SPP Southwest Power Pool

Impact Study for Generation Interconnection Request GEN – 2003 – 019

SPP Coordinated Planning
(#GEN-2003-019)

June 2005

Summary

Pterra LLC performed the following Study at the request of the Southwest Power Pool (SPP) for Generation Interconnection request Gen-2003-019. The request for interconnection was placed with SPP in accordance with SPP's Open Access Transmission Tariff, which covers new generation interconnections on SPP's transmission system.

Pursuant to the tariff, Pterra LLC was asked to perform a detailed Impact Re-Study of the generation interconnection request to satisfy the Impact Study Agreement executed by the requesting customer and SPP.

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

To this end SPP recommends that the Customer strongly consider these reliability requirements of the wind farm based on the FERC final rule.

GE 1.5 MW Wind Turbine Generators

The study found that for 2 of the 22 faults studied in the summer case and 3 of the 22 faults studied in the winter case with the GE 1.5 MW standard protection scheme allowed the wind farm to trip due to high frequency.

Vestas 1.8 MW Wind Turbine Generators

The study found that for 13 of the 22 faults studied in the summer case and 2 of the 22 faults studied in the winter case with the Vestas 1.8 MW standard protection package scheme allowed the wind farm to trip due to low voltage. The study also found that 9 of the 22 faults studied in the summer case and 2 of the 22 faults studies in the winter case with the Vestas 1.8 MW standard protection package encountered stability issues.
The study found, by adding the Vestas AGO4 protection package, two (2) 10 Mvar capacitor banks with two (2) 5 Mvar SVC's the simulation results indicated only tripping or stability of the Farm switching station to Rose Hill 345 kV line

(FLT13PH). As noted in the report the Customer shall investigate that implementation of an automatic switching scheme that will trip the 230 kV line segment from the wind farm tap to Knoll 230 kV simultaneously with the other 230 kV line segment from Summit to the wind farm tap.

Based on the study results the GE standard ride through package for the GE 1.5 MW WTG's satisfy the first and second FERC requirements noted above. Based on the study results the Vestas AGO4 protection package with the capacitor banks and the SVC will satisfy the first and second FERC requirements noted above.

Pterra Consulting

Report No. R114-05

"Impact Study for Generation Interconnection Request GEN-2003-019"

Submitted to

The Southwest Power Pool

June 2005

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Report No. R114-05

"Impact Study for Generation Interconnection Request GEN-2003-019"

1. Executive Summary

This report presents the stability simulation findings of the impact study of a proposed interconnection (Gen-2003-019). The analysis was conducted through the Southwest Power Pool Tariff for a 230 kV interconnection for 250 MW wind farm in Lincoln County, Kansas. This wind farm would be interconnected to a new 230 kV three-breaker ring bus on the Knoll to Summit line jointly owned by WERE and MIDW. The customer has asked for an Impact study case of 100% MW. Two types of wind turbine generators were studied according to the customer request; GE 1.5 MW and Vestas V-80 wind turbines.

Two base cases each comprising of a power flow and corresponding dynamics database for 2006 summer and winter were provided by SPP. Transient stability simulations were conducted with the proposed wind farm in service with a full output of 250 MW. In order to integrate the proposed 250 MW wind farm in SPP system, the existing generation in the SPP footprint was re-dispatched as provided by SPP.

Twenty two (22) contingencies were considered for the transient stability simulations which included 3-phase faults, as well as, 1-phase to ground faults, at the locations defined by SPP.

1.1 GE 1.5 MW Wind Turbine Generators

For GE 1.5 MW wind turbine generator (WTG), the proposed wind generators were modeled with under/over voltage/frequency ride through protection. The settings were in accordance with standard or default settings. The simulations using the GE WTG conducted in the study did not find any angular or voltage instability problems for the twenty two contingencies. However, tripping of the wind farm was observed as follows:

With GE 1.5 MW WTGs for peak summer and winter loading conditions, the proposed 250MW wind farm tripped due to relay actuation in the following disturbances:

- Disturbances #1, and #2 (3-phase and 1-phase faults respectively, at Summit 230 kV bus). The fault clearing procedures require tripping of the 230 kV line segment from Summit to the wind farm tap.

- Disturbances #11, and #12 (3-phase and 1-phase faults, respectively, at Summit 345 kV bus); and disturbances #13, and #14 (3-phase and 1-phase faults, respectively, at Summit 230 kV bus). Tripping of the proposed 250 MW wind farm was due to high frequency excursions.

- For the winter case, the results show that some of the wind farm units trip for disturbance #3 (Fault on the Wind Farm Gen-2003-019 Switching Station to Knoll 230 kV line, near Knoll) because of high frequency excursion.

Based on the trips the following recommendations are made.

- It is recommended that implementation of an automatic switching scheme that will trip the 230 kV line segment from the wind farm tap to Knoll 230 kV simultaneously with the other 230 kV line segment from Summit to the wind farm tap be considered. This way, the wind farm will be tripped as part of the fault clearing procedures.

- The threshold settings and time durations for tripping the GE 1.5 MW WTGs vary significantly from the standard ride through to the low voltage ride through controls. Consequently, in order to avoid the reported tripping, the customer shall consider revised settings for both frequency and the voltage relays by using the low voltage ride through settings per the manufacturer.

1.2 Vestas 1.8 MW Wind Turbine Generators

With Vestas 1.8 MW WTG, the proposed 250 MW wind farm was initially modeled with under/over voltage/frequency ride through protection. The settings were in accordance with standard or default settings. In order to achieve unity power factor at the proposed wind farm 34.5 kV interconnection points, two capacitors banks of 10 and 5 MVAR would be needed. The simulation results showed that:

- The proposed 250 MW wind farm tripped for thirteen (13) disturbances (disturbances # 1, 2, 3, 5, 6, 11, 12, 13, 14, 15, 17, 19, and 21) out of the twenty two (22) disturbances simulated. The trippings were all due to relay actuation on low voltage. The standard protection settings would trip the wind turbine at voltages equal to or less than 0.75 P.U for time duration of at least 0.08 seconds. This suggests the implementation of the Advanced Grid Option 4 (AGO4) for the Vestas wind turbine. AGO4 allows the wind turbine to withstand grid voltages as low as 0.5 P.U for up to 0.2 seconds.

