SPP Southwest Power Pool

Impact Study for Generation Interconnection Request GEN – 2004 – 014

SPP Tariff Studies
(#GEN-2004-014)

March, 2006

Summary

Pursuant to the tariff and at the request of the Southwest Power Pool (SPP), 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-2004-014. 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.

The impact study found that the Customer will need to install a 15kV, 24 MVAR capacitor bank on the high side bus at the Customer's wind farm substation in order for the wind farm to operate at unity power factor.

The impact study showed the wind farm tripped during contingency #18, which simulated an Order #661A LVRT fault. However, by further examination of the data by SPP, it was determined that the turbines did not trip due to failure of low voltage ride through, but tripped due to high voltage. This high voltage condition occurs when the 230/115kV autotransformer is outaged and the entire 154 MW wind farm's only outlet is into Midwest Energy's 115kV system, which has an emergency rating of 92 MVA. When the Customer requests transmission service on the Southwest Power Pool OATT, transmission request studies will indicate further system reinforcements will be needed for the full output of the wind farm.

Nothing in this study should be construed as a guarantee of transmission service. If the customer wishes to sell power from the facility, a separate request for transmission service shall be requested on Southwest Power Pool's OASIS by the Customer.

Pterra Consulting

Report No. R101-06

"Impact Study for Generation Interconnection Request GEN-2004-014"

Submitted to

The Southwest Power Pool

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Pterra

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Report No. R101-06

"Impact Study for Generation Interconnection Request GEN-2004-014"

1. Executive Summary

This report presents the stability simulation findings for the impact study of proposed interconnection, Gen-2004-014. Pterra Consulting (Pterra) was contracted by the Southwest Power Pool (SPP) to conduct the impact study under the Southwest Power Pool Tariff. Gen-2004-014 is a 154 MW wind farm proposed in Ford County, Kansas. The wind farm is to be interconnected to a new 230/115kV transmission substation with terminations for 230kV lines to Aquila's Sprearville and Mullergren substations, one 230/115kV autotransformer, and a 115kV line to Midwest Energy's North Kinsley substation. The wind farm will use Gamesa 2.0 MW wind turbines with the standard ride through package. A 24 MVAR capacitor is to be installed at the high voltage side of wind farm's 115/34.5 kV transformer to reflect unity power factor at the point of the interconnection.

Two base cases each comprising of a power flow and corresponding dynamics database were provided by SPP. Pterra added detailed modeling of the proposed wind farm, with under/over voltage/frequency ride through protection. The settings were in accordance with standard or default settings. The wind farm generation was dispatched against generation in Entergy. Pterra then conducted transient stability simulations with the wind farm at full output of 154 MW.

Eighteen (18) contingencies were simulated for transient stability performance tests, comprising of 3-phase faults and single-phase-to-ground faults. Single-phase-to-ground faults were simulated by applying a fault impedance to the positive sequence network at the fault location, representing 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.)

The simulations demonstrate no system angular or voltage instability problems for all the contingencies. However, the following tripping was observed for peak summer and winter loading conditions:

- The proposed wind farm tripped due to relay actuation in disturbances #1 and #18 (3-phase faults at the Spearville 230 kV- bus and on the 115 kV bus of the wind farm interconnection substation, respectively).
- The following prior projects also tripped due to relay actuation in disturbance #1 (3-phase faults at the Spearville 230 kV- bus):
    - Mullinville 115 kV 105 MW wind farm
    - Spearville 230 kV 150 MW wind farm
    - Gray county 110 MW wind farm

- For disturbance # 9 (3-phase fault at the Spearville 345 kV bus), the following prior projects were tripped due to relay actuation:
  - Spearville 230 kV 150 MW wind farm
  - Gray county 110 MW wind farm

All oscillations were well damped. Pterra finds that the proposed 154 MW wind farm project shows stable performance of the SPP system for the contingencies tested on the supplied base cases.

2. Introduction

2.1 Project Overview

The proposed 154 MW wind farm is to be interconnected to a new 230/115kV transmission substation with terminations for 230kV lines to Aquila's Sprearville and Mullergren substations, one 230/115kV autotransformer, and a 115kV line to Midwest Energy's North Kinsley substation. Figure 1 shows the interconnection diagram of the proposed GEN-2004-014 project to the SPP system.

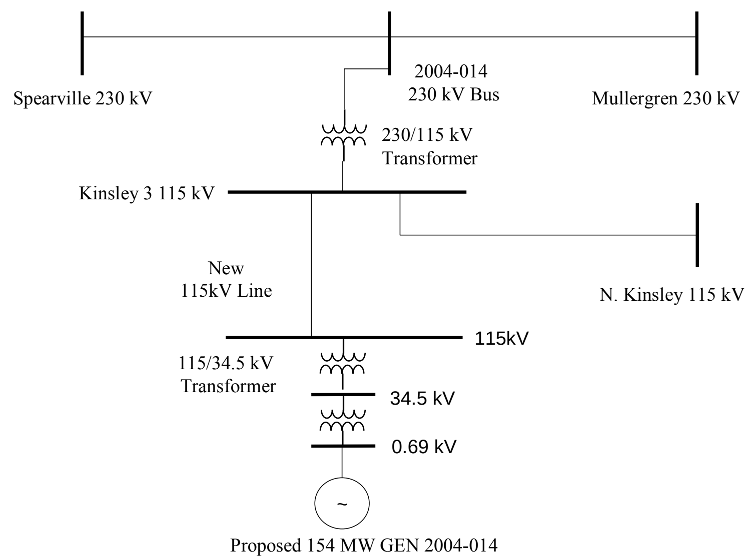

Figure 1. Interconnection Plan for GEN 2004-014 to the SPP System

In order to integrate the proposed 154 MW wind farm in SPP system, dispatch for the existing generation in Entergy area was scaled down by 154 MW. A 24 MVAR capacitor was included with the wind farm model, to be installed at the high voltage side of the 115/34.5 kV transformer to reflect unity power factor at the point of the interconnection.

In order to simplify the model of the wind farm while still capturing the effect on stability simulations of the different cable impedances, the wind turbines were aggregated in a such a manner as to have one equivalent unit for several turbines connected to the same 34.5kV feeder end point. The equivalent impedance of each feeder was represented in the load flow database by taking the equivalent series impedances of the different feeders connecting the wind turbines. Using this approach, the proposed 154 MW wind farm was modeled with 27 equivalent units. SPP provided data for:

- Impedance values for the different feeders at 34.5kV level
- Data for 34.5kV feeders
- Electrical parameters for generator step up transformers
- Data for 115kV/34.5 kV and 230/115 kV transformers
- Data for the new 115kV line

The load-flow cases and dynamic library included prior queued projects. These projects are:

- Gray County Wind Farm -110 MW consisting of 167 Vestes V47 turbines
- GEN-2001-039A – Mullinville 115kV Wind Farm – 105 MW consisting of Clipper wind turbines (CITMR3 model used)
- GEN-2002-025A – Spearville 230kV Wind Farm – 150 MW wind farm consisting of 100 GE turbines
- GEN-2003-019 – Wind Farm on the Summitt-Knoll 230kV line – 240 MW consisting of 160 GE turbines.

2.2 Objective

The objective of the study was to determine the impact on system stability of connecting the proposed 154 MW wind farm to SPP's transmission system.

3. Stability Analysis

3.1 Modeling of the Wind Turbines

The wind farm was modeled with Gamesa 2.0 MW wind turbine generators (WTG). The WTG model was comprised of several user models for dynamic simulation as follows:

1. Doubly-fed induction generator model including provision for rotor control,
2. Active rotor control model (representation of rotor converter circuit)
3. Pitch angle control model
4. Wind model allowing wind gusts and ramps to be applied,
5. 2-mass shaft model to represent the effects of the rotor/hub connected via a 'flexible' shaft to the generator,
6. Aerodynamic model which calculates the aerodynamic torque applied to the rotor taking into account wind speed, tip speed ratio Lambda, performance coefficient etc.,
7. Model to read the turbine Cp matrix,
8. Under/over frequency generator tripping relay.
9. Under/over voltage generator tripping relay.

In the power flow, equivalent WTGs and generator step-up (GSU) transformers were used to represent the detailed distribution of individual WTGs. In addition, dynamic data for the wind turbines and the different models listed above, plus the voltage/frequency protection components were added to the dynamics database. Since the proposed WTGs have ride-through capability for voltage and frequency, detailed relay settings for voltage/frequency protection schemes were included in the model.

3.2 Under/Over Voltage/Frequency Relay Models

The protection models for under/over frequency and under/over voltage models were located at the generator bus to which the WTG equivalents were connected. These models monitor the frequency/voltage on that bus over the course of a simulation period. The models trip the WTG equivalent for under- and over- frequency or voltage conditions on the generator bus. The current standard ride-through capability available is reflected in the Gamesa wind turbine model package as shown in Table 1 and Table 2 for frequency and voltage, respectively. These standard settings were used in the study.

Table 1: Over/Under Frequency Relay Settings for Gamesa WTG

Frequency Settings in Hertz	Time Delay in Seconds	Breaker time in Seconds
$62 \leq F \leq 57$	0.0	0.05

Table 2. Over/Under Voltage Relay Settings for Gamesa WTG

Voltage Settings Per Unit	Time Delay in Seconds	Breaker time in Seconds
$V \leq 0.15$	0.04	0.05
$0.15 < V \leq 0.3$	0.625	0.05
$0.30 < V \leq 0.45$	1.10	0.05
$0.45 < V \leq 0.65$	1.575	0.05
$0.65 < V \leq 0.75$	2.05	0.05
$0.75 < V \leq 0.90$	2.55	0.05
$V \geq 1.1$	0.06	0.05

3.3 Gamesa 2.0 MW WTG Parameters

Data for the Gamesa 2.0 MW WTG and generator step-up transformer are shown in Table 3.

3.4 Assumptions

The following assumptions were adopted for the study:

1. A constant maximum and uniform wind speed was considered during the entire period of study.

2. The WTG control models were used with their default values.

3. The settings for the under/over voltage/frequency were set according to the standard manufacturer data.

Table 3. Gamesa 2.0 MW Wind Generator Data

Parameter	Value
BASE KV	0.690
WTG MBASE	2.00
TRANSFORMER MBASE	2.50
TRANSFORMER R ON TRANSFORMER BASE	0.006
TRANSFORMER X ON TRANSFORMER BASE	0.060
GTAP	1.00
PMAX (MW)	2.0
PMIN	0.0
RA	0.01022
LA	0.14283
LM Delta	7.21137
LM Y	6.94532
RMACH	0.01008
L1	0.17503

3.5 Contingencies Simulated

Eighteen (18) contingencies were simulated for transient stability, comprising three phase faults and single-line-to-ground faults. Single-line-to-ground 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 4 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 4. List of Contingencies

Cont. No.	Cont. Name	Description
1	FLT13PH	Fault on the Wind Farm Gen-2004-014 Switching Station (99976) to Spearville (58795) 230 kV line, near Spearville a. Apply Fault at the Spearville bus (58795). b. Clear Fault after 5 cycles by removing the line from Gen-2004-014 Switching Station (99976) to Spearville (58795) 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-2004-014 Switching Station (99976) to Mullergren (58779) 230 kV line, near Mullergren a. Apply Fault at the Mullergren bus (58779). b. Clear Fault after 5 cycles by removing the line from Gen-2004-014 Switching Station (99976) to Mullergren (58779) 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.
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). 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.

Cont. No.	Cont. Name	Description
8	FLT81PH	Single phase fault and sequence like Cont. No. 7
9	FLT93PH	Fault on the Spearville (56469) to Holcomb (56449) 345 kV line, near Spearville. e. Apply fault at the Spearville bus (56469). f. Clear fault after 5 cycles by tripping the line from Spearville (56469) to Holcomb (56449). g. Wait 20 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.
10	FLT101PH	Single phase fault and sequence like Cont. No. 9
11	FLT113PH	Fault on the Medicine Lodge (58773) to GEN-2001-039A station (1005) 115 kV line, near Medicine Lodge. i. Apply fault at the Medicine Lodge bus (58773). j. Clear fault after 5 cycles by tripping the all lines from Medicine Lodge (58773) to GEN-2001-039A (1005). k. Wait 20 cycles, and then re-close line in (b) back into the fault. l. 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 Judson Large (58771) to Cudahy (58759) 115 kV line, near Judson Large. a. Apply fault at the Judson Large bus (58771). b. Clear fault after 5 cycles by tripping the line from Judson Large (58771) to Cudahy (58759). 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.
14	FLT141PH	Single phase fault and sequence like Cont. No. 13
15	FLT153PH	Fault on the Knoll (56561) to South Hays (56553) 115 kV line, near Knoll. a. Apply fault at the Hays bus (56561). b. Clear fault after 5 cycles by tripping the line from Knoll (56561) to South Hays (56553). 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

Cont. No.	Cont. Name	Description
		fault.
16	FLT161PH	Single phase fault and sequence like Cont. No. 15
17	FLT173PH	Fault on the St John (56624) to Edwards (56617) 115 kV line, near St John. a. Apply fault at the St John bus (56624). b. Clear fault after 5 cycles by tripping the line from St John (56624) to Edwards (56617) 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.
18	FLT181PH	Bus fault on the 115kV bus of the interconnection substation a. Apply 3-Phase fault to the 115kV bus of the interconnection substation. The fault admittance should not allow the interconnection substation voltage to drop below 0.15 p.u. during the fault. b. Clear fault after 5 cycles by tripping the autotransformer from service.

3.6 Simulation Results

Simulations were performed with a 0.1-second steady-state run followed by the appropriate disturbance as described in Table 4. Simulations were run for a minimum of 10-second duration to confirm proper machine damping.

Based on the simulation results, the system remained stable for all the simulated faults with the proposed 154 MW wind farm project in service. All oscillations were well damped. The study finds that the proposed 154MW wind farm project, on the basis of base cases, modeling assumptions described within this report, and for the tested contingencies (on the supplied base cases) showed stable response of SPP system.

A complete set of the transient stability plots for rotor angle, speed, and voltages for the monitored buses in SPP for all contingencies for the two base cases with the proposed 154 MW wind farm in service, are in an electronic format on the accompanying CD.

The simulations conducted in the study did not find any system angular or voltage instability problems for the eighteen contingencies. However, the following tripping was observed for peak summer and winter loading conditions:

- The proposed wind farm tripped due to relay actuation in disturbances #1 and #18 (3-phase fault at the Spearville 230 kV bus and on the 115 kV bus of the wind farm interconnection substation, respectively).

- The following prior projects also tripped due to relay actuation in disturbance #1 (3-phase fault at the Spearville 230 kV bus):
  - Mullinville 115 kV 105 MW wind farm
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- For disturbance # 9 (3-phase fault at Spearville 345 kV bus), the following prior projects were tripped due to relay actuation:
  - Spearville 230 kV 150 MW wind farm
  - Gray county 110 MW wind farm

All oscillations were well damped. The study finds that the proposed 154 MW wind farm project shows stable performance of SPP system for the contingencies tested on the supplied base cases.

4. Conclusions

The stability simulation findings of the impact study for proposed interconnection Gen-2004-014 were presented in this report.

Two base cases each comprising of a power flow and corresponding dynamics database were provided by SPP. Pterra added detailed modeling of the proposed wind farm, with under/over voltage/frequency ride through protection. The settings were in accordance with standard or default settings.. The wind farm generation was dispatched against generation in Entergy.

Eighteen (18) contingencies were simulated transient stability comprising of three phase faults and single-line-to-ground faults. Single-line-to-ground 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.

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