Southwest Power Pool

Impact Study for Generation Interconnection Request GEN – 2002 – 019

SPP Coordinated Planning
(#GEN-2002-019)

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 and SPP for SPP Generation Interconnection request Gen-2002-019. 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.

GEN-2002-019 Interconnection Study

Issued: November 10, 2004

Prepared for Southwest Power Pool, Little Rock, AR

Report Number: 2004-10916-1

SUBMITTED BY:

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Electric Systems Consulting			**Technical Report**
GEN-2002-019 Interconnection Study	**No.** 2004-10916-1		
Prepared for Southwest Power Pool	**Dept.** **ESC**	Date 11/10/2004	Pages 22

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Reviewed by: W. Quaintance

Approved by:

Executive Summary

The main objective of this study was to assess the impact on stability of interconnecting the proposed GEN-2002-019 wind farm located in Carson County, Texas. This proposed wind farm would be interconnected to the Xcel Energy (SPS) transmission system and will have a nominal rating of 160 MW. The wind farm has previously been studied by ABB assuming Mitsubishi wind turbines (rated 1.0 MW each, model MWT-1000a) (Please, refer to report #2003-10875-1.r01.0 "GEN-2002-019 Wind Farm Interconnection Study"). On request of SPP and the wind farm developer, the proposed wind farm has now been studied assuming GE, Vestas and NEG Micon (NM82) wind turbine generators. A summary table for the stability results is shown on the next page.

The following conclusions are reached from the studies:

GEN-2002-019 with GE wind turbine generators

- Overall, the post-fault recoveries show stable system performance for GEN-2002-019 with GE wind turbine generators.

- The wind turbines do not trip with the standard under-voltage ride-through settings.

GEN-2002-019 with Vestas wind turbine generators

- GEN-2002-019 will trip due to low voltage in case of Vestas wind turbine generators for faults near the wind farm. Undervoltage protection settings are the major factor influencing the GEN-2002-019 tripping.

- With delayed undervoltage trip settings (i.e. undervoltage ride-through), voltage collapse is observed on loss of the Nichols-GEN-2002-019 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-2002-019) output to 120MW, installing a dedicated cross-tripping scheme, or providing a dynamic VAR source at the GEN-2002-019 Wind Farm substation (e.g. an SVC).

- The under-voltage tripping scheme should not be relied upon for mitigating the voltage collapse problem. A dedicated cross-tripping scheme would be required.

- The Vestas results should be repeated when updated Vestas model is released.

<u>GEN-2002-019 with NEG Micon (NM82) wind turbine generators</u>

- ❑ GEN-2002-019 will trip due to low voltage in case of NM82 wind turbine generators for the faults at the POI of the proposed wind farm. Undervoltage protection settings are the major factor influencing the tripping of GEN-2002-019.

- ❑ With delayed undervoltage trip settings, voltage collapse is observed on loss of Nichols-GEN-2002-019 230kV because NM82 wind turbines do not provide dynamic voltage support.

- ❑ The voltage collapse situation can be mitigated by reducing the wind farm (GEN-2002-019) output to 120 MW, installing a dedicated cross-tripping scheme, or providing a 125 Mvar SVC at the GEN-2002-019 Wind Farm substation.

- ❑ The under-voltage tripping scheme should not be relied upon for mitigating the voltage collapse problem. A dedicated cross-tripping scheme would be required.

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Summary Table For Gen-2002-019 Stability Results

FAULT	**FAULT DEFINITION**	**RESULTS**					
		GE		**VESTAS**		**NM82**	
		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 >Customer< Wind Farm (#99950) 230kV Trip >Customer<-Nichols 230kV line after 5cy Reclose >Customer<-Nichols 230kV line on fault after 20cy Trip >Customer<-Nichols 230kV line after 5cy and clear the fault	Stable	Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable
FLT_1_3PH-nt	Same as FLT_1_3PH, with higher undervoltage trip settings for GEN-2002-019	Not tested	Not tested	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**
FLT_1_3PH-120 MW	Same as FAULT_1_3PH with GEN-2002-019 at reduced output and undervoltage protection disabled	Not tested	Not tested	Stable	Stable	Stable	Stable
FLT_2_1PH	SLG fault at >Customer< Wind Farm (#99950) 230kV Trip >Customer<-Nichols 230kV line after 5cy Reclose >Customer<-Nichols 230kV line on fault after 20cy Trip >Customer<-Nichols 230kV line after 5cy and clear the fault	Stable	Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable
FLT_2_1PH-nt	Same as FLT_2_1PH, with higher undervoltage trip settings for GEN-2002-019	Not tested	Not tested	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**
FLT_2_1PH-120 MW	Same as FAULT_2_1PH with GEN-2002-019 at reduced MW output and undervoltage protection disabled	Not tested	Not tested	Stable	Stable	Stable	Stable

FAULT	FAULT DEFINITION	RESULTS					
		GE		VESTAS		NM82	
		SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10
FLT_3_3PH	3 Phase Fault at Grapevine 230kV Trip >Customer<-Grapevine 230kV line after 5cy Reclose >Customer<-Grapevine 230kV line on fault after 20cy Trip >Customer<-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable
FLT_3_3PH-nt	Same as FLT_3_3PH, with higher undervoltage trip settings for GEN-2002-019	Not tested	Not tested	Stable	Stable	Stable	Stable
FLT_4_1PH	SLG Fault at Grapevine230kV Trip >Customer<-Grapevine 230kV line after 5cy Reclose >Customer<-Grapevine 230kV line on fault after 20cy Trip >Customer<-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable
FLT_5_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_6_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

FAULT	FAULT DEFINITION	RESULTS					
		GE		VESTAS		NM82	
		SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10
FLT_7_3PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable
FLT_8_1PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault	Stable	Stable	Stable	Stable	Stable	Stable
FLT_9_3PH	3 Phase Fault at >Customer< Wind Farm (#99950) 230kV Trip >Customer<-Grapevine 230kV line after 5cy Reclose >Customer<-Grapevine 230kV line on fault after 20cy Trip >Customer<-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable
FLT_9_3PH-nt	Same as FLT_9_3PH, with higher undervoltage trip settings for GEN-2002-019	Not tested	Not tested	Stable	Stable	Stable	Stable
FLT_10_1PH	SLG Fault at >Customer< Wind Farm (#99950) 230kV Trip >Customer<-Grapevine 230kV line after 5cy Reclose >Customer<-Grapevine 230kV line on fault after 20cy Trip >Customer<-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.85PU), Stable

FAULT	FAULT DEFINITION	RESULTS					
		GE		VESTAS		NM82	
		SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10	SUMMER PEAK 05	SUMMER PEAK 10
FLT_10_1PH-nt	Same as FLT_10_1PH, with higher undervoltage trip settings for GEN-2002-019	Not tested	Not tested	Stable	Stable	Stable	Stable

TABLE OF CONTENTS

1. INTRODUCTION

A stability analysis is performed to study the impact of proposed GEN-2002-019 wind farm on stability. The proposed wind farm is located in the Carson Co, Texas. This proposed wind farm would be connected to the Xcel Energy (SPS) transmission system, and will have a nominal rating of 160 MW. The wind farm has previously been studied by ABB using Mitsubishi wind turbines (rated 1.0 MW each, model MWT-1000a) (Please refer report #2003-10875-1.r01.0 "GEN-2002-019 Wind Farm Interconnection Study"). On request of SPP and the wind farm developer, the proposed wind farm has now been studied for three new options:

- GE wind turbines (1.5MW each)
- Vestas wind turbines (1.8MW each)
- NEG Micon wind turbines, NM82 (1.65MW 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-2002-019]".

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

GEN-2002-019 with GE Wind Turbines

CASE DEVELOPMENT

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 proposed wind farm (GEN-2002-019) was added to the base cases 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 2.1 shows the list of redispatched generation.

Table 2.1a List of generators for redispatching for SP05

BUS NO	BUS NAME	UNIT	ORIGINAL MW	CHNG MW
50504	LP-MACK-269.0	2	30	0
52362	MADDX21 13.80	1	31	0
52211	CUNN11 13.80	1	70	0
52215	CUNN31 22.00	1	105	74

Table 2.1b List of generators for redispatching for SP10

BUS NO	BUS NAME	UNIT	ORIGINAL MW	CHNG MW
50504	LP-MACK-269.0	2	20	0
50913	NICHOL31 22.0	1	63	0
50911	NICHOL11 13.80	1	99	20

Wind Farm Power Flow Model

The GEN-2002-019 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 calculations that went into development of the GEN-2002-019 wind farm power flow model are given in Appendix A.

Ultimately, 108 identical 1.5MW GE turbine generators are modeled as single 162MW generator for developing the case with GE wind turbines. A PSS/E one-line drawing of the power flow model for the plant and surrounding buses is shown in Figure 2.1.

The IPLAN program ("GE15WIND9.IRF") provided with PSS/E DFIG model was used to model the GSU transformer and the generator.

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 proposed wind farm was represented by the PSS/E DFIG model for the GE 1.5 MW wind turbine generators. The power flow parameters used for this model were based on available information and the default parameters embedded in the setup files for the PSS/E DFIG. The stability model parameters were based on default data provided with the PSS/E DFIG 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

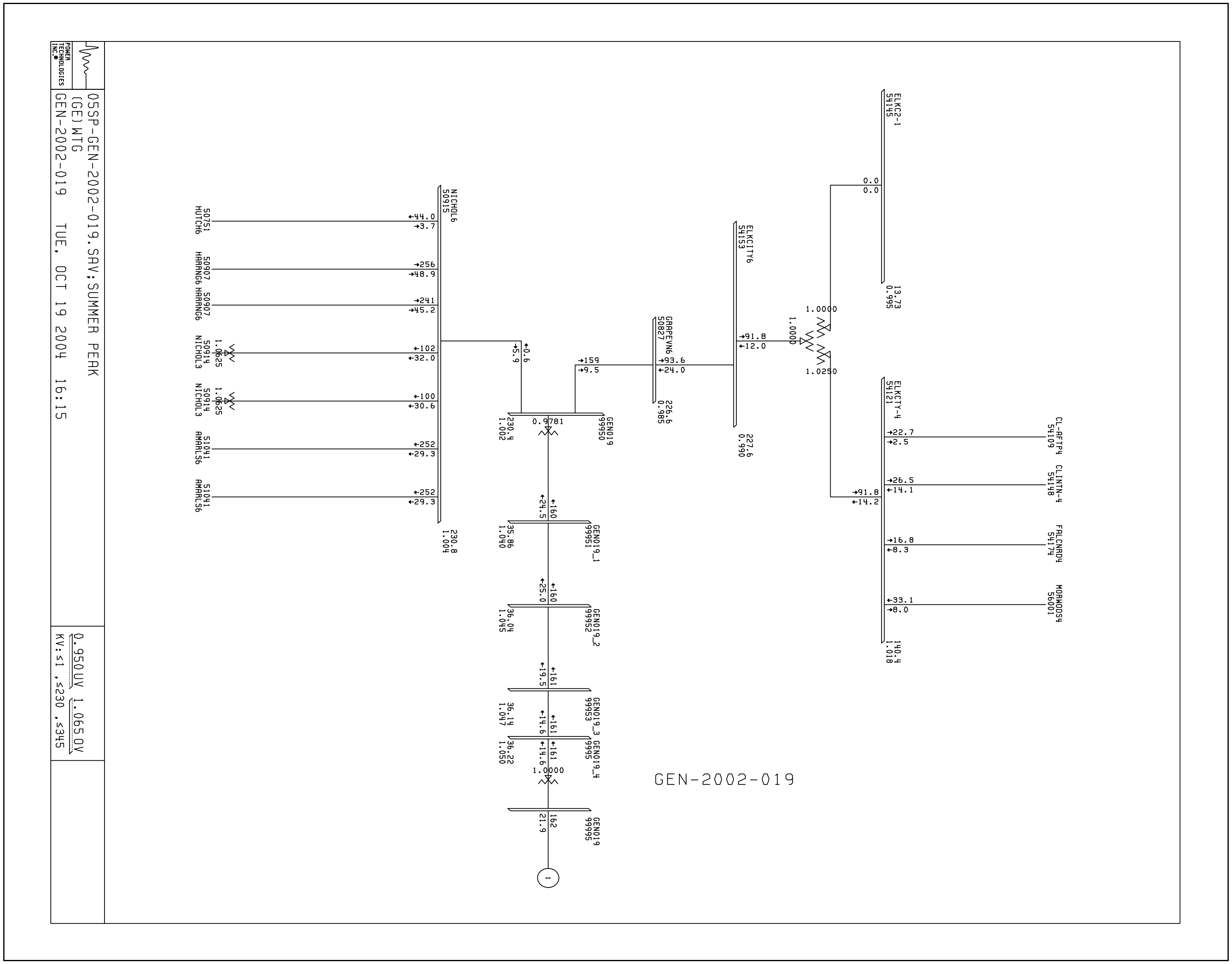

Figure 2.1 One-line Diagram for GEN-2002-019

2.2 STABILITY ANALYSIS

The fault scenarios considered for the stability assessment are listed in Table 2.2. The sequence impedances used to model the SLG faults were typical values calculated by ABB.

Table 2.2 Fault scenarios considered for stability assessment

FAULTS	FAULT DEFINITION
FLT_1_3PH	3 Phase Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Nichols 230kV line after 5cy Reclose GEN-2002-019-Nichols 230kV line on fault after 20cy Trip GEN-2002-019-Nichols 230kV line after 5cy and clear the fault
FLT_2_1PH	SLG fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Nichols 230kV line after 5cy Reclose GEN-2002-019-Nichols 230kV line on fault after 20cy Trip GEN-2002-019-Nichols 230kV line after 5cy and clear the fault
FLT_3_3PH	3 Phase Fault at Grapevine 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault
FLT_4_1PH	SLG Fault at Grapevine230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault
FLT_5_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_6_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_7_3PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault

FLT_8_1PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault
FLT_9_3PH	3 Phase Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault
FLT_10_1PH	SLG Fault at GEN-2002-019 Wind Farm(#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault

STABILITY RESULTS

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

All faults were run for 10 seconds.

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

In summary, stability assessment indicates that the GEN-2002-019 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 and no instability for the faults simulated in this study.

Turbine Shaft Oscillations

Simulation plots showed poorly damped oscillations in the speeds of local area wind farms (at #90964 and #90820) for all the faults. Figure 2.2 shows the speeds of the local area wind farm generators for fault 'FAULT_3_3PH'. This oscillation does not show up in the electrical power of the generators, and as such it is a purely mechanical mode of oscillation not affecting the electrical system. The default value for shaft damping in PSS/E Vestas TSHAFT model is 1.0 pu. We consider this to be unrealistically low and not an accurate representation of the actual wind turbine design.

To illustrate that the above oscillations are indeed attributable to the damping constant in the stability models of the local area wind farms, the shaft damping for the local area wind farms (at #90964 and #90820) was increased from 1.0 pu to 2.0 pu. Fault 'FAULT_3_3PH' was repeated. As shown in Figure 2.2, the oscillations in the local area wind farms are well damped with a higher shaft damping value.

Similar oscillations between the generator and turbine were seen in early versions of the PTI GE Wind model. The latest version has a higher damping value and does not show this issue. The Vestas model needs to be similarly updated.

Table 2.3 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 GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Nichols 230kV line after 5cy Reclose GEN-2002-019-Nichols 230kV line on fault after 20cy Trip GEN-2002-019-Nichols 230kV line after 5cy and clear the fault	Stable	Stable
FLT_2_1PH	SLG fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Nichols 230kV line after 5cy Reclose GEN-2002-019-Nichols 230kV line on fault after 20cy Trip GEN-2002-019-Nichols 230kV line after 5cy and clear the fault	Stable	Stable
FLT_3_3PH	3 Phase Fault at Grapevine 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable
FLT_4_1PH	SLG Fault at Grapevine230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable
FLT_5_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_6_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
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FLT_9_3PH	3 Phase Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable
FLT_10_1PH	SLG Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable

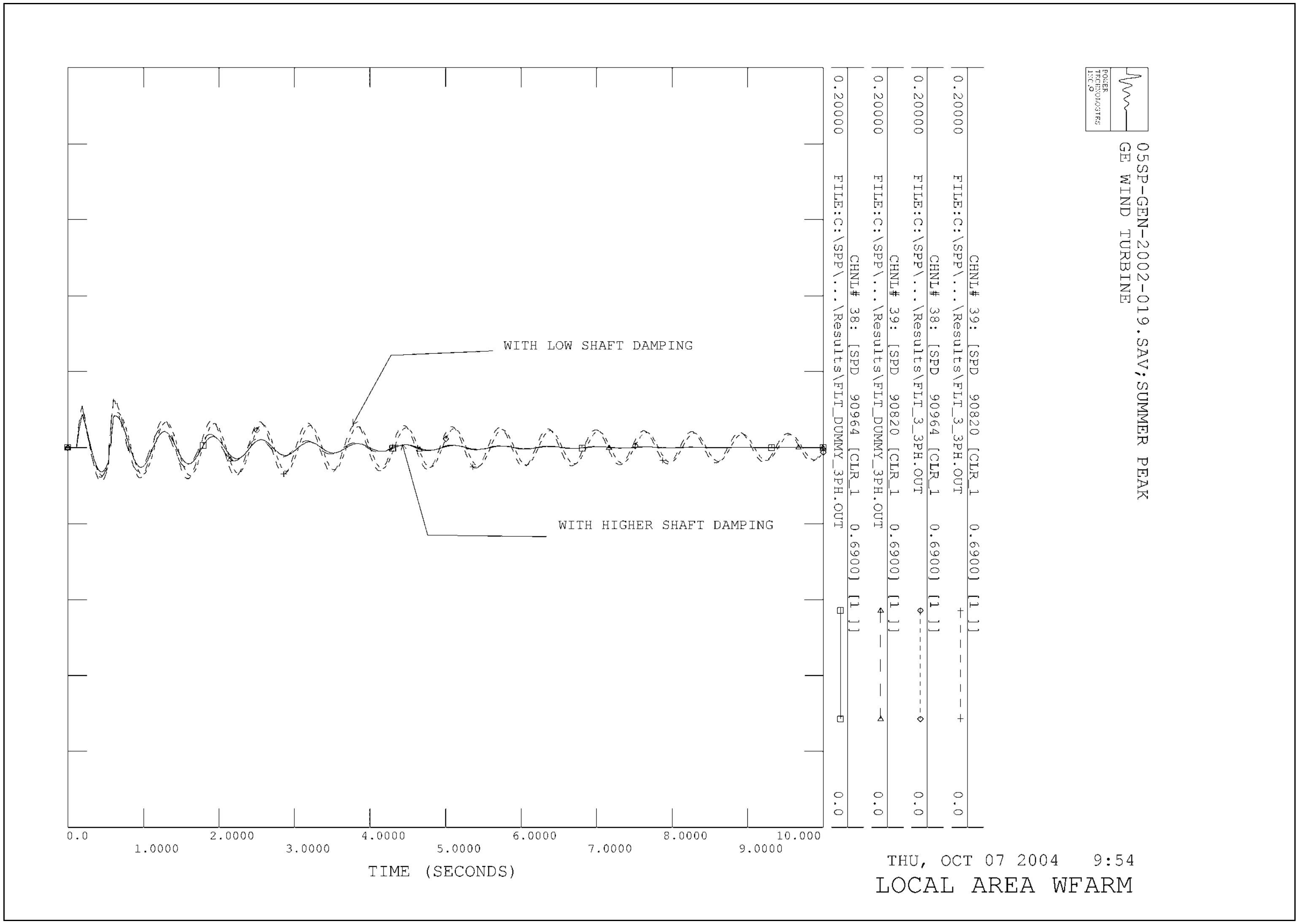

Figure 2.2 Generator Speed Oscillations in the Local Area Wind Farms, with shaft damping of 1.0 and 2.0

GEN-2002-019 with Vestas Wind Turbines

CASE DEVELOPMENT

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 proposed wind farm (GEN-2002-019) 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 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
50504	LP-MACK-269.0	2	30	0
52362	MADDX21 13.80	1	31	0
52211	CUNN11 13.80	1	70	0
52215	CUNN31 22.00	1	105	74

Table 3.1.b List of generators for redispatching for SP10

BUS NO	BUS NAME	UNIT	ORIGINAL MW	CHNG MW
50504	LP-MACK-269.0	2	20	0
50913	NICHOL31 22.0	1	63	0
50911	NICHOL11 13.80	1	99	22

Wind Farm Power Flow Model

The GEN-2002-019 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 calculations that went into development of the GEN-2002-019 wind farm model are shown in Appendix A.

Ultimately, 90 identical 1.8MW Vestas turbine generators are modeled as single 162MW generator for developing the case with Vestas wind turbines.

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

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 proposed wind farm was represented by the PSS/E Vestas model for the Vestas 1.8MW wind turbine generator. The power flow parameters used for this model were based on available information and the default parameters embedded in the setup files of the model. The stability parameters were based on default data provided with the 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%.

To create a Vestas generator model of the wind farm with a unity power factor at the 230 kV point of interconnection required 76 Mvar of capacitor bank located at the generation step-up transformer terminals and also 31 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.

2.3 STABILITY ANALYSIS

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

Table 3.2 Fault scenarios simulated for stability assessment

FAULT	FAULT DEFINITION
FLT_1_3PH	3 Phase Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Nichols 230kV line after 5cy Reclose GEN-2002-019-Nichols 230kV line on fault after 20cy Trip GEN-2002-019-Nichols 230kV line after 5cy and clear the fault
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FLT_4_1PH	SLG Fault at Grapevine230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault
FLT_5_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
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FAULT	FAULT DEFINITION
FLT_7_3PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault
FLT_8_1PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault
FLT_9_3PH	3 Phase Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault
FLT_10_1PH	SLG Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault

STABILITY RESULTS

Table 3.3 summarizes the results for stability simulations for Summer Peak 2005 and Summer Peak 2010.

All faults were run for 10 seconds.

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

The faults at the 230kV bus of GEN-2002-019 Wind farm resulted in tripping of the proposed wind farm (GEN-2002-019) by undervoltage protection, when the standard Vestas undervoltage protection is applied. A three-phase fault at Grapevine 230 kV also results in tripping of the wind farm. The undervoltage tripping will still occur at lower wind farm output as well due to the 0.75 p.u. instantaneous (80ms) undervoltage protection setting. Reducing the power output level of the proposed wind farm cannot mitigate the tripping condition, as the tripping condition is detected during the fault.

The faults for which GEN-2002-019 was tripping due to undervoltage protection were simulated with delayed undervoltage trip settings (i.e. ride-through) (named with extension "-nt" to the fault ID) as follows:

Undervoltage protection trip settings (i.e. Ride-through capacity)

Default Settings			Delayed 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-2002-019 plant remained on-line following the fault. There were no stability criteria violations observed with delayed undervoltage trip settings **except for FAULT_1_3PH and FAULT_2_1PH**. During FAULT_1_3PH and FAULT_2_1PH, on loss of the Nichols-GEN-2002-019 230kV line, GEN-2002-019 Wind Farm has only a weak connection to Grapevine and Elk City. As there is no voltage control capability in the Vestas machines or anywhere near the plant, these faults result in voltage collapse. As the PSS/E 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 response that still results in voltage collapse (see Figure 3.2).

A QV analysis was performed on the Power flow case with Nichols-GEN-2002-019 230kV line out of service, which indicated an 8.3Mvar deficit at the point of interconnection. Figure 3.1 shows the QV curve for the GEN-2002-019 Wind Farm 230 kV bus. 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.

An attempt at sizing an SVC to help the wind farm survive FAULT_1_3PH and FAULT_2_1PH was made. However, the poor performance of the Vestas wind turbine model caused invalid results. See the SVC sizing analysis in the NEG-Micon section below to get an idea of the SVC size that might be needed with Vestas wind turbines.

However, an accurate Vestas wind turbine model will be needed to properly size an SVC with these turbines.

To prevent voltage collapse, a dedicated cross-tripping scheme can be implemented for loss of the Nichols-GEN-2002-019 230 kV line if Vestas wind turbines are used.

Note that using 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 Nichols-GEN-2002-019 230 kV line. For example, a simple line tripping with no fault will not initially trip the GEN-2002-019 plant on under-voltage. However, voltage collapse will occur and will subsequently result in loss of this wind farm and probably the load centers in the Grapevine and Elk City areas, violating reliability criteria.

Reduced wind farm size for GEN-2002-019

The faults for which the voltage collapse was observed were repeated with GEN-2002-019 at reduced output level (120MW and 130MW) and with delayed trip settings. There was no voltage collapse and no other stability criteria violations observed for GEN-2002-019 at 120MW. For GEN-2002-019 at 130MW, there were no stability criteria violations observed, but the post-fault recovery of the voltage at GEN-2002-019 230kV bus indicates a stressed system. Because of the questionable response of the Vestas Model, FLT_1_3PH was repeated with a CIMTR3 model for GEN-2002-019 at 130MW. The CIMTR3 model showed extremely slow voltage recovery at 130 MW. Given the Vestas and CIMTR3 responses at 130 MW, this generation level is judged to be unacceptable. Thus, to avoid voltage collapse, GEN-2002-019 must be limited to 120MW. The plots for the FLT_1_3PH and FLT_2_1PH with reduced output levels (120MW and130MW) are included in Appendix D. The recommended 120 MW plant output was tested and confirmed in the 2010 case as well.

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 voltage setting is 0.9 pu by default. 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 jumps up and down at a high frequency, producing “scribbles” or noise in the plots.

Vestas engineers have indicated that the actual protection on the turbines is for over-current protection of the power electronics controlling the rotor resistance. When rotor current gets too high, the controls turn on the full rotor resistance. The PSS/E model is inaccurate because it senses terminal voltage. The wind farm developer should consult Vestas and be sure that this issue is addressed at commissioning.

Simulation plots from the runs showed poorly damped oscillations in the speeds of local area wind farms (at #90964 and #90820) for all the faults. These oscillations are attributable to the default damping used in the Vestas TSHAFT model of the local area wind farms. The oscillations are purely mechanical in nature and do not affect the electrical system. In section 2.3.1 of this report it has been illustrated that the oscillations of the local area wind farms will be damped out with a more realistic shaft damping constant. These oscillations are not attributable to the proposed wind farm.

In summary, it can be concluded that with the exception of faults involving loss of the Nichols-GEN-2002-019 230kV line, interconnection of the proposed wind farm (GEN-2002-019) with Vestas Wind Turbines Generators does not adversely affect the stability of other generators in the local area. For loss of the Nichols-GEN-2002-019 230kV line with Vestas turbines, the size of the plant must be reduced, a dedicated cross-tripping scheme must be installed, or a dynamic var source such as an SVC must be installed at the GEN-2002-019 substation.

As with the NEG-Micon generator the Vestas will require approximately 125 Mvar SVC at the 230 kV POI to provide dynamic VAR support. Depending on the final location of this SVC will determine whether the cost will be considered as a Network Upgrade or as direct assignment to the Customer.

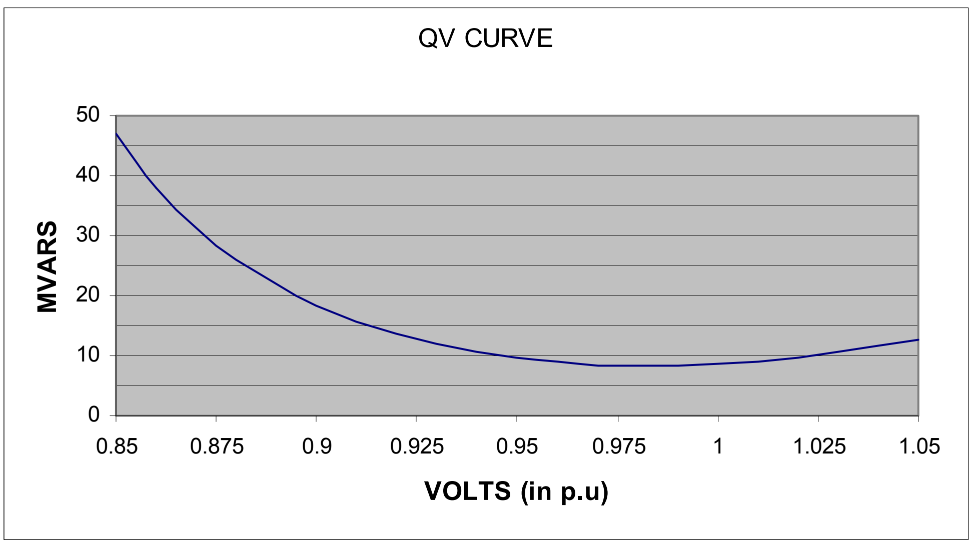

Figure 3.1 Q-V curve for GEN-2002-019 Wind Farm 230kV bus with Vestas wind turbines and Nichols - GEN-2002-019 Wind Farm 230 kV line out

Table 3.3 Stability simulation results Summer Peak 2005 and 2010, Vestas wind turbines

FAULT	FAULT DEFINITION	RESULTS	
		SUMMER PEAK 05	**SUMMER PEAK 10**
FLT_1_3PH	3 Phase Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Nichols 230kV line after 5cy Reclose GEN-2002-019-Nichols 230kV line on fault after 20cy Trip GEN-2002-019-Nichols 230kV line after 5cy and clear the fault	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable
FLT_1_3PH-nt	Same as FLT_1_3PH, with higher undervoltage trip settings for GEN-2002-019	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**
Flt_1_PH-nt-120MW	Same as FLT_1_3PH with delayed undervoltage protection and 120MW output	Stable	Stable
FLT_2_1PH	SLG fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Nichols 230kV line after 5cy Reclose GEN-2002-019-Nichols 230kV line on fault after 20cy Trip GEN-2002-019-Nichols 230kV line after 5cy and clear the fault	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable
FLT_2_1PH-nt	Same as FLT_2_1PH, with higher undervoltage trip settings for GEN-2002-019	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**
FLT_3_3PH	3 Phase Fault at Grapevine 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable
FLT_3_3PH-nt	Same as FLT_3_3PH, with higher undervoltage trip settings for GEN-2002-019	Stable	Stable
FLT_4_1PH	SLG Fault at Grapevine230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable
FLT_5_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_6_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_7_3PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault	Stable	Stable
FLT_8_1PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault	Stable	Stable
FLT_9_3PH	3 Phase Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable
FLT_9_3PH-nt	Same as FLT_9_3PH, with higher undervoltage trip settings for GEN-2002-019	Stable	Stable
FLT_10_1PH	SLG Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable	GEN-2002-019 tripped for Undervoltage (below 0.75PU), Stable
FLT_10_1PH-nt	Same as FLT_10_1PH, with higher undervoltage trip settings for GEN-2002-019	Stable	Stable

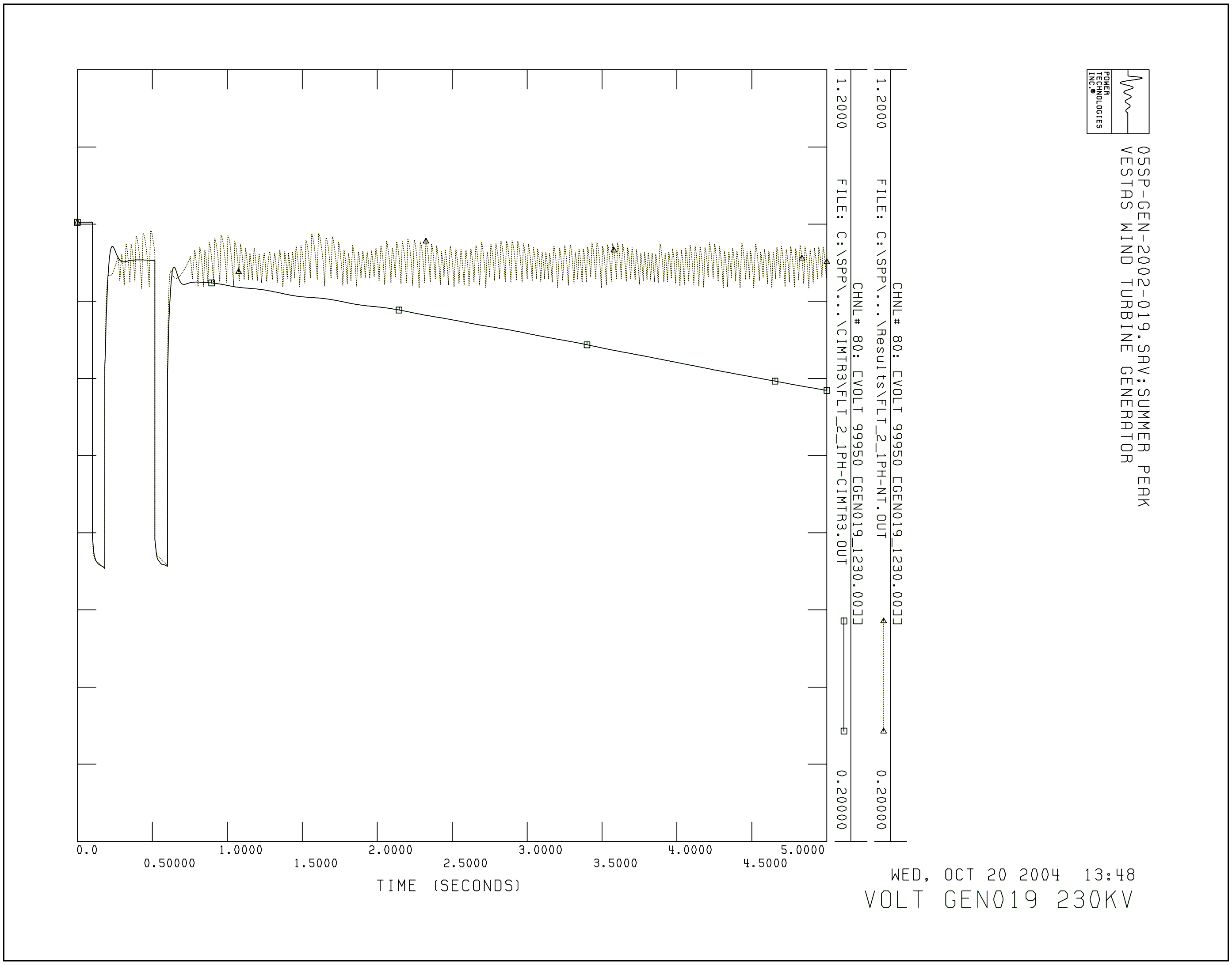

Figure 3.2 Voltage collapse comparison of Vestas and CIMTR3 model for GEN-2002-019

GEN-2002-019 with NEG Micon (NM82) Wind Turbines

CASE DEVELOPMENT

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 proposed wind farm (GEN-2002-019) 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 2.1 shows the list of redispatched generation.

Table 4.1a List of generators for redispatching for SP05

BUS NO	BUS NAME	UNIT	ORIGINAL MW	CHNG MW
50504	LP-MACK-269.0	2	30	0
52362	MADDX21 13.80	1	31	0
52211	CUNN11 13.80	1	70	0
52215	CUNN31 22.00	1	105	77

Table 4.1b List of generators for redispatching for SP10

BUS NO	BUS NAME	UNIT	ORIGINAL MW	CHNG MW
50504	LP-MACK-269.0	2	20	0
50913	NICHOL31 22.0	1	63	0
50911	NICHOL11 13.80	1	99	20

Wind Farm Power Flow Model

The GEN-2002-019 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 calculations that went into development of the GEN-2002-019 wind farm power flow model are given in Appendix A.

Ultimately, 99 identical 1.65MW NEG Micon (NM82) turbine generators are modeled as single 163MW generator for developing the case with NM82 wind turbines. The NM82 generator has been modeled with Full Load compensation and a capacitor bank at substation level to obtain unity p.f. at POI.

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 NM82 parameters were provided by SPP. The standard undervoltage protection scheme was modeled as per the NM82 datasheet.

To create the NEG-Micon generator model of the wind farm with a unity power factor at the 230 kV point of interconnection required 76 Mvar of capacitor bank located at the generation step-up transformer terminals and also 26 Mvar bank of capacitors located on the 34.5 kV bus. The use of the NEG-Micon 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.

2.4 STABILITY ANALYSIS

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 Fault scenarios considered for stability assessment

FAULTS	FAULT DEFINITION
FLT_1_3PH	3 Phase Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Nichols 230kV line after 5cy Reclose GEN-2002-019-Nichols 230kV line on fault after 20cy Trip GEN-2002-019-Nichols 230kV line after 5cy and clear the fault
FLT_2_1PH	SLG fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Nichols 230kV line after 5cy Reclose GEN-2002-019-Nichols 230kV line on fault after 20cy Trip GEN-2002-019-Nichols 230kV line after 5cy and clear the fault
FLT_3_3PH	3 Phase Fault at Grapevine 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault
FLT_4_1PH	SLG Fault at Grapevine230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault

FLT_5_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_6_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_7_3PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault
FLT_8_1PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault
FLT_9_3PH	3 Phase Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault
FLT_10_1PH	SLG Fault at GEN-2002-019 Wind Farm (#99950) 230kV Trip GEN-2002-019-Grapevine 230kV line after 5cy Reclose GEN-2002-019-Grapevine 230kV line on fault after 20cy Trip GEN-2002-019-Grapevine 230kV line after 5cy and clear the fault

STABILITY RESULTS

Table 4.3 summarizes the results for stability simulations for Summer Peak 2005 and Summer Peak 2010 using the NEG Micon (NM82) 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 E.

The faults at the GEN-2002-019 Wind Farm 230 kV bus resulted in tripping of the proposed wind farm (GEN-2002-019) by undervoltage protection, when the standard NM82 undervoltage protection is applied. A three-phase fault at Grapevine 230 kV also results in tripping of the wind farm. Reducing the power output level of the proposed wind farm cannot mitigate the tripping condition, as the tripping condition is detected during the fault.

The faults for which GEN-2002-019 was tripping due to undervoltage protection were simulated by disabling the undervoltage trip settings (named with extension "-nt" to the fault ID) as follows:

With the delayed trip settings, the GEN-2002-019 plant remained on-line following the fault. There were no stability criteria violations observed with delayed undervoltage trip settings **except for FAULT_1_3PH and FAULT_2_1PH**. During FAULT_1_3PH and FAULT_2_1PH, on loss of the Nichols-GEN-2002-019 230kV line, GEN-2002-019 Wind Farm is connected with a weak connection to Grapevine and Elk City. As there is no voltage control capability in the NM82 machines or anywhere near the plant, these faults result in voltage collapse.

A QV analysis was performed on the Power flow case with Nichols-GEN-2002-019 230kV line out of service, which indicated an 8.3Mvar deficit at the point of interconnection. Figure 4.1 shows the QV curve for the GEN-2002-019 Wind Farm 230 kV bus. 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.

Dynamic VAR support at the POI

An SVC at the GEN-2002-019 POI was studied as a possible solution to mitigate the voltage collapse by providing dynamic VAR support. An SVC of size 100 Mvar at the POI of the proposed wind farm was studied. GEN-2002-019 became unstable with only 100 Mvar SVC at POI. Next, an SVC of size 125 Mvar was studied. No stability violations were observed following loss of the Nichols - GEN-2002-019 230kV line. Detailed plots with SVC at POI of proposed wind farm are included in the Appendix F.

Cross-tripping

To prevent the voltage collapse with NM82 wind turbines, another option is a dedicated cross-tripping scheme for loss of the Nichols-GEN-2002-019 230 kV line.

Reduced Output Level for GEN-2002-019

The faults for which voltage collapse was observed were repeated with GEN-2002-019 at reduced output level (120MW and 130MW) and with delayed trip settings. There was no voltage collapse and no other stability criteria violations observed for GEN-2002-019 at 120MW. For GEN-2002-019 at 130MW, voltage collapse was observed in the both Summer Peak 2005 and 2010 cases. Thus, to avoid the voltage collapse, without any other reinforcements the output level of GEN-2002-019 must be limited to 120MW with NM82 wind turbine generators.

In summary, it can be concluded that the proposed wind farm does not adversely affect the stability of the generators in the local area except for the faults involving loss of the Nichols - GEN-2002-019 230kV line. For the loss of this line, voltage collapse was observed. The voltage collapse can be averted by reducing the output of GEN-2002-019 to 120MW, cross-tripping the GEN-2002-019 after the fault, or by installing a 125Mvar SVC at the GEN-2002-019 POI to provide dynamic VAR support. Depending on the final location of this SVC will determine whether the cost will be considered as a Network Upgrade or as direct assignment to the Customer.

Table 2.3 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 >Customer< Wind Farm (#99950) 230kV Trip >Customer<-Nichols 230kV line after 5cy Reclose >Customer<-Nichols 230kV line on fault after 20cy Trip >Customer<-Nichols 230kV line after 5cy and clear the fault	Stable	Stable
FLT_1_3PH-nt	Same as FLT_1_3PH, with higher undervoltage trip settings for GEN-2002-019	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**
FLT_1_3PH-120MW	Same as FAULT_1_3PH with GEN-2002-019 at 120MW output and undervoltage protection disabled	Stable	Stable
FLT_2_1PH	SLG fault at >Customer< Wind Farm (#99950) 230kV Trip >Customer<-Nichols 230kV line after 5cy Reclose >Customer<-Nichols 230kV line on fault after 20cy Trip >Customer<-Nichols 230kV line after 5cy and clear the fault	Stable	Stable
FLT_2_1PH-nt	Same as FLT_2_1PH, with higher undervoltage trip settings for GEN-2002-019	**Unstable, Voltage Collapse**	**Unstable, Voltage Collapse**
FLT_2_1PH-120MW	Same as FAULT_2_1PH with GEN-2002-019 at 120MW output and undervoltage protection disabled	Stable	Stable
FLT_3_3PH	3 Phase Fault at Grapevine 230kV Trip >Customer<-Grapevine 230kV line after 5cy Reclose >Customer<-Grapevine 230kV line on fault after 20cy Trip >Customer<-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable
FLT_3_3PH-nt	Same as FLT_3_3PH, with higher undervoltage trip settings for GEN-2002-019	Stable	Stable
FLT_4_1PH	SLG Fault at Grapevine230kV Trip >Customer<-Grapevine 230kV line after 5cy Reclose >Customer<-Grapevine 230kV line on fault after 20cy Trip >Customer<-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable

FAULT	FAULT DEFINITION	RESULTS	
		SUMMER PEAK 05	SUMMER PEAK 10
FLT_5_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_6_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_7_3PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault	Stable	Stable
FLT_8_1PH	3 Phase fault at Kirby (#50826) 115kV Trip Kirby-Grapevine 115kV line after 5 cy Reclose Kirby-Grapevine 115kv line on fault after 20 cy Trip Kirby-Grapevine 115kV line after 5 cy and clear the fault	Stable	Stable
FLT_9_3PH	3 Phase Fault at >Customer< Wind Farm (#99950) 230kV Trip >Customer<-Grapevine 230kV line after 5cy Reclose >Customer<-Grapevine 230kV line on fault after 20cy Trip >Customer<-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable
FLT_9_3PH-nt	Same as FLT_9_3PH, with higher undervoltage trip settings for GEN-2002-019	Stable	Stable
FLT_10_1PH	SLG Fault at >Customer< Wind Farm (#99950) 230kV Trip >Customer<-Grapevine 230kV line after 5cy Reclose >Customer<-Grapevine 230kV line on fault after 20cy Trip >Customer<-Grapevine 230kV line after 5cy and clear the fault	Stable	Stable
FLT_10_1PH-nt	Same as FLT_10_1PH, with higher undervoltage trip settings for GEN-2002-019	Stable	Stable

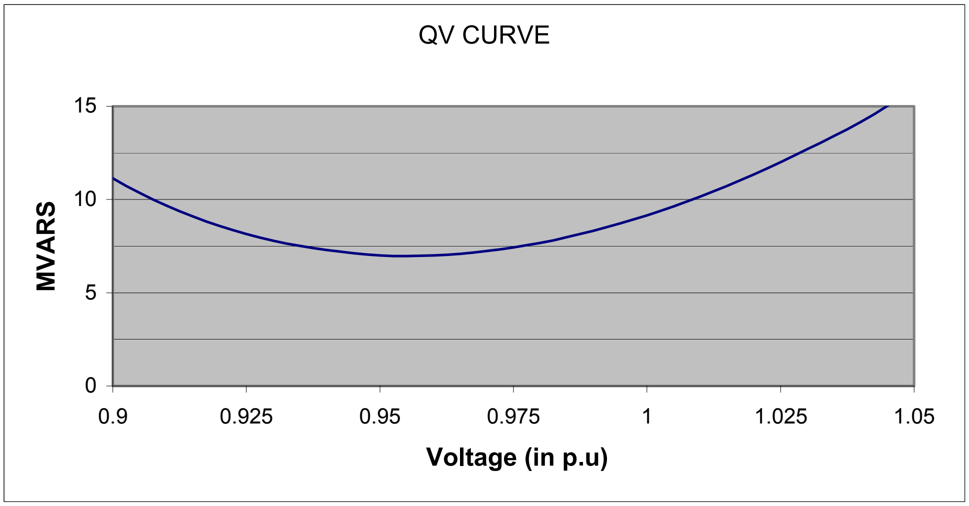

Fig. 4.1. QV Curve for GEN-2002-019 230kV bus with Gen-2002-019-Nichols 230kV line tripped

CONCLUSIONS

A comprehensive range of local faults defined by SPP has been simulated to study the impact of proposed GEN-2002-019 wind farm on local stability.

The following conclusions are reached from the studies:

GEN-2002-019 with GE wind turbine generators

- ❑ Overall, the post-fault recoveries show stable system performance for GEN-2002-019 with GE wind turbine generators.
- ❑ The wind turbines do not trip with the standard under-voltage ride-through settings.

GEN-2002-019 with Vestas wind turbine generators

- ❑ GEN-2002-019 will trip due to low voltage in case of Vestas wind turbine generators for faults near the wind farm. Undervoltage protection settings are the major factor influencing the GEN-2002-019 tripping.
- ❑ With delayed undervoltage trip settings (i.e. undervoltage ride-through), voltage collapse is observed on loss of the Nichols-GEN-2002-019 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-2002-019) output to 120MW, installing a dedicated cross-tripping scheme, or providing a dynamic VAR source at the GEN-2002-019 Wind Farm substation (e.g. an SVC).
- ❑ The under-voltage tripping scheme should not be relied upon for mitigating the voltage collapse problem. A dedicated cross-tripping scheme would be required.
- ❑ The Vestas results should be repeated when an updated Vestas model is released.

GEN-2002-019 with NEG Micon (NM82) wind turbine generators

- ❑ GEN-2002-019 will trip due to low voltage in case of NM82 wind turbine generators for the faults at the POI of the proposed wind farm. Undervoltage protection settings are the major factor influencing the tripping of GEN-2002-019.
- ❑ With delayed undervoltage trip settings, voltage collapse is observed on loss of Nichols-GEN-2002-019 230kV because NM82 wind turbines do not provide dynamic voltage support.

- The voltage collapse situation can be mitigated by reducing the wind farm (GEN-2002-019) output to 120 MW, installing a dedicated cross-tripping scheme, or providing a 125 Mvar SVC at the GEN-2002-019 Wind Farm substation.

- The under-voltage tripping scheme should not be relied upon for mitigating the voltage collapse problem. A dedicated cross-tripping scheme would be required.

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

APPENDIX A - GEN-2002-019 WIND FARM MODEL DEVELOPMENT

APPENDIX B - LOAD FLOW AND STABILITY DATA USED FOR STUDY

APPENDIX C - SIMULATION PLOTS FOR STABILITY ANALYSIS (GE WTG)

APPENDIX D - SIMULATION PLOTS FOR STABILITY ANALYSIS (VESTAS WTG)

APPENDIX E - SIMULATION PLOTS FOR STABILITY ANALYSIS (NEG Micon-NM82 WTG)

APPENDIX F - SIMULATION PLOTS FOR STABILITY ANALYSIS (SVC WITH NEG MICON)