- Further analysis for those disturbances where there was no tripping of the proposed 250 MW wind farm showed that post-disturbance voltage did not recover fully and oscillatory voltage behavior was observed. Consequently, dynamic voltage support is recommended comprising of two 5 MVAR SVCs located at the 34.5 kV interconnection points. The SVCs were set to float during normal conditions with MVAR outputs close to zero.

Simulations were repeated with AGO4, capacitor banks, and the proposed SVCs in place; the simulation results show no tripping of the proposed 250 MW wind farm for the studied twenty two (22) disturbances. However, for disturbances #1 and #2, the simulation results show that the proposed 250 MW wind farm needs a huge amount of reactive power to stabilize the post-disturbance voltage.

Based on the trips the following recommendations are made.

- It is recommended that implementation of an automatic switching scheme that will trip the 230 kV line segment from the wind farm tap to Knoll 230 kV simultaneously with the other 230 kV line segment from Summit to the wind farm tap be considered. This way, the wind farm will be tripped as part of the fault clearing procedures.

- It is recommended that the Customer use the Vestas 1.8 MW WTG AGO4 with two (2) 10 Mvar capacitor banks and two (2) 5 Mvar SVC's to provide stable performance and be able to ride through the faults as shown by the Impact Study. This way the 250 MW wind farm will provide stable performance on the SPP system.

2. Introduction

2.1 Project Overview

The proposed 250MW wind farm would be interconnected via a three-breaker ring bus on the Knoll to Summit 230 kV line. A new 230 kV line from the three-breaker ring bus to the wind farm collector bus will be built. Figure 1 shows the interconnection diagram of the proposed GEN-2003-019 project to the 230 kV transmission network. The detailed connection diagram of the wind farm was provided by SPP.

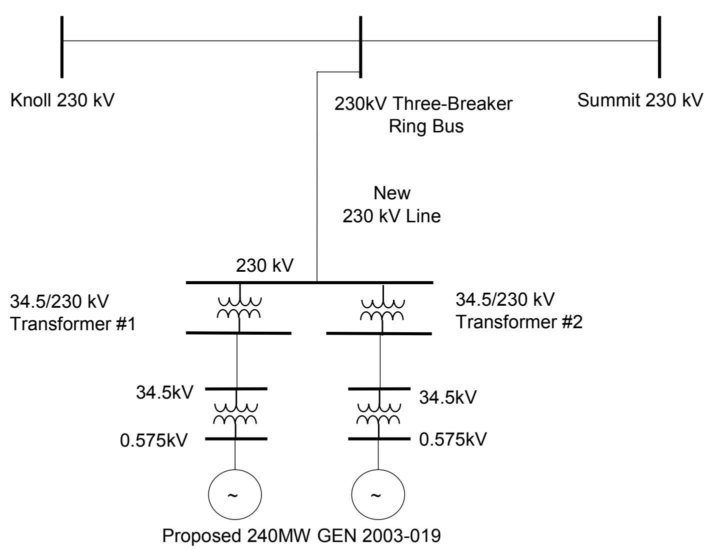

Figure 1 Interconnection Plan for GEN-2003-019 to the 230 kV System

In order to integrate the proposed 250MW wind farm in SPP system as an Energy Resource, existing generation in the following areas SWPA, AEPW, GRRP, OKGE, WFEC, SPS, MIDW, WERE, KACP, EMDE, and SPRM was scaled down by 250 MW.

In order to simplify the model of the wind farm while capturing the effect of the different impedances of cables (due to change of the conductor size and length), the wind turbines connected to the same 34.5kV feeder end points were aggregated into one equivalent unit. An equivalent impedance of that feeder is represented by taking the equivalent series impedances of the different feeders connecting the wind turbines. Using this approach, the proposed 250MW wind farm was modeled with 50 equivalent units (using GE 1.5 MW WTGs) and, alternatively, as 49 equivalent units (using Vestas 1.8 MW WTGs) as shown in Figures 2 and 3 respectively. The number in each circle in the diagram shows the number of individual wind turbine units that were aggregated at that bus. SPP provided the impedance values for the different feeders at 34.5kV level. SPP provided the data for the following equipment:

1. 34.5kV feeders
2. Generating unit step up transformers
3. 230kV/34.5kV transformers

Data for the new 230kV line were assumed to be similar to those of the 230kV line from Summit to Knoll.

In addition, Gen 2002-026, which was already modeled in the provided cases, was rolled up to full nameplate rating of 121 MW. Generation re-dispatch for the existing SPP footprint generation was adjusted to maintain overall generation level.

2.2 Objective

The objective of the study is to determine the impact on system stability of connecting the proposed 250MW wind farm to SPP's 230 kV transmission system.

3. Stability Analysis

3.1 Modeling of the GE 1.5 MW Wind Turbine Generators

Equivalents for the wind turbine and generator step-up (GSU) transformer in the load flow case were modeled. For the stability simulations, the GE 1.5 MW wind turbine generators were modeled using the latest GE wind turbine model set. Figure 2 shows the GE 1.5 MW Wind Farm equivalent of the proposed GEN-2003-019 project connected to the 230 kV transmission network. The detailed data used to create the equivalent of the wind farm was provided by SPP.

Table 1 GE 1.5 MW Wind Generator Data

Parameter	Value
BASE KV	0.575
WTG MBASE	1.667
TRANSFORMER MBASE	1.75
TRANSFORMER R ON TRANSFORMER BASE	0.0077
TRANSFORMER X ON TRANSFORMER BASE	0.0579
GTAP	1.05
PMAX (MW)	1.5
PMIN	0.0
RA	0.00706
LA	0.1714
LM	2.904
R1	0.005
L1	0.1563
INERTIA	0.57
DAMPING	0.0
QMAX (MVAR)	0.49
QMIN (MVAR)	-0.73

The wind turbine generators have ride-through capability for voltage and frequency. Detailed relay settings are shown in the following tables.

Table 2 Over/Under Frequency Relay Settings for GE Wind Turbine

Frequency Settings in Hertz	Time Delay in Seconds	Breaker time in Seconds
F ≤ 56.5	0.02	0.15
56.5 < F ≤ 57.5	10.0	0.15
61.5 < F ≤ 62.5	30.0	0.15
F ≥ 62.5	0.02	0.15

Table 3 Over/Under Voltage Relay Settings for GE Wind Turbine

Voltage Settings Per Unit	Time Delay in Seconds	Breaker time in Seconds
V ≤ 0.30	0.02	0.15
0.30 < V ≤ 0.70	0.10	0.15
0.70 < V ≤ 0.75	1.00	0.15
0.75 < V ≤ 0.85	10.0	0.15
V ≥ 1.10	1.00	0.15
1.10 > V ≥ 1.15	0.10	0.15
1.15 > V ≥ 1.3	0.02	0.15

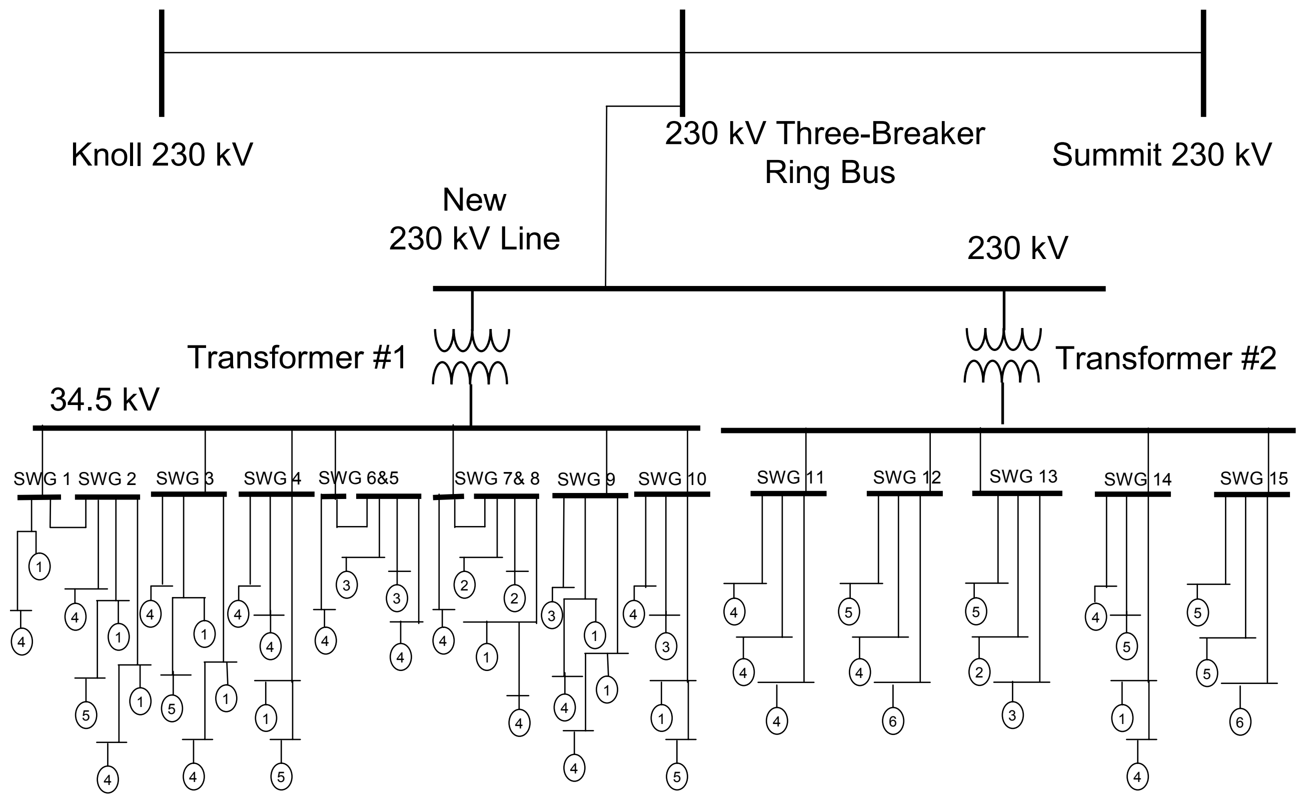

Figure 2 Wind Farm Equivalent Representation in Load Flow (GE 1.5 MW WTG)

3.2 Modeling of the Vestas 1.8 MW Wind Turbine Generators

Equivalents for the wind turbine and generator step-up (GSU) transformer in the load flow case were modeled. For the stability simulations, the Vestas 1.8 MW wind turbine generators were modeled using the latest Vestas wind turbine model set. Figure 3 shows the Vestas 1.8 MW Wind Farm equivalent of the proposed GEN-2003-019 project connected to the 230 kV transmission network. The detailed data used to create the equivalent of the wind farm was provided by SPP.

Table 4 Vestas 1.8 MW Wind Generator Data

Parameter	Value
BASE KV	0.69
WTG MBASE	2
TRANSFORMER MBASE	1.85
TRANSFORMER R ON TRANSFORMER BASE	0
TRANSFORMER X ON TRANSFORMER BASE	0.075
GTAP	1
PMAX	1.8
PMIN	0
RA	0.00489
LA	0.12602
LM	6.8399
R_ROT_MACH	0.004419
L1	0.18084
INERTIA	0.644
DAMPING	0

The wind turbine generators have standard ride-through capability for voltage and frequency. Detailed standard relay settings are shown in the following tables.

Table 5 Over/Under Frequency Relay Settings for Vestas Wind Turbine

Frequency Settings in Hertz	Time Delay in Seconds	Breaker time in Seconds
$F \leq 57$	0.02	0.08
$57 < F < 62.0$	Continuous	0.08
$F \geq 62.5$	0.02	0.08

Table 6 Over/Under Voltage Relay Settings for Vestas Wind Turbine

Voltage Settings Per Unit	Time Delay in Seconds	Breaker time in Seconds
$V \leq 0.75$	0.08	0.08
$0.75 < V \leq 0.85$	0.40	0.08
$0.85 < V \leq 0.94$	60.0	0.08
$V \geq 1.135$	0.2	0.08

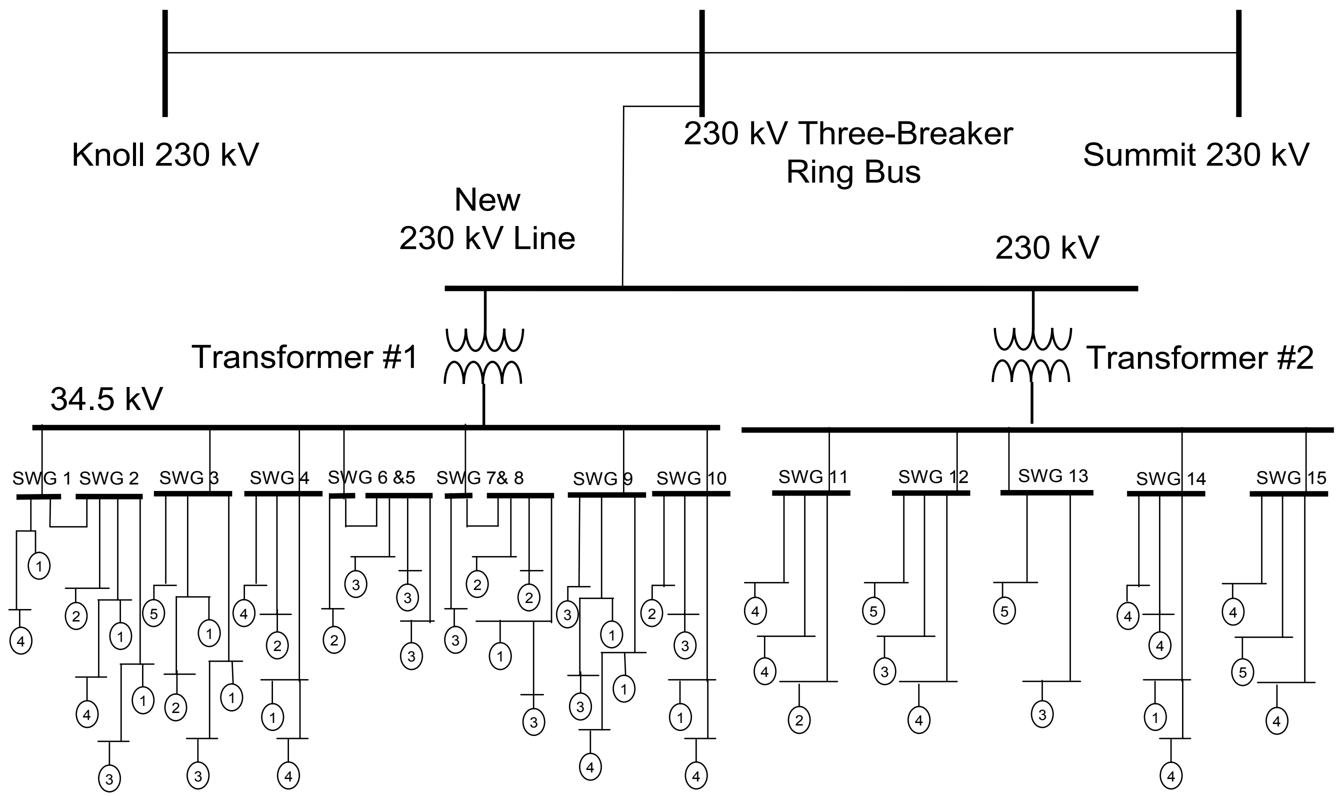

Figure 3 Wind Farm Equivalent Representation in Load Flow (Vestas 1.8 MW WTG)

3.3 Assumptions

The following assumptions were adopted for the study:

1. Constant maximum and uniform wind speed for the entire period of study.
2. Wind turbine control models with their default values.
3. Under/over voltage/frequency protection set to standard manufacturer data.

3.4 Contingencies Simulated

Twenty two (22) contingencies were considered for the transient stability simulations which included three phase faults, as well as single phase line faults, at the locations defined by SPP. Single-phase line faults were simulated by applying a fault impedance to the positive sequence network at the fault location to represent the effect of the negative and zero sequence networks on the positive sequence network. The fault impedance was computed to give a positive sequence voltage at the specified fault location of approximately 60% of pre-fault voltage. This method is in agreement with SPP current practice. Table 7 shows the list of simulated contingencies. The table also shows the fault clearing time and the time delay before re-closing for all the study contingencies.

Table 7 List of Contingencies

Dist. No.	Dist. Name	Description
1	FLT13PH	Fault on the Wind Farm Gen-2003-019 Switching Station (167) to Summit (56873) 230 kV line, near Summit a. Apply Fault at the Summit bus (56873). b. Clear Fault after 5 cycles by removing the line from Gen-2003-019 Switching Station (167) to Summit (56873) c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
2	FLT21PH	Single phase fault and sequence like Cont. No. 1
3	FLT33PH	Fault on the Wind Farm Gen-2003-019 Switching Station 167) to Knoll (56558) 230 kV line, near Knoll. a. Apply fault at the Knoll bus (56558). b. Clear fault after 5 cycles by removing the line from the Gen-2003-019 Switching Station (167) to Knoll (56558). c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
4	FLT41PH	Single phase fault and sequence like Cont. No. 3
5	FLT53PH	Fault on the Circle (56871) to Mullergren (58799) 230 kV line, near Circle. a. Apply Fault at the Circle bus (56871). b. Clear fault after 5 cycles by removing the line from Circle (56871) to Mullergren (58799). c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
6	FLT61PH	Single phase fault and sequence like Cont. No. 5
7	FLT73PH	Fault on the Heizer (56601) to Mullergren (58799) 230 kV line, near Heizer. a. Apply Fault at the Heizer bus (56601). b. Clear fault after 5 cycles by removing the line Heizer (56601) to Mullergren (58799).

Dist. No.	Dist. Name	Description
		c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
8	FLT81PH	Single phase fault and sequence like Cont. No. 7
9	FLT93PH	Fault on the Manhattan (56861) to Concordia (58758) 230 kV line, near Manhattan. a. Apply fault at the Manhattan bus (56861). b. Clear fault after 5 cycles by tripping the line from Manhattan (56861) to Concordia (58758). c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
10	FLT101PH	Single phase fault and sequence like Cont. No. 9
11	FLT113PH	Fault on the Jefferies Energy Center (56766) to Summit (56773) 345 kV line, near Summit. a. Apply fault at the Summit bus (56773). b. Clear fault after 5 cycles by tripping the line from Jefferies Energy Center (56766) to Summit (56773). c. Wait 30 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
12	FLT121PH	Single phase fault and sequence like Cont. No. 11
13	FLT133PH	Fault on the Morris (56863) to Summit (56873) 230 kV line, near Summit. a. Apply fault at the Summit bus (56873). b. Clear fault after 5 cycles by tripping the line Morris (56863) to Summit (56873). c. Wait 20 cycles, and then re-close line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
14	FLT141PH	Single phase fault and sequence like Cont. No. 13
15	FLT153PH	Fault on the Knoll (56561) to Redline (56605) 115 kV line, near Knoll. a. Apply fault at the Knoll bus (56561). b. Clear fault after 5 cycles by tripping the line from Knoll

Dist. No.	Dist. Name	Description
		(56561) to Redline (56605). c. Wait 15 cycles, and then re-close line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
16	FLT161PH	Single phase fault and sequence like Cont. No. 15
17	FLT173PH	Fault on the Hays (56562) to Vine (56591) 115 kV line, near Hays. a. Apply fault at the Hays bus (56562). b. Clear fault after 5 cycles by tripping the line from Hays (56562) to Vine (56591). c. Wait 15 cycles, and then re-close the line in (b) back into the fault. *d.* Leave fault on for 5 cycles, then trip the line in (b) and remove fault
18	FLT181PH	Single phase fault and sequence like Cont. No. 17
19	FLT193PH	Fault on the Knoll (56561) to South Hays (56553) 115 kV line, near Knoll. e. Apply fault at the Hays bus (56561). f. Clear fault after 5 cycles by tripping the line from Knoll (56561) to South Hays (56553). g. Wait 15 cycles, and then re-close the line in (b) back into the fault. *h.* Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
20	FLT201PH	Single phase fault and sequence like Cont. No. 19
21	FLT213PH	Fault on the Knoll (56561) to Saline (56551) 115 kV line, near Knoll. a. Apply fault at the Knoll bus (56561). b. Clear fault after 5 cycles by tripping the line from Knoll (56561) to Saline (56551). c. Wait 15 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
22	FLT221PH	Single phase fault and sequence like Cont. No. 21

3.5 Simulation Results

Simulations were performed with a 0.1-second steady-state run followed by the appropriate disturbance as described in Table 7. Simulations were run for a minimum 10-second duration to confirm proper machine damping.

3.5.1 GE 1.5 MW Wind Turbine Generators

With GE 1.5 MW WTGs, the proposed 250 MW wind generators were initially modeled with under/over voltage/frequency ride through protection. The settings are in accordance with standard or default settings shown in Tables 2 and 3. From the simulation results obtained, the following conclusions can be made when using GE 1.5 MW WTGs for summer and winter cases:

- Disturbances #1, and #2 (3-phase and 1-phase faults, respectively, at Summit 230 kV bus). The fault clearing procedures require tripping of the 230 kV line segment from Summit to wind farm tap. We recommend that an automatic switching scheme be implemented which will trip the 230 kV line segment from the wind farm tap to Knoll 230 kV simultaneously with the other 230 kV line segment from Summit to the wind farm tap. This way, the wind farm will be tripped as part of the fault clearing procedures.

- Disturbances #11, and #12 (3-phase and 1-phase faults, respectively, at Summit 345 kV bus); and disturbances #13, and #14 (3-phase and 1-phase faults respectively, at Summit 230 kV bus). Tripping of the proposed 250 MW was due to high frequency excursions.

- For the winter case, the results show that part of the wind farm units trip for disturbance #3 (Fault on the Wind Farm Gen-2003-019 Switching Station (167) to Knoll (56558) 230 kV line, near Knoll) because of high frequency excursion.

- The simulation results are summarized in Table 8 for GE 1.5 MW WTG

Table 8 Summary of the Simulation Results for GE 1.5 MW WTG

Cont. No.	Cont. Name	Summer Peak	Winter Peak
1	FLT13PH	OF	OF
2	FLT21PH	OF	OF
3	FLT33PH	--	OF
4	FLT41PH	--	--
5	FLT53PH	--	--
6	FLT61PH	--	--
7	FLT73PH	--	--

Cont. No.	Cont. Name	Summer Peak	Winter Peak
8	FLT81PH	--	--
9	FLT93PH	--	--
10	FLT101PH	--	--
11	FLT113PH	OF	OF
12	FLT121PH	OF	OF
13	FLT133PH	OF	OF
14	FLT141PH	OF	OF
15	FLT153PH	--	--
16	FLT161PH	--	--
17	FLT173PH	--	--
18	FLT181PH	--	--
19	FLT193PH	--	--
20	FLT201PH	--	--
21	FLT213PH	--	--
22	FLT221PH	--	--

OF : Study WTG tripped due to high Frequency, SPP system was stable
-- : Wind Farm did not trip; SPP system was stable

3.5.2 Vestas 1.8 MW Wind Turbine Generators

With Vestas 1.8 MW WTGs, the proposed 250 MW wind generators were initially modeled with under/over voltage/frequency ride through protection. The settings are in accordance with standard or default settings shown in Tables 5 and 6. In order to achieve unity power factor at the proposed wind farm 34.5 kV interconnection points, two capacitors banks of 10 and 5 MVARs are recommended.

With the standard settings for under/over voltage/frequency ride through protection, the simulation results showed that:

- The proposed 250 MW wind farm tripped for thirteen (13) disturbances (disturbances # 1, 2, 3, 5, 6, 11, 12, 13, 14, 15, 17, 19, and 21) out of the twenty two (22) disturbances simulated. The proposed 250 MW wind farm was tripped by relay actuation on low voltages. The standard protection settings trip the wind turbine at voltages equal to or less than 0.75 P.U for a duration of at least 0.08 seconds (as shown in table 6). This suggests the implementation of the Advanced Grid Option 4 (AGO4) for Vestas wind turbine. AGO4 allows the wind turbine to withstand grid voltages as low as 0.5 P.U for up to 0.2 seconds. The settings of the AGO4 frequency and voltage protection schemes are shown in Tables 9 and 10.

Table 9 Over/Under Frequency Relay Settings for Vestas Wind Turbines with AGO4 Protection Scheme

Frequency Settings in Hertz	**Time Delay in Seconds**	**Breaker time in Seconds**
$F \leq 55.5$	0.02	0.08
$55.5 < F \leq 56.5$	0.35	0.08
$56.5 < F \leq 57.0$	2.0	0.08
$63.0 > F \geq 61.5$	90	0.08
$66.0 > F \geq 63.0$	0.02	0.08
$F > 66.0$	0.35	0.08

Table 10 Over/Under Voltage Relay Settings for Vestas Wind Turbine with AGO4 Protection scheme

Voltage Settings Per Unit	**Time Delay in Seconds**	**Breaker time in Seconds**
$V \leq 0.50$	0.20	0.08
$0.50 < V \leq 0.75$	0.08	0.08
$V \leq 0.90$	300	0.08
$1.10 \leq V < 1.15$	60	0.08
$1.15 \leq V < 1.20$	30	0.08
$1.2 \leq V > 1.25$	2.0	0.08
$V \geq 1.25$	0.08	0.08

- Furthermore, for those disturbances where there was no tripping of the proposed 250 MW wind farm, it was observed that post-disturbance voltage failed to recover and showed oscillatory behavior. It is thus recommended that dynamic voltage support be provided. The recommended implementation is two 5 MVAR SVCs located at the 34.5 kV interconnection points. These would operate in such a way that the pre-disturbance MVAR outputs are close to zero.

- Simulations were repeated with AGO4 package, capacitor banks, and the proposed SVCs in place; the simulations results show no tripping of the proposed 250 MW wind farm for the studied twenty two (22) disturbances. However, for disturbances #1, and #2, the simulation results show that the proposed 250 MW wind farm needs a huge amount of reactive power to stabilize the post-disturbance voltage. Consequently, it is recommended that an automatic switching scheme to trip the 230 kV line segment from the wind farm tap to Knoll 230 kV simultaneously with the other 230 kV line segment from Summit to the wind farm tap be implemented. This way, the wind farm will be tripped as part of the fault clearing procedures.

- The simulation results are summarized in Table 11 for Vestas 1.8 MW WTG

Table 11 Summary of the Simulation Results for Vestas 1.8 MW WTG

Dist. No.	Dist. Name	Summer Peak Without AGO4/SVC	Summer Peak With AGO4/SVC	Winter Peak With AGO4/SVC
1	FLT13PH	UV	-- S	-- S
2	FLT21PH	UV	-- S	-- S
3	FLT33PH	UV	--	--
4	FLT41PH	-- S	--	--
5	FLT53PH	UV	--	--
6	FLT61PH	UV	--	--
7	FLT73PH	-- S	--	--
8	FLT81PH	-- S	--	--
9	FLT93PH	-- S	--	--
10	FLT101PH	-- S	--	--
11	FLT113PH	UV	--	--
12	FLT121PH	UV	--	--
13	FLT133PH	UV	--	--
14	FLT141PH	UV	--	--
15	FLT153PH	UV	--	--
16	FLT161PH	-- S	--	--
17	FLT173PH	UV	--	--
18	FLT181PH	-- S	--	--
19	FLT193PH	UV	--	--
20	FLT201PH	-- S	--	--
21	FLT213PH	UV	--	--
22	FLT221PH	-- S	--	--

UV : Tripped due to low voltage
S : Stability issues encountered
-- : Wind Farm did not trip

For disturbance #7 (Fault on the Heizer to Mullergren 230 kV line, near Heizer), Figure 4 shows a comparison of the post-disturbance voltage at one of the 34.5 kV collector buses for GEN 2003-019 for the cases with and without the proposed two 5-MVAR SVCs. For that disturbance there was no tripping for the proposed 250 MW WTG; however, without the proposed 5 MVAR SVCs, post-disturbance voltage did not recover fully and oscillatory voltage behavior was observed as shown in Figure 4. With a dynamic voltage support comprising of two 5 MVAR SVCs located at the 34.5 kV interconnection points, the post-disturbance voltage was fully recovered with no sustained oscillations.

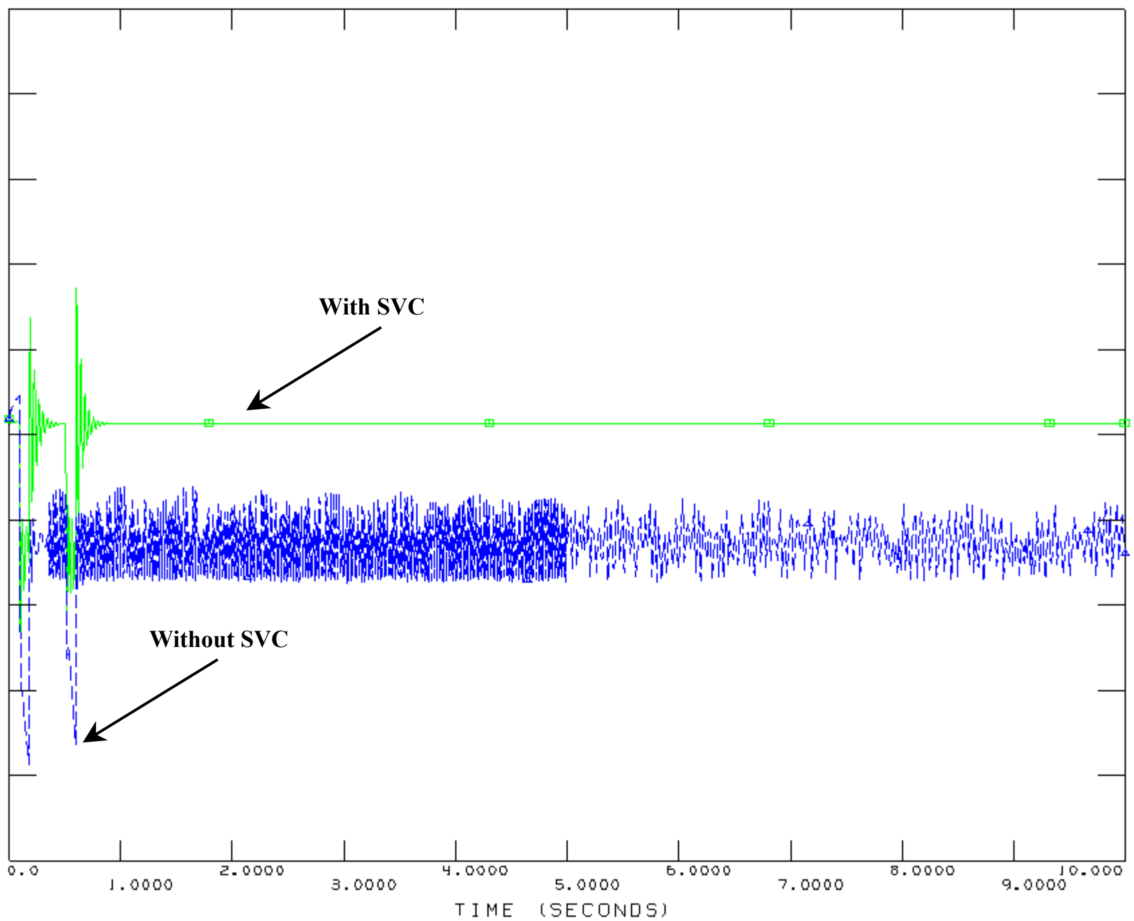

Figure 4 Comparison of the Post-Disturbance Voltage at one of the 34.5 kV Collector Buses for GEN 2003-019 with/without the proposed 5-MVAR SVCs

For disturbance #3(Fault on the Wind Farm Gen-2003-019 Switching Station to Knoll 230 kV line, near Knoll), Figure 5 shows a comparison of the post-disturbance voltage at one of the 34.5 kV collector buses for GEN 2003-019 for the cases with and without the Advanced Grid Option 4 (AGO4) protection package. Without AGO4, the proposed 250 MW WTG was tripped because of post-disturbance low voltage as shown in Figure 5. With the AGO4 protection package, the proposed 250 MW WTG is not tripping. Moreover, the post-disturbance voltage was fully recovered with no sustained oscillations because of the proposed two 5-MVAR SVCs.

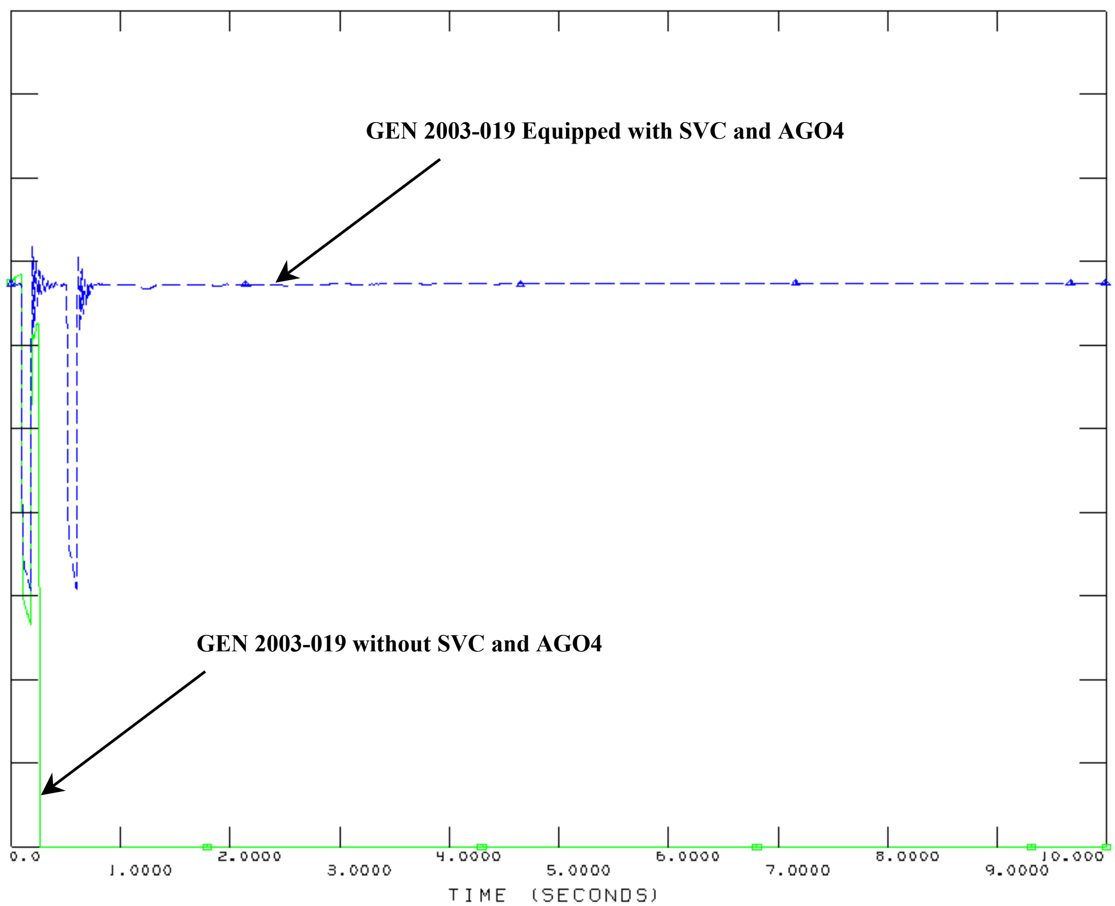

Figure 5 Comparison of the Post-Disturbance Voltage at one of the 34.5 kV Collector Buses for GEN 2003-019 with/without the proposed 5-MVAR SVCs and AGO4

With a protection scheme for Knoll-wind farm tap when using the GE WTG, and with the same scheme plus capacitors, AGO4 and two 5-MVAR SVCs when using the Vestas WTG, all oscillations are well damped. Based on the obtained simulation results, and with the aforementioned operating schemes and reinforcement, the system remained stable for all the simulated faults with the proposed 250MW wind farm project in service. All oscillations were well damped. The study finds that the proposed 250MW wind farm project, on the basis of base cases, modeling assumptions and recommended operating schemes and reinforcement for the system, and for the tested contingencies (on the supplied base cases), does not degrade the stable performance of SPP system.

4. Conclusion

The stability simulation findings of the impact study of a proposed interconnection (Gen-2003-019) were presented in this report. The study was conducted through the Southwest Power Pool Tariff for a 230 kV 250 MW wind farm in Lincoln County, Kansas. This wind farm would be interconnected to a new 230 kV three-breaker ring bus on the Knoll to Summit line jointly owned by WERE and MIDW. The impact study case considered 100% MW of the wind farm proposed output. Two types of wind turbine generators were studied according to the customer request; GE 1.5 MW and VESTAS V-80 wind turbines.

The 2006 summer and winter load flow cases together with the necessary data needed for the transient stability simulations were provided by SPP. Transient stability simulations were conducted with the proposed wind farm in service with a full output of 250 MW. In order to integrate the proposed 250MW wind farm in SPP system, re-dispatch for the existing SPP footprint generation was provided by SPP.

Twenty two (22) contingencies were considered for the transient stability simulations which included three phase faults, as well as single line to ground faults, at the locations defined by SPP. Single-phase faults were simulated by applying a fault impedance to the positive sequence network at the fault location to represent the effect of the negative and zero sequence networks on the positive sequence network. The fault impedance was computed to give a positive sequence voltage at the specified fault location of approximately 60% of pre-fault voltage. This method is in agreement with SPP current practice.

4.1 GE 1.5 MW Wind Turbine Generators

For GE 1.5 MW wind turbine generators (WTGs), the proposed wind farm was modeled with voltage/frequency ride through protection. The settings of both under/over voltage and frequency relays were in accordance with standard or default settings.

The simulations conducted in the study did not find any angular or voltage instability problems for twenty of the contingencies. However, tripping of the wind farm was observed as follows:

- Disturbances #1, and #2 (3-phase and 1-phase faults, respectively, at Summit 230 kV bus). The fault clearing procedures require tripping of the 230 kV line segment from Summit to the wind farm tap. It is recommended that an automatic switching scheme to trip the 230 kV line segment from the wind farm tap to Knoll 230 kV simultaneously with the other 230 kV line segment from Summit to the wind farm tap be implemented. This way, the wind farm will be tripped as part of the fault clearing procedures.

- Disturbances #11, and #12 (3-phase and 1-phase faults, respectively, at Summit 345 kV bus); and disturbances #13, and #14 (3-phase and 1-phase faults respectively, at Summit 230 kV bus). Tripping of the proposed 250 MW was due to high frequency excursions.

- For the winter case, the results show that some wind farm units trip for disturbance #3 because of high frequency excursion.

Based on the trips the following recommendations are made.

- It is recommended that implementation of an automatic switching scheme that will trip the 230 kV line segment from the wind farm tap to Knoll 230 kV simultaneously with the other 230 kV line segment from Summit to the wind farm tap be considered. This way, the wind farm will be tripped as part of the fault clearing procedures.

- The threshold settings and time durations for tripping the GE 1.5 MW WTGs vary significantly from the standard ride through to the low voltage ride through controls. Consequently, in order to avoid the reported tripping, the customer shall consider revised settings for both frequency and the voltage relays by using the low voltage ride through settings per the manufacturer.

4.2 Vestas 1.8 MW Wind Turbine Generators

With Vestas 1.8 MW WTGs, the proposed 250 MW wind generators were initially modeled with under/over voltage/frequency ride through protection. The settings were in accordance with standard or default settings. In order to achieve unity power factor at the proposed wind farm 34.5 kV interconnection points, two capacitors banks of 10 and 5 MVAR would be needed. The simulation results showed that:

- The proposed 250 MW wind farm tripped for ten (13) disturbances (disturbances # 1, 2, 3, 5, 6, 11, 12, 13, 14, 15, 17, 19, and 21) out of the twenty two (22) disturbances simulated. The proposed 250 MW wind farm was tripped by relay actuation on low voltages. The standard protection settings trip the wind turbine at voltages equal to or less than 0.75 P.U for time duration of at least 0.08 seconds. This suggests the implementation of the Advanced Grid Option 4 (AGO4) for Vestas wind turbine. AGO4 allows the wind turbine to withstand grid voltages as low as 0.5 P.U for up to 0.2 seconds.

- Furthermore, for those disturbances where there was no tripping of the proposed 250 MW wind farm, the post-disturbance voltage showed no recovery and oscillatory behavior. Hence, dynamic voltage support is recommended. This would comprise of two 5 MVAR SVCs located at the 34.5 kV interconnection points. They are operated in such a way that the pre-disturbance MVAR outputs are close to zero.

- Simulations were repeated with AGO4, capacitor banks, and the proposed SVCs in place; the simulation results show no tripping of the proposed 250 MW wind farm for the studied twenty two (22) disturbances. However, for disturbances #1, and #2, the simulation results show that the proposed 250 MW wind farm needs a huge amount of reactive power to stabilize the post-disturbance voltage. Consequently, it is recommended that an automatic switching scheme to trip the 230 kV line segment from the wind farm tap to Knoll 230 kV simultaneously with the other 230 kV line segment from Summit to the wind farm tap be implemented. This way, the wind farm will be tripped as part of the fault clearing procedures.

Based on the trips the following recommendations are made.

- It is recommended that implementation of an automatic switching scheme that will trip the 230 kV line segment from the wind farm tap to Knoll 230 kV simultaneously with the other 230 kV line segment from Summit to the wind farm tap be considered. This way, the wind farm will be tripped as part of the fault clearing procedures.

- It is recommended that the Customer use the Vestas 1.8 MW WTG AGO4 with two (2) 10 Mvar capacitor banks and two (2) 5 Mvar SVC's to provide stable performance and be able to ride through the faults as shown by the Impact Study. This way the 250 MW wind farm will provide stable performance on the SPP system.