Southwest Power Pool

Impact Study For Generation Interconnection Request GEN-2006-024S

SPP Tariff Studies

(#GEN-2006-024S)

February, 2007

Summary

Pursuant to the tariff and at the request of the Southwest Power Pool (SPP), Pterra Consulting (Pterra) conducted the following Impact Study to satisfy the Impact Study Agreement executed by the requesting customer and SPP for SPP Generation Interconