SPP Southwest Power Pool

Impact Study For Generation Interconnection Request GEN-2003-019

SPP Tariff Studies

(#GEN-2003-019)

February, 2007

Summary

Pursuant to the tariff and at the request of the Southwest Power Pool (SPP), Pterra Consulting Inc. (Pterra) performed the following Impact Study to satisfy the Impact Study Agreement executed by the requesting Customer and SPP for SPP Generation Interconnection request #GEN-2003-019.

The Customer had previously studied this request and executed an Interconnection Agreement using G.E. 1.5MW turbines. The Customer has now asked to change the turbine manufacturer to Vestes V80 1.8MW turbines. This study addressed the stability and reactive compensation required for the Vestes wind turbines.

<u>Reactive Compensation Required</u>

The Customer has asked to interconnect a total of 248.4 MW of Vestes Wind turbines. The Impact Study determined that the Customer will be required to install at least two 34.5kV capacitor banks for the wind farm. One 34.5kV capacitor bank of 8 Mvar will be required on the substation transformer station which collects the energy from fifty-six (56) Vestes turbines for a total 100.8MW. The second transformer station which collects energy from the remaining 147.6MW (82 turbines) will be required to have a 34.5kV, 26 MVAR capacitor bank. Each of these banks are required regardless whether or not the wind farm project is brought on in phases.

The Impact Study determined that a total of two (2) 34.5kV, +/- 20 MVAR STATCOM devices are necessary for the wind farm to meet FERC Order #661A requirements for low voltage ride through. Per the study, with no STATCOM devices, a total of 147.6MW of wind turbines trip for contingency #FLT21PH. These STATCOM devices will be placed on the 34.5kV side of each of the Customer's 230/34.5kV transformers.

> <u>Phasing Considerations</u> – The Customer has indicated that the wind farm project may be brought on in phases, with the first phase being the transformer station that includes the fifty-six turbines for 100.8MW. The Impact Study determined that a STATCOM was not necessary for only 100.8MW of wind generation. In this case the Customer would not have to install the +/-20MVAR STATCOM device until the second phase is brought on-line.
>
> <u>Need for Reactor Bank</u> - However, for the outage of the 230kV line from the wind farm to Summit (FLT13PH and FLT21PH), unacceptable high voltages are observed for a wind farm configuration containing only 100.8MW and no STATCOM device. Voltages are observed on the wind turbine buses as high as 1.15pu and voltages at the 230kV bus are observed to be as high as 1.10pu.
>
> Therefore, the Customer will be required to install a 34.5kV, 9Mvar reactor bank in its substation for the situation in which only 100.8MW of wind generation will be in service and there is no STATCOM device present in the substation. The STATCOM device could be installed in the first phase in lieu of the reactor bank.

Interconnection Facilities

Facilities to be required by the Customer are shown in Table 1 and Table 2.

Table 1. Customer Interconnection Facilities

Facility	Cost
Customer – Two (2) 230-34.5kV transformation substation including two (2) 230-34.5kV 120/160/200MVA transformers, breakers and associated equipment	Customer determined
Two (2) 34.5kV capacitor banks, 8 Mvar and 26 Mvar on each of the Customer transformers	Customer determined
Two (2) 34.5kV +/- 20MVA STATCOM devices to be installed on each of the Customer transformers	Customer determined
One (1) 34.5kV, 9 Mvar reactor bank (to be installed in the case that the first phase is installed with no STATCOM device)	Customer determined
Metering and Line Terminal Equipment at the Switching Station to the Customer substation(s)	$232,000

Table 2. Network Upgrades

Facility	Cost
MIDW – 230kV switching station on the Knoll-Summit line as described in the Interconnection Agreement between Customer, Midwest Energy, and SPP	$4,537,000

Pterra Consulting

Technical Report R143-06 Rev 2

Impact Study for Generation Interconnection Request GEN-2003-019

Submitted to

The Southwest Power Pool

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The Southwest Power Pool (SPP) contracted Pterra LLC (Pterra) to perform stability analyses for a proposed 248.4 MW wind farm. The wind farm project ("the Project"), located in Lincoln County in Kansas, consists of 138 Vestas V-80 with AGO-4 wind units of 1.8 MW each.

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 a study case of 100% MW. The stability results should also include reduced stability runs to determine the maximum MW with no upgrades. The Project shall further comply with the latest FERC order on low voltage ride through (LVRT) for wind farms. Therefore, the wind farm should not trip off line for faults for under voltage relay actuation. If the wind farm is seen to trip off line, an appropriate sized SVC or STATCOM device shall be specified to keep the wind farm on-line for the fault.

The Customer has previously studied this request using GE 1.5 MW wind turbines using the standard ride through package and Vestas V-80 with AGO-4. Customer is now requesting a restudy of the Vestas V-80 with AGO-4 using the new dynamic model for the Vestas turbines recently made available. Figure 1-1 shows the interconnection schematic for the proposed wind farm.

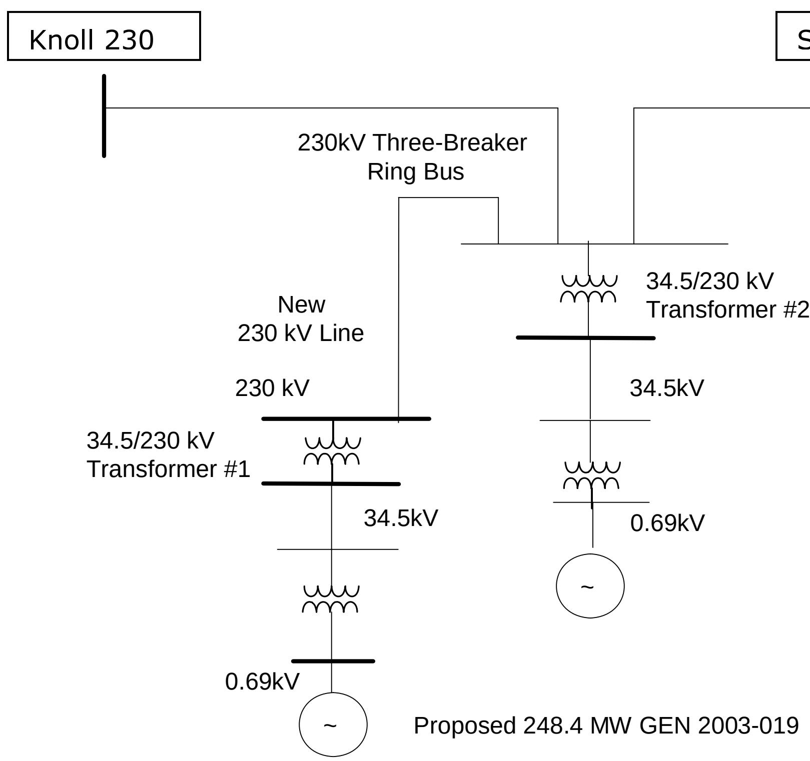

Figure 1-1: Interconnection Scheme for GEN-2003-019 to SPP

In order to have unity power factor at the POI (230 kV), two capacitor banks of 8 and 26 MVAR are required at the 34.5 kV bus of each transformer TR #1 and TR #2 (shown in Figure 1-1), respectively.

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. The simulation runs are performed for a study case at 100% MW plant dispatch with dynamic reactive compensation as required. Runs were also made to determine maximum MW without compensation, as necessary.

For two of the contingencies tested, the Project fails the LVRT standard. In contingency FLT21PH, a single-phase fault on the 230 kV line from the Project's Switching Station to Summit, near Summit, 147.6 MW of the Project trips due to low voltage relay actuation in both the summer and winter cases. In contingency FLT13PH, a three-phase fault on the same 230 kV line, 88.2 MW and 46.8 MW of the Project trip for the winter and summer cases, respectively.

Two STATCOM (Static Synchronous Compensator) devices of with control range of +20/-20 MVAR, each at the 34.5 kV, low voltage side of transformers #1 and 2 (Figure 1-1), would provide for compliance with the LVRT standard at full MW output from the Project. A reduced MW of 100.8 MW without compensation would also allow the Project to meet the LVRT requirement.

From a system perspective, the stability simulations show stable results for the SPP system for both 2007 Winter Peak and 2011 Summer Peak dispatch scenarios.

Section 1. Introduction

1.1. Project Overview

The Southwest Power Pool (SPP) contracted Pterra LLC (Pterra) to perform stability analyses for a proposed 248.4 MW wind farm. The wind farm project ("the Project"), located in Lincoln County in Kansas, consists of 138 Vestas V-80 with AGO-4 wind units of 1.8 MW each.

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 a study case of 100% MW. The stability results should also include reduced stability runs to determine the maximum MW with no upgrades. The Project shall further comply with the latest FERC order on low voltage ride through (LVRT) for wind farms. Therefore, the wind farm should not trip off line for faults for under voltage relay actuation. If the wind farm is seen to trip off line, an appropriate sized SVC or STATCOM device shall be specified to keep the wind farm on-line for the fault.

Figure 1-1 shows the interconnection schematic for the proposed wind farm.

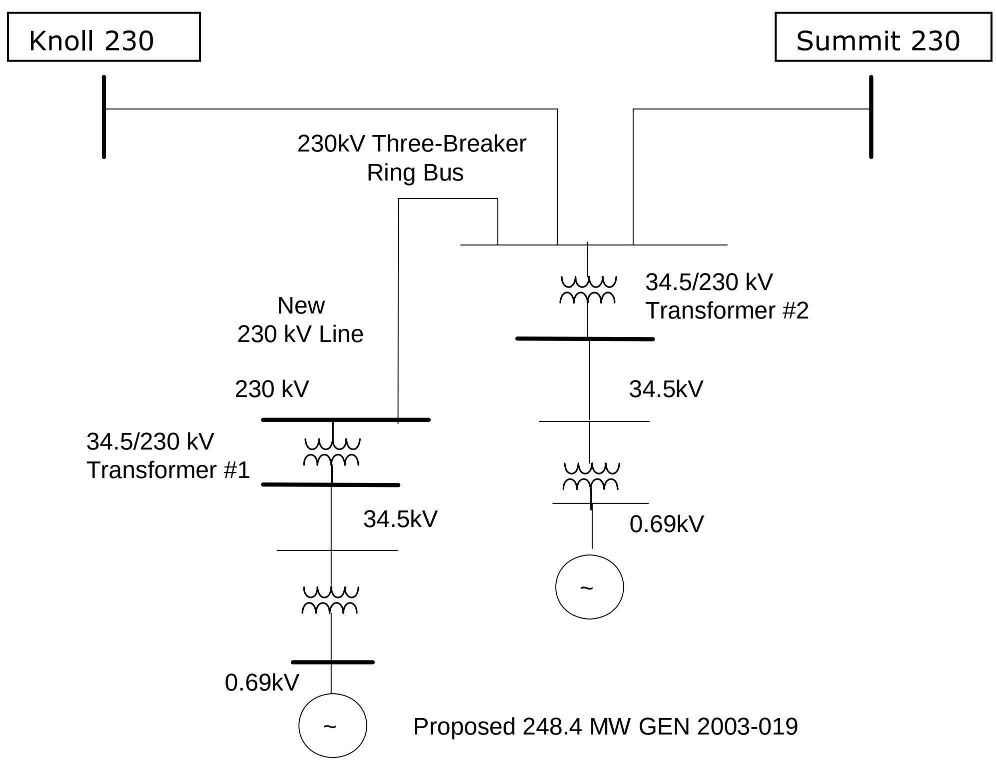

Figure 1-1: Interconnection Scheme for GEN-2003-019 to SPP

The study was performed with two dispatch scenarios provided by SPP:

1. 2007 Winter Peak Case and
2. 2011 Summer Peak Case.

Per SPP directions, generation in areas 520, 524 and 525 were scaled down to dispatch the Project in the winter 2007 and summer 2011 cases.

In addition to the base cases and interconnection configuration, SPP provided the Project data consisting of generating units and their generating step-up transformers. To simplify the model of the wind farm, the wind turbines were aggregated in such a manner as to lump several turbines connected to the same 34.5kV feeder end point as one equivalent. Several equivalents were developed in the modeling.

In order to have unity power factor at the POI (230 kV), two capacitor banks of 8 and 26 MVAR are required at the 34.5 kV bus of each transformer TR #1 and TR #2 (shown in Figure 1-1), respectively.

1.2. Objective

The objective of the study is to determine the impact on system stability of connecting the Project to SPP's 230 kV transmission system. The stability results also included 100% power runs with dynamic compensation, and reduced stability runs, as necessary, to determine the maximum MW with no upgrades.

2.1. Modeling of the Wind Turbines

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 V80 60 Hz wind turbine model set. Table 2-1, Table 2-2 and Table 2-3 show parameter data.

Table 2-1: Vestas V80 60 Hz 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	0.0048897
LA	0.12602
LM	6.8399
R_ROT_MACH	0.004419
R_ROT_MAX	0.109941
L1	0.18084

The wind turbine generators have Low Voltage Ride-Through (AGO-4) capability for voltage and frequency. Detailed standard relay settings are shown in the following tables.

Table 2-2: Over/Under Frequency Relay Settings for Vestas V80 60 Hz Wind Turbine

Frequency Settings in Hertz	Time Delay in Seconds	Breaker time in Seconds
F ≤ 55.2	0.2	0.08
F ≤ 57	2.0	0.08
F ≥ 62.0	90.0	0.08
F ≥ 63.0	0.2	0.08

Table 2-3: Over/Under Voltage Relay Settings for Vestas V80 Wind Turbine

Voltage Settings (Per Unit)	Time Delay (Seconds)	Breaker time (Seconds)
$V \leq 0.15$	0.35	0.08
$V \leq 0.75$	2.65	0.08
$V \leq 0.85$	10.00	0.08
$V \leq 0.90$	300.00	0.08
$V \geq 1.10$	60.00	0.08
$V \geq 1.15$	60.00	0.08
$V \geq 1.20$	2.00	0.08
$V \geq 1.25$	0.08	0.08

2.2. 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 advanced protection manufacturer data.

2.3. Contingencies Simulated

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-line-to-ground faults were simulated by applying 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 60-65 % of pre-fault voltage.

Table 2-4 shows the list of simulated contingencies. SPP provided the fault clearing time and the time delay before re-closing for all the study contingencies.

Table 2-4: List of Simulated Contingencies and Result Summary of Dynamic Response for 2007 Winter Peak and 2011 Summer Peak Scenarios.

No	Contingency	Description	Winter Peak 2007	Summer Peak 2011
1	FLT13PH	Fault on the Wind Farm Gen-2003-019 Switching Station (167) to Summit (56873) 230 kV line, near Summit	Stable (88.2 MW of the Project trips)	Stable (46.8 MW of the Project trips)
1A	FLT13PH-STATCOM	Fault on the Wind Farm Gen-2003-019 Switching Station (167) to Summit (56873) 230 kV line, near Summit	Stable (with STATCOM)	Stable (with STATCOM)
2	FLT21PH	Single phase fault and sequence like Cont. No. 1	Stable (147.6 MW of the Project trips)	Stable (147.6 MW of the Project trips)
2A	FLT21PH-STATCOM	Single phase fault and sequence like Cont. No. 1	Stable (with STATCOM)	Stable (with STATCOM)
2B	FLT21PH- At reduced power of 100.8 MW	Single phase fault and sequence like Cont. No. 1	Stable	Stable
3	FLT33PH	Fault on the Wind Farm Gen-2003-019 Switching Station 167) to Knoll (56558) 230 kV line, near Knoll.	Stable	Stable
4	FLT41PH	Single phase fault and sequence like Cont. No. 3	Stable	Stable
5	FLT53PH	Fault on the Circle (56871) to Mullergren (58799) 230 kV line, near Circle.	Stable	Stable
6	FLT61PH	Single phase fault and sequence like Cont. No. 5	Stable	Stable
7	FLT73PH	Fault on the Heizer (56601) to Mullergren (58799) 230 kV line, near Heizer.	Stable	Stable

No	Contingency	Description	Winter Peak 2007	Summer Peak 2011
8	FLT81PH	Single phase fault and sequence like Cont. No. 7	Stable	Stable
9	FLT93PH	Fault on the Manhattan (56861) to Concordia (58758) 230 kV line, near Manhattan.	Stable	Stable
10	FLT101PH	Single phase fault and sequence like Cont. No. 9	Stable	Stable
11	FLT113PH	Fault on the Jefferies Energy Center (56766) to Summit (56773) 345 kV line, near Summit.	Stable	Stable
12	FLT121PH	Single phase fault and sequence like Cont. No. 11	Stable	Stable
13	FLT133PH	Fault on the Morris (56863) to Summit (56873) 230 kV line, near Summit.	Stable	Stable
14	FLT141PH	Single phase fault and sequence like Cont. No. 13	Stable	Stable
15	FLT153PH	Fault on the Knoll (56561) to Redline (56605) 115 kV line, near Knoll.	Stable	Stable
16	FLT161PH	Single phase fault and sequence like Cont. No. 15	Stable	Stable
17	FLT173PH	Fault on the Hays (56562) to Vine (56591) 115 kV line, near Hays.	Stable	Stable
18	FLT181PH	Single phase fault and sequence like Cont. No. 17	Stable	Stable
19	FLT193PH	Fault on the Knoll (56561) to South Hays (56553) 115 kV line, near Knoll.	Stable	Stable
20	FLT201PH	Single phase fault and sequence like Cont. No. 19	Stable	Stable
21	FLT213PH	Fault on the Knoll (56561) to Saline (56551) 115 kV line, near Knoll.	Stable	Stable

No	Contingency	Description	Winter Peak 2007	Summer Peak 2011
22	FLT221PH	Single phase fault and sequence like Cont. No. 21	Stable	Stable

2.4. Simulation Results

Stability simulations were performed with a 0.5-second steady-state run followed by the appropriate disturbance as described in Table 4. Simulations were run for 20-second duration and plotted. Project terminal voltages, reactive power and electrical torques, as well as angles, bus voltages and frequency are plotted for buses in monitored areas: MIDW, WERE and KACP. Simulation plots are provided in a separate CD-ROM.

The stability simulations show stable results for the SPP system for both 2007 Winter Peak and 2011 Summer Peak dispatch scenarios.

For two of the contingencies tested, the Project fails the LVRT standard. In contingency FLT21PH, a single-phase fault on the 230 kV line from the Project's Switching Station to Summit, near Summit, 147.6 MW of the Project trips due to low voltage relay actuation in both the summer and winter cases. In contingency FLT13PH, a three-phase fault on the same 230 kV line, 88.2 MW and 46.8 MW of the Project trip for the winter and summer cases, respectively.

Two STATCOM (Static Synchronous Compensator) devices of control range +20/-20 MVAR, each at 34.5 kV, low voltage side of transformers #1 and 2 (Figure 1-1), would provide for compliance with the LVRT standard at full MW output from the Project. A reduced MW of 100.8 MW without compensation would also allow the Project to meet the LVRT requirement.

From a system perspective, the stability simulations show stable results for the SPP system for both 2007 Winter Peak and 2011 Summer Peak dispatch scenarios.

Section 3. Conclusions

The stability simulations show stable results for the SPP system for both 2007 Winter Peak and 2011 Summer Peak dispatch scenarios.

For contingencies at the POI the Project trips partially due to low voltage relay actuation. Two STATCOM (Static Synchronous Compensator) devices of control range +20/-20 MVAR, each at 34.5 kV would provide for compliance with the LVRT standard at full MW output from the Project. A reduced MW of 100.8 MW without compensation would also allow the Project to meet the LVRT requirement.

Appendix A. Simulation Plots

Stability simulations are run and plotted by Power-tek and provided in a separate CD-ROM.