

- GE wind turbines (1.5MW each)
- Vestas wind turbines (1.8MW each)
- Bonus Wind Turbines (2.3MW each)

Proper modeling of the wind farm is always a significant consideration for wind farm studies. Care has been taken in preparation of the equivalent model for the wind farm, and the assumptions in developing this model are presented in the report.

The cases run for the study were those defined in the SPP document "Scope of Interconnection Impact Study for GEN-2002-022".

A description of the model, assumptions, and case results are given in the report.

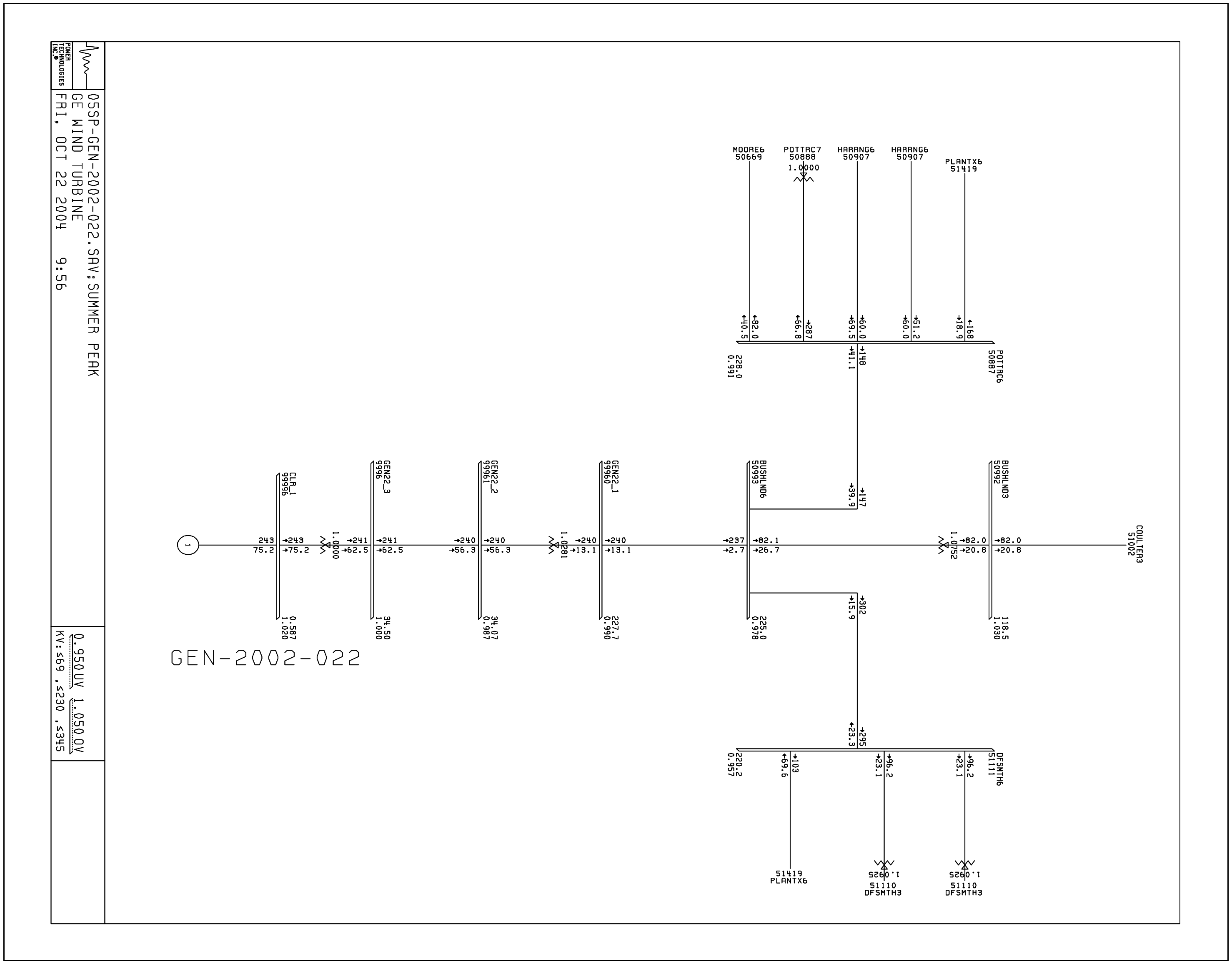

FIG 1.1 One-line Diagram for GEN-2002-022

2 GEN-2002-022 with GE Wind Turbines

2.1 CASE DEVELOPMENT

2.1.1 Power Flow Case Development

SPP provided two (2005 and 2010) loadflow base cases (file name '05sp-basecase.sav' and '10sp-basecase.sav') as input to the study. By using the provided base cases, the prior-queued generation "GEN-2002-019" was added, assuming GE wind turbines, to develop the case (GEN-2002-019) for system conditions before the addition of the proposed wind farm, GEN-2002-022. Next, the proposed wind farm (GEN-2002-022) was added to the Pre-GEN-2002-022 case to create the corresponding cases with the plant. The plant was redispatched against the generation as per "526 SPS Dispatch Info 040414.xls" provided by SPP. Table 2.1 shows the list of redispatched generation.

Table 2.1a List of generators for redispatching for SP05

BUS NO	BUS NAME	ORIGINAL MW	CHNG MW
52215	CUNN3 122	74	0
52214	CUNN4 122	105	0
51422	PLNTX2 113.8	97	36

Table 2.1b List of generators for redispatching for SP10

BUS NO	BUS NAME	ORIGINAL MW	CHNG MW
50911	NICHOL111 13.8	20	0
51421	PLANTX1	45	0
52362	MADDX2 113.8	66	0
52211	CUNN 113.8	70	0
52215	CUNN3 122	105	66

2.1.2 Wind Farm Power Flow Model

The proposed wind farm has all collector buses equidistant from the interconnection point. The typical plant layout was given in two drawings labeled E1 and E2 (Appendix A). The symmetry of the wind farm layout lends itself to modeling the entire plant as a single machine for simulating the plant's response to faults on the system. The detailed reasoning and calculations that went into development of the wind farm model is included in Appendix A.

Finally, 162 identical 1.5MW GE turbine generators are modeled as single 243MW generator for developing the case with GE wind turbines.

The IPLAN program ("GE15WIND9.IRF") provided with the PTI GE Wind model was used to model the GSU transformer (with impedance 0.0077+j0.0579 p.u. on transformer base)

2.1.3 Dynamic data

Snapshot files corresponding to the Summer Peak 2005 and 2010 loadflow cases were provided by SPP for the study (" 05sp-basecase.DYR" and "10sp-basecase.DYR").

The dynamic data for prior-queued GEN-2002-019 is added, assuming GE wind turbines, to create the snapshot for system conditions before addition of GEN-2002-022. Next, the GE dynamic data for the proposed GEN 2002-022 plant is added to create the snapshot for GEN-2002-022 case. The power flow parameters used for this model were based on available information and the default parameters embedded in the setup files for the PTI GE Wind model. The stability model parameters were based on default data provided with the PTI GE Wind model. This model incorporates the standard ride-through capability that allows wind turbine generator operation below 70% terminal voltage for up to 100ms and instantaneous tripping (~20ms) for terminal voltages below 30%. The wind farm was modeled assuming generator terminal voltage control.

The GE doubly fed induction generators themselves provided all of the reactive power needed to achieve unity power factor at the 230 kV interconnection point. The use of the GE generators will require no direct assignment installation of capacitor banks for the wind farm.

The power flow and stability model representation is included in Appendix B

2.2 STABILITY SIMULATIONS

The fault scenarios considered for the local stability assessment are listed in Table 2.2. The sequence impedance used to model the SLG faults were estimated by ABB.

Table 2.2 List of Disturbances simulated for Local Stability Analysis

FAULT	FAULT DEFINITION
FLT_1_3PH	3 Phase Fault at Potter Co. (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault

FAULT	FAULT DEFINITION
FLT_2_1PH	SLG Fault at Potter (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault
FLT_3_3PH	3 Phase Fault at Finney (#50858) 345kV Trip Potter-Finney 230kV line after 4cy and Clear the fault
FLT_4_3PH	3 Phase Fault at Coulter (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault
FLT_5_1PH	SLG Fault at Finney (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault
FLT_6_3PH	3 Phase Fault at Randall (#51021) 230kV Trip Harrington-Randall 230kV line after 5cy Reclose Harrington-Randall 230kV line on fault after 20cy Trip Harrington-Randall 230kV line after 5cy and clear the fault
FLT_7_1PH	SLG Fault at Randall (#51002) 230kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 230kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault
FLT_8_3PH	3 Phase Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault
FLT_9_1PH	SLG Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault
FLT_10_3PH	3 Phase fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault
FLT_11_1PH	SLG fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault
FLT_12_1PH	3 Phase Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault
FLT_13_1PH	SLG Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault
FLT_14_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Potter Co 230kV line after 5cy Reclose Bushland-Potter Co 230kV line on fault after 20cy Trip Bushland-Potter Co 230kV line after 5cy and clear the fault
FLT_15_1PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault

FAULT	FAULT DEFINITION
FLT_16_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland 230/115kV transformer after 5cy Reclose Bushland 230/115kV transformer on fault after 20cy Trip Bushland 230/115kV transformer after 5cy and clear the fault

2.3 STABILITY RESULTS

Table 2.3 summarizes the results for local stability simulations for Summer Peak 2005 and Summer Peak 2010 using the GE Wind Turbine model for the new wind farm.

All faults were run for 10 seconds.

The detailed simulation plots for all the faults are included in Appendix C.

In summary, local stability assessment indicates that the GEN-2002-022 plant with GE Wind Turbine Generators does not adversely affect the stability of the system. With the standard under-voltage ride-through capability (see section 2.1.3), these GE wind turbines show no tripping for the faults simulated in this study.

Table 2.3 Local Stability simulation results (Summer Peak 2005 and 2010)

FAULT	FAULT DEFINITION	RESULTS	
		SUMMER PEAK 05	SUMMER PEAK 10
FLT_1_3PH	3 Phase Fault at Potter Co. (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault	Stable	Stable
FLT_2_1PH	SLG Fault at Potter (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault	Stable	Stable
FLT_3_3PH	3 Phase Fault at Finney (#50858) 345kV Trip Potter-Finney 230kV line after 4cy and Clear the fault	Stable	Stable
FLT_4_3PH	3 Phase Fault at Coulter (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable
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FLT_7_1PH	SLG Fault at Randall (#51002) 230kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 230kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable
FLT_8_3PH	3 Phase Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable	Stable

FAULT	FAULT DEFINITION	RESULTS	
		SUMMER PEAK 05	SUMMER PEAK 10
FLT_9_1PH	SLG Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable	Stable
FLT_10_3PH	3 Phase fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault	Stable	Stable
FLT_11_1PH	SLG fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault	Stable	Stable
FLT_12_1PH	3 Phase Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault	Stable	Stable
FLT_13_1PH	SLG Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault	Stable	Stable
FLT_14_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Potter Co 230kV line after 5cy Reclose Bushland-Potter Co 230kV line on fault after 20cy Trip Bushland-Potter Co 230kV line after 5cy and clear the fault	Stable	Stable
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3 GEN-2002-022 with VESTAS Wind Turbines

3.1 CASE DEVELOPMENT

3.1.1 Power Flow Case Development

SPP provided two (2005 and 2010) loadflow base cases (file name '05sp-basecase.sav' and '10sp-basecase.sav') as input to the study. By using the provided base cases, the prior-queued generation "GEN-2002-019" was added, assuming Vestas wind turbines, to develop the case (GEN-2002-019) for system conditions before the addition of the proposed wind farm, GEN-2002-022. Next, the proposed wind farm (GEN-2002-022) was added to the Pre-GEN-2002-022 case to create the corresponding cases with the plant. The plant was redispatched against the generation as per "526 SPS Dispatch Info 040414.xls" provided by SPP. Table 3.1 shows the list of redispatched generation.

Table 3.1a List of generators for redispatching for SP05

BUS NO	BUS NAME	UNIT	ORIGINAL MW	CHNG MW
52215	CUNN3 122	1	74	0
52214	CUNN4 122	1	105	0
51422	PLNTX2 113.8	1	97	36

Table 3.1b List of generators for redispatching for SP10

BUS NO	BUS NAME	ORIGINAL MW	CHNG MW
50911	NICHOL111 13.8	20	0
51421	PLANTX1	45	0
52362	MADDX2 113.8	66	0
52211	CUNN 113.8	70	0
52215	CUNN3 122	105	66

3.1.2 Wind Farm Power Flow Model

The GEN-2002-022 wind farm has all collector buses equidistant from the interconnection point. The typical plant layout was given in two drawings labeled E1 and E2 (Appendix A). The symmetry of the wind farm layout lends itself to modeling the entire plant as a single machine for simulating the plant's response to faults on the system. The detailed reasoning and calculations that went into development of the wind farm model is included in Appendix A.

Finally, 135 identical 1.8MW Vestas turbine generators are modeled as single 243MW generator for developing the case with Vestas wind turbines.

The IPLAN program ("v80wind20.IRF") provided with PSS/E model was used to model the GSU transformer.

3.1.3 Dynamic data

Snapshot files corresponding to the Summer Peak 2005 and 2010 power flow cases were provided by SPP for the study ("05sp-basecase.DYR" and "10sp-basecase.DYR").

The dynamic data for prior-queued GEN-2002-019 is added, assuming Vestas wind turbines, to create the snapshot for system conditions before addition of GEN-2002-022. Next, the Vestas dynamic data for the proposed GEN 2002-022 plant is added to create the snapshot for GEN-2002-022 case. The power flow parameters used for this model were based on available information and the default parameters embedded in the setup files of the Vestas model. The stability parameters were based on default data provided with the Vestas model. This model incorporates the standard ride-through capability that allows wind turbine generator operation below 85% terminal voltage for up to 400ms and instantaneous tripping (~80ms) for terminal voltages below 75%. The typical value of shaft damping provided with the Vestas models is low (1.00pu), so the GEN-2002-022 is modeled with shaft damping of 2.00pu.

To create a Vestas generator model of the wind farm with a unity power factor at the 230 kV point of interconnection required 113 Mvar of capacitor bank located at the generation step-up transformer terminals and also 78 Mvar bank of capacitors located on the 34.5 kV bus. The use of the Vestas generators for the wind farm will require the Customer to install the noted capacitor banks as direct assignment upgrades.

The power flow and stability model representation is included in Appendix B.

3.2 STABILITY ANALYSIS

The fault scenarios considered for the local stability assessment are listed in Table 3.2. The sequence impedance used to model the SLG faults were calculated by ABB.

Table 3.2 Fault scenarios considered for Local stability assessment

FAULT	FAULT DEFINITION
FLT_1_3PH	3 Phase Fault at Potter Co. (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault

FAULT	FAULT DEFINITION
FLT_2_1PH	SLG Fault at Potter (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault
FLT_3_3PH	3 Phase Fault at Finney (#50858) 345kV Trip Potter-Finney 230kV line after 4cy and Clear the fault
FLT_4_3PH	3 Phase Fault at Coulter (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault
FLT_5_1PH	SLG Fault at Finney (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault
FLT_6_3PH	3 Phase Fault at Randall (#51021) 230kV Trip Harrington-Randall 230kV line after 5cy Reclose Harrington-Randall 230kV line on fault after 20cy Trip Harrington-Randall 230kV line after 5cy and clear the fault
FLT_7_1PH	SLG Fault at Randall (#51002) 230kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 230kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault
FLT_8_3PH	3 Phase Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault
FLT_9_1PH	SLG Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault
FLT_10_3PH	3 Phase fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault
FLT_11_1PH	SLG fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault
FLT_12_1PH	3 Phase Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault
FLT_13_1PH	SLG Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault
FLT_14_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Potter Co 230kV line after 5cy Reclose Bushland-Potter Co 230kV line on fault after 20cy Trip Bushland-Potter Co 230kV line after 5cy and clear the fault
FLT_15_1PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault

FAULT	FAULT DEFINITION
FLT_16_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland 230/115kV transformer after 5cy Reclose Bushland 230/115kV transformer on fault after 20cy Trip Bushland 230/115kV transformer after 5cy and clear the fault

3.3 STABILITY RESULTS

Table 3.3 summarizes the results for stability simulations for Summer Peak 2005 and Summer Peak 2010 using the Vestas Wind Turbine model for the new wind farm.

All faults were run for 10 seconds.

The detailed simulation plots for all faults are included in Appendix D.

The faults for which GEN-2002-022 and GEN-2002-019 were tripping due to undervoltage protection were simulated again with delayed undervoltage trip settings (named with extension "-nt" to the fault ID) changes as follows:

Default Setting of VESTAS Model		Changed Trip Settings	
Voltage below 75%	0.08 Sec	Voltage below 50%	0.2 Sec
Voltage below 85%	0.40 Sec	Voltage below 75%	0.8 Sec

With the delayed trip settings the GEN-2002-022 and GEN-2002-019 remained on-line through the fault. And there were no stability criteria violation observed with higher undervoltage trip settings **except for FAULT_1_3PH, FAULT_2_1PH and FAULT_14_3PH**. During these faults, following loss of the Bushland-Potter Co 230kV line, GEN-2002-022 Wind Farm is connected with weaker connection to Deaf Smith. As the PTI Vestas model had showed "scribbled" responses during voltage collapse condition, the same faults were simulated with a CIMTR3 model (Induction Generator Model with rotor flux transients) with typical parameters for a Vestas variable-rotor-resistance generator. The results show a smooth but collapsing voltage response (see Figure 3.2).

One option would be to intentionally cross-trip the GEN-2002-022 plant following loss of the Bushland-Potter 230 kV line. However, choosing the default under-voltage trip settings for the Vestas machines is not a sufficient solution for the voltage collapse problem because this will not trip the wind farm for all events that result in loss of the Bushland- Potter Co. 230 kV line. For example, a simple line tripping with no fault will not initially trip the GEN-2002-022 plant. However, voltage collapse will occur and will subsequently result in violating reliability criteria (Refer Fig 3.3 and 3.4). A dedicated cross-tipping scheme is needed.

Another option is to reduce the size of the GEN-2002-022 plant. The faults for which the voltage collapse was observed were repeated with GEN-2002-022 at reduced output (220MW and 230MW) and with delayed trip settings. The Vestas Model showed the "scribbled" response. So the CIMTR3 model was used to determine the reduced output level to avert the instability. There was no voltage collapse and no other stability criteria violations observed for GEN-2002-022 at 220MW (with CIMTR3 model). With PTI Vestas model "scribbled" response were observed at both 220MW and 230MW output level. The response of the Vestas model is suspicious, so the stable results of GEN-2002-022 with CIMTR3 model will be used.

Because of the problems with the Vestas dynamic model, SVC sizing was not possible with the Vestas model. However, it is expected that the 25 Mvar SVC determined in the Bonus wind turbine section below would be sufficient for the Vestas wind turbines as well.

In summary, the proposed wind farm does not adversely impact the local stability except for the fault involving loss of Bushland-Potter Co 230kV line. To avert the voltage collapse following loss of Bushland-Potter Co 230kV line, three options are available: cross-tripping the plant, reducing the plant size to 220 MW, or installing a 25 Mvar SVC at the GEN-2002-022 34.5kV substation bus to provide dynamic VAR support. Since the SVC has to be installed on the 34.5kV substation bus, the cost will be considered as a direct assignment to the Customer.

3.4 VESTAS MODEL ISSUE

The Vestas wind turbine controls in PSS/E include a feature that will move the variable rotor resistance to its maximum value if the voltage goes too low. This has the effect of reducing the reactive power drawn by the induction generator, and thus increasing the voltage. However, for a weak system condition, the voltage may jump up significantly following the reduction in reactive power drawn by the machine. This large increase in voltage will then move the resistance back into variable mode. Thus, the machine reactive power and terminal voltage may jump up and down at a high frequency, producing “scribbles” or noise in the plots.

Whether or not the implementation of this control is accurate in the PSS/E model is unknown. It is also unknown if this control is adjustable on the real equipment for weaker system conditions. The wind farm developer should consult Vestas and be sure that this issue is addressed at commissioning.

Table 3.3 Local Stability simulation results Summer Peak 2005 and 2010

FAULT	FAULT DEFINITION	RESULTS	
		SUMMER PEAK 05	SUMMER PEAK 10
FLT_1_3PH	3 Phase Fault at Potter Co. (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault	Stable, GEN-2002-019 and GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-019 and GEN-2002-022 tripped for Undervoltage (below 0.75PU)
FLT_1_3PH-nt	Same as FLT_1_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**
FLT_1_3PH-nt-220MW	Same as FLT_1_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022 and GEN-2002-022 at 220MW output	Stable	Stable
FLT_2_1PH	SLG Fault at Potter (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault	Stable	Stable
FLT_2_1PH-nt-220MW	Same as FLT_2_1PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022 and GEN-2002-022 at 220MW output	Stable	Stable
FLT_3_3PH	3 Phase Fault at Finney (#50858) 345kV Trip Potter-Finney 230kV line after 4cy and Clear the fault	Stable	Stable
FLT_4_3PH	3 Phase Fault at Coulter (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable
FLT_5_1PH	SLG Fault at Finney (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable
FLT_6_3PH	3 Phase Fault at Randall (#51021) 230kV Trip Harrington-Randall 230kV line after 5cy Reclose Harrington-Randall 230kV line on fault after 20cy Trip Harrington-Randall 230kV line after 5cy and clear the fault	Stable, GEN-2002-019 and GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-019 and GEN-2002-022 tripped for Undervoltage (below 0.75PU)
FLT_6_3PH-nt	Same as FLT_6_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Stable	Stable
FLT_7_1PH	SLG Fault at Randall (#51021) 230kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 230kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable
FLT_8_3PH	3 Phase Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable
FLT_8_3PH-nt	Same as FLT_8_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Stable	Stable

FAULT	FAULT DEFINITION	RESULTS	
		SUMMER PEAK 05	SUMMER PEAK 10
FLT_9_1PH	SLG Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable	Stable
FLT_10_3PH	3 Phase fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault	Stable	Stable
FLT_11_1PH	SLG fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault	Stable	Stable
FLT_12_1PH	3 Phase Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault	Stable	Stable
FLT_13_1PH	SLG Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault	Stable	Stable
FLT_14_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Potter Co 230kV line after 5cy Reclose Bushland-Potter Co 230kV line on fault after 20cy Trip Bushland-Potter Co 230kV line after 5cy and clear the fault	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)
FLT_14_3PH-nt	Same as FLT_14_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**
FLT_14_3PH-nt-220Mw	Same as FLT_14_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022 and GEN-2002-022 at 220Mw output	Stable	Stable
FLT_15_1PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)
FLT_15_3PH-nt	Same as FLT_15_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Stable	Stable
FLT_16_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland 230/115kV transformer after 5cy Reclose Bushland 230/115kV transformer on fault after 20cy Trip Bushland 230/115kV transformer after 5cy and clear the fault	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)	Stable, GEN-2002-022 tripped for Undervoltage (below 0.75PU)
FLT_16_3PH-nt	Same as FLT_16_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022	Stable	Stable

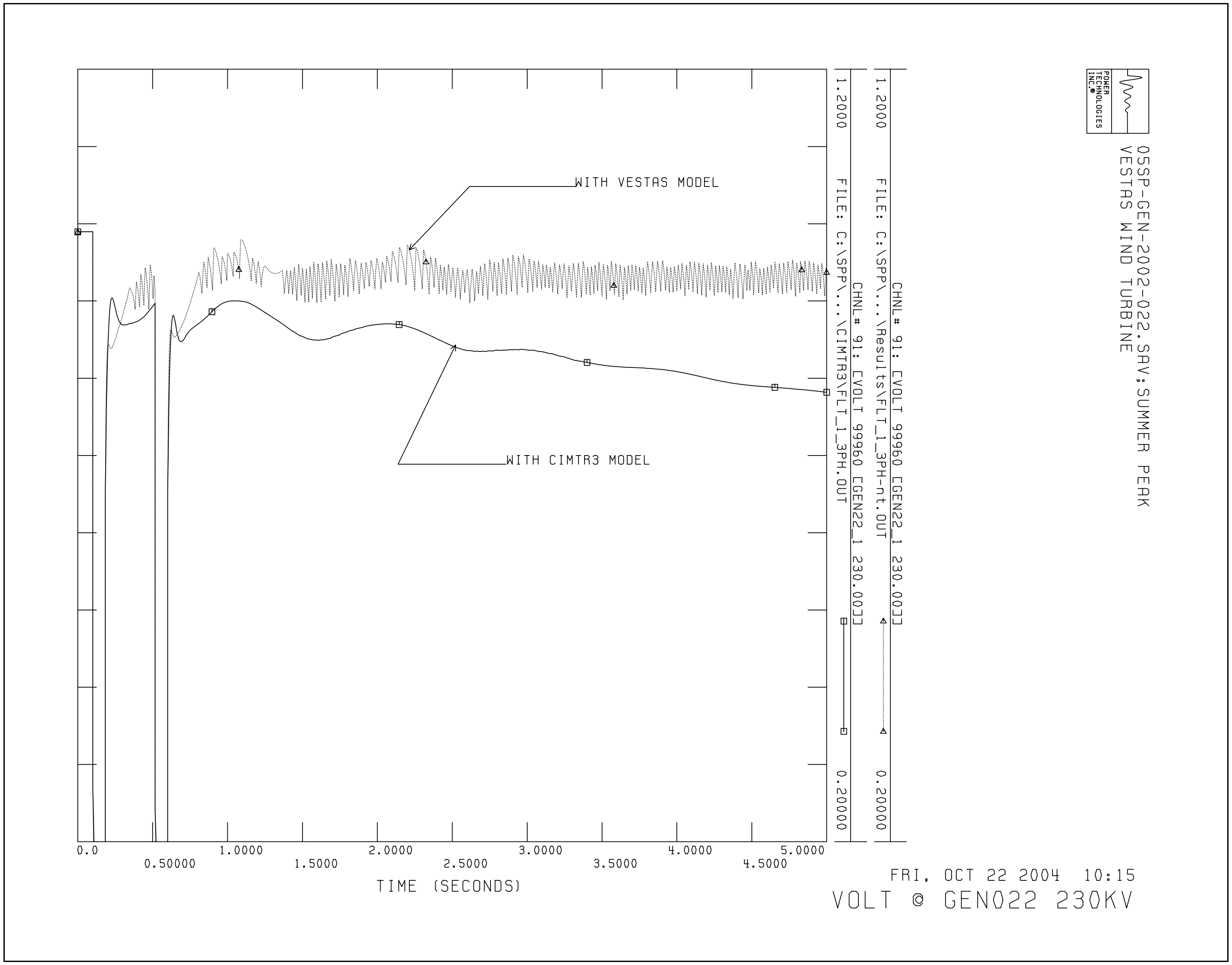

Figure 3.1 Voltage collapse comparison of Vestas and CIMTR3 model for GEN-2002-022 for FAULT_1_3PH

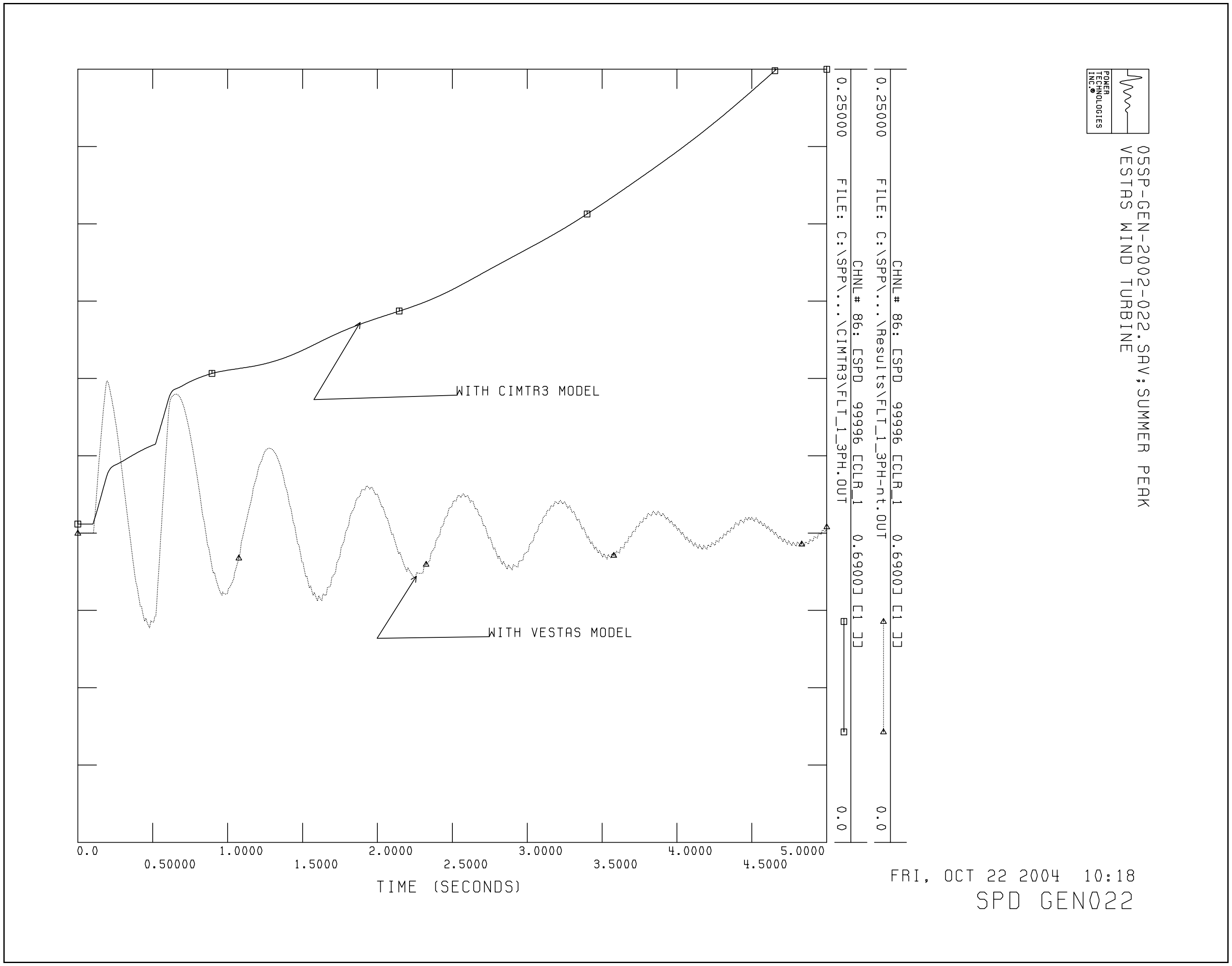

Figure 3.2 Speed of GEN-2002-022 with CIMTR3 and Vestas Model for FAULT_1_3PH

4 GEN-2002-022 with Bonus Wind Turbines

4.1 CASE DEVELOPMENT

4.1.1 Power Flow Case Development

SPP provided two (2005 and 2010) power flow base cases (file name '05sp-basecase.sav' and '10sp-basecase.sav') as input to the study. The prior-queued generation GEN-2002-019 was added to the base case, assuming NEG-Micon wind turbines, to create the Pre-GEN-2002-022 case. Next, the proposed wind farm (GEN-2002-022) with Bonus wind turbines was added to the base case to create the corresponding cases with the plant. The plant was redispatched against other generation as per "526 SPS Dispatch Info 040414.xls" provided by SPP. Table 4.1 shows the list of redispatched generation.

Table 4.1a List of generators for redispatching for SP05

BUS NO	BUS NAME	ORIGINAL MW	CHNG MW
52215	CUNN3 122	77	0
52214	CUNN4 122	105	0
51422	PLNTX2 113.8	97	39

Table 4.1b List of generators for redispatching for SP10

BUS NO	BUS NAME	ORIGINAL MW	CHNG MW
50911	NICHOL111 13.8	20	0
51421	PLANTX1	45	0
52362	MADDX2 113.8	66	0
52211	CUNN 113.8	70	0
52215	CUNN3 122	105	66

4.1.2 Wind Farm Power Flow Model

The GEN-2002-022 wind farm has all collector buses equidistant from the interconnection point. The typical plant layout was given in two drawings labeled E1 and E2 (Appendix A). The symmetry of the wind farm layout lends itself to modeling the entire plant as a single machine for simulating the plant's response to faults on the system. The detailed reasoning that went into development of the wind farm model is included in Appendix A. The same single equivalent impedance for the collector bus system with Vestas wind turbine is used for modeling GEN-2002-022 with Bonus wind turbines.

Ultimately, 105 identical 2.3MW Bonus Wind turbine generators are modeled as a single 241.5MW generator for developing the case with Bonus wind turbines. The plant has been modeled to get unity p.f. at the POI by adding shunt capacitors.

4.1.3 Dynamic Data

Snapshot files corresponding to the Summer Peak 2005 and 2010 power flow cases were provided by SPP for the study ("05sp-basecase.DYR" and "10sp-basecase.DYR").

The dynamic data for prior-queued GEN-2002-019 is added, assuming NEG-Micon wind turbines, to create the snapshot for system conditions before addition of GEN-2002-022. Next, the Bonus dynamic data for the proposed GEN 2002-022 plant is added to create the snapshot for GEN-2002-022 case. The parameters for Bonus Wind Turbine generator were provided by SPP. As per the data sheet, no undervoltage protection has been modeled for GEN-2002-022. The proposed wind farm has been modeled as single cage induction generator.

To create the Bonus generator model of the wind farm with a unity power factor at the 230 kV point of interconnection required 125 Mvar of capacitor bank located at the generation step-up transformer terminals and also 76 Mvar bank of capacitors located on the 34.5 kV bus. The use of the Bonus generators for the wind farm will require the Customer to install the noted capacitor banks as direct assignment upgrades.

The machine parameters used for modeling are included in the Appendix B.

4.2 STABILITY SIMULATIONS

The fault scenarios considered for the stability assessment are listed in Table 4.2. The sequence impedance used to model the SLG faults were typical values calculated by ABB.

Table 4.2 List of Disturbances simulated for Local Stability Analysis

FAULT	FAULT DEFINITION
FLT_1_3PH	3 Phase Fault at Potter Co. (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault

FAULT	FAULT DEFINITION
FLT_2_1PH	SLG Fault at Potter (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault
FLT_3_3PH	3 Phase Fault at Finney (#50858) 345kV Trip Potter-Finney 230kV line after 4cy and Clear the fault
FLT_4_3PH	3 Phase Fault at Coulter (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault
FLT_5_1PH	SLG Fault at Finney (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault
FLT_6_3PH	3 Phase Fault at Randall (#51021) 230kV Trip Harrington-Randall 230kV line after 5cy Reclose Harrington-Randall 230kV line on fault after 20cy Trip Harrington-Randall 230kV line after 5cy and clear the fault
FLT_7_1PH	SLG Fault at Randall (#51002) 230kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 230kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault
FLT_8_3PH	3 Phase Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault
FLT_9_1PH	SLG Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault
FLT_10_3PH	3 Phase fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault
FLT_11_1PH	SLG fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault
FLT_12_1PH	3 Phase Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault
FLT_13_1PH	SLG Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault
FLT_14_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Potter Co 230kV line after 5cy Reclose Bushland-Potter Co 230kV line on fault after 20cy Trip Bushland-Potter Co 230kV line after 5cy and clear the fault
FLT_15_1PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault

FAULT	FAULT DEFINITION
FLT_16_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland 230/115kV transformer after 5cy Reclose Bushland 230/115kV transformer on fault after 20cy Trip Bushland 230/115kV transformer after 5cy and clear the fault

4.3 STABILITY RESULTS

Table 4.3 summarizes the results for Local stability simulations for Summer Peak 2005 and Summer Peak 2010 using the Bonus Wind Turbine model for the new wind farm.

All faults were run for 10 seconds.

The detailed simulation plots for all faults are included in Appendix E.

There were no stability criteria violations observed after addition of GEN-2002-022 **except for FAULT_1_3PH, FAULT_2_1PH and FAULT_14_3PH**. During these faults, on loss of the Bushland-Potter Co. 230kV line, GEN-2002-022 becomes unstable. Following loss of Bushland-Potter Co 230kV line GEN-2002-022 wind farm is connected with weaker connection to Deaf Smith resulting in poor post-fault recovery, as Bonus wind turbines do not provide dynamic VAR support.

One option would be to intentionally cross-trip the GEN-2002-022 plant following loss of the Bushland-Potter 230 kV line.

Another option is to reduce the size of the GEN-2002-022 plant. The faults involving loss of Bushland-Potter Co. 230kV line were repeated with GEN-2002-022 at reduced output level (230MW). The system is stable with GEN-2002-022 at 230MW.

A QV analysis was performed on the Power flow case with Bushland-Potter Co. 230kV line out of service, which indicated a 22.6 Mvar deficit at the point of interconnection. Figure 4.1 shows the QV curve for the GEN-2002-022 Wind Farm at the POI. The wind farm has been modeled with enough capacitors on the 34.5 kV substation bus to give approximately unity p.f. at the point of interconnection with all lines in service.

A 25 Mvar SVC at the GEN-2002-022 POI 230kV bus was simulated as a possible solution to mitigate the voltage collapse by providing dynamic VAR support. This location did not work to avoid instability of the GEN-2002-022 generators. The SVC was moved to the 34.5 kV bus of the GEN-2002-022 substation, and the plant and system are stable following the critical fault. These results indicate that the center of the instability is located inside the wind farm facilities for this critical fault. Compare this to the previous GEN-2002-019 study where the wind farm is connected to a long radial 230 kV line in the post fault condition and locating the SVC on the 230 kV bus is acceptable.

Stability plots with the SVC are shown in Appendix F.

In summary, the proposed wind farm does not adversely impact the local stability except for the faults involving loss of Bushland-Potter Co 230kV line. To avert the voltage collapse following loss of Bushland-Potter Co 230kV line, three options are available: cross-tripping the plant, reducing the plant size to 230 MW, or installing a 25 Mvar SVC at the GEN-2002-022 34.5 kV substation bus to provide dynamic VAR support. Since the SVC has to be installed on the 34.5kV substation bus, the cost will be considered as a direct assignment to the Customer.

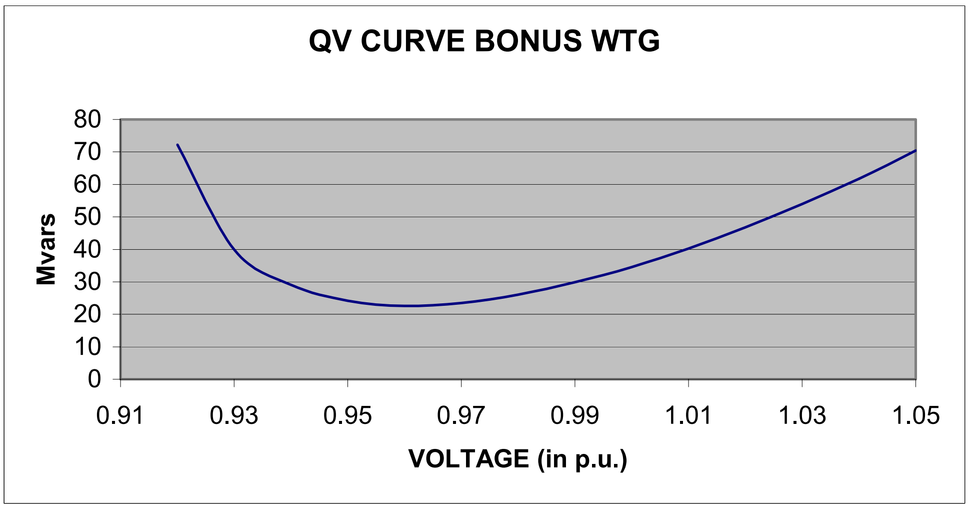

Fig 4.1 QV curve for GEN-2002-022 with Bushland-Potter Co 230kv line out of service

Table 4.3: Local Stability simulation results Summer Peak 2005 and 2010

FAULT	FAULT DEFINITION	RESULTS	
		SUMMER PEAK 05	SUMMER PEAK 10
FLT_1_3PH	3 Phase Fault at Potter Co. (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**
FLT_1_3PH-nt-230MW	Same as FLT_1_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022 at 230MW	Stable	Stable
FLT_2_1PH	SLG Fault at Potter (#50887) 230kV Trip Potter-Bushland 230kV line after 5cy Reclose Potter-Bushland 230kV line on fault after 20cy Trip Potter-Bushland 230kV line after 5cy and clear the fault	**GEN-2002-022 Unstable**	**GEN-2002-022 Unstable**
FLT_2_1PH-nt-230MW	Same as FLT_2_1PH, with delayed Undervoltage Trip settings for GEN-2002-019 and GEN-2002-022 at 230MW	Stable	Stable
FLT_3_3PH	3 Phase Fault at Finney (#50858) 345kV Trip Potter-Finney 230kV line after 4cy and Clear the fault	Stable	Stable
FLT_4_3PH	3 Phase Fault at Coulter (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable
FLT_5_1PH	SLG Fault at Finney (#51002) 115kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 115kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable
FLT_6_3PH	3 Phase Fault at Randall (#51021) 230kV Trip Harrington-Randall 230kV line after 5cy Reclose Harrington-Randall 230kV line on fault after 20cy Trip Harrington-Randall 230kV line after 5cy and clear the fault	Stable	Stable
FLT_6_3PH-nt	Same as FLT_6_3PH, with delayed undervoltage trip settings for GEN-2002-019	Stable	Stable
FLT_7_1PH	SLG Fault at Randall (#51021) 230kV Trip Bushland-Coulter 230kV line after 5cy Reclose Bushland-Coulter 230kV line on fault after 20cy Trip Bushland-Coulter 230kV line after 5cy and clear the fault	Stable	Stable
FLT_8_3PH	3 Phase Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable	Stable
FLT_9_1PH	SLG Fault at Deaf Smith (#51111) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable	Stable
FLT_10_3PH	3 Phase fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault	Stable	Stable

FAULT	FAULT DEFINITION	RESULTS	
		SUMMER PEAK 05	SUMMER PEAK 10
FLT_11_1PH	SLG fault at ELK city (#54153) 230kV Trip Elk City-Grapevine 230kV line after 5 cy Reclose Elk City-Grapevine 230kV line on fault after 20 cy Trip Elk City-Grapevine 230kV line after 5 cy and clear the fault	Stable	Stable
FLT_12_1PH	3 Phase Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault	Stable	Stable
FLT_13_1PH	SLG Fault at Terry Co (#51830) 115kV Trip Terry Co-Wolfforth Interchange 115kV line after 5cy Reclose Terry Co-Wolfforth Interchange 115kV line on fault after 20cy Trip Terry Co-Wolfforth Interchange 115kV line after 5cy and clear the fault	Stable	Stable
FLT_14_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Potter Co 230kV line after 5cy Reclose Bushland-Potter Co 230kV line on fault after 20cy Trip Bushland-Potter Co 230kV line after 5cy and clear the fault	Stable	Stable
FLT_14_3PH-nt-230MW	Same as FLT_14_3PH, with delayed Undervoltage Trip settings for GEN-2002-019 with GEN-2002-022 at 230MW	Stable	Stable
FLT_15_1PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland-Deaf Smith 230kV line after 5cy Reclose Bushland-Deaf Smith 230kV line on fault after 20cy Trip Bushland-Deaf Smith 230kV line after 5cy and clear the fault	Stable	Stable
FLT_16_3PH	3 Phase Fault at Bushland (#50993) 230kV Trip Bushland 230/115kV transformer after 5cy Reclose Bushland 230/115kV transformer on fault after 20cy Trip Bushland 230/115kV transformer after 5cy and clear the fault	Stable	Stable

5 CONCLUSIONS

A comprehensive range of fault cases defined by SPP has been run in for stability analysis.

The following conclusions are reached from the studies:

GEN-2002-022 with GE wind turbine generators

- ❑ Overall, the post-fault recoveries show stable system performance for GEN-2002-022 with GE wind turbine generators.
- ❑ The wind turbines do not trip with the standard under-voltage ride-through settings

GEN-2002-022 with Vestas wind turbine generators

- ❑ GEN-2002-022 and GEN-2002-019 will trip due to low voltage in case of VESTAS Wind turbine Generators for faults near the wind farm. Undervoltage protection trip settings are major factor influencing the GEN-2002-022 tripping.
- ❑ With delayed undervoltage trip settings, voltage collapse was observed following loss of Bushland- Potter Co. 230kV line because the Vestas turbines do not provide dynamic voltage support.
- ❑ The voltage collapse situation can be mitigated by reducing the wind farm (GEN-2002-022) output to 220MW, installing a dedicated cross-tripping scheme, or installing a 25 Mvar SVC at the GEN-2002-022 34.5kV substation bus to provide dynamic VAR support. Since the SVC has to be installed on the 34.5kV substation bus, the cost will be considered as a direct assignment to the Customer.
- ❑ Depending on quick under-voltage trip settings is not sufficient to eliminate the voltage collapse problem.

GEN-2002-022 with Bonus Wind Turbine Generators

- ❑ As the GEN-2002-022 with Bonus Wind Turbine was modeled without undervoltage protection, no undervoltage tripping observed for simulated faults.
- ❑ Following loss of Bushland-Potter Co 230kV line GEN-2002-022 becomes unstable.
- ❑ Following loss of Bushland-Potter co 230kV line, instability can be averted by reducing the wind farm (GEN-2002-022) output to 230MW, installing a dedicated cross-tripping scheme, or installing a 25 Mvar SVC at the GEN-2002-022 34.5kV substation bus to provide dynamic VAR support. Since the SVC has to be installed on the 34.5kV substation bus, the cost will be considered as a direct assignment to the Customer.

Appendices are not included in the SPP posting due to size restraints

APPENDIX A - GEN-2002-022 WIND FARM MODEL DEVELOPMENT

APPENDIX B - LOAD FLOW AND STABILITY DATA FOR GEN-2002-022

APPENDIX C - SIMULATION PLOTS (GE WTG)

APPENDIX D - SIMULATION PLOTS (VESTAS WTG)

APPENDIX E - SIMULATION PLOTS (BONUS WTG)

APPENDIX F - SIMULATION PLOTS (BONUS WTG with SVC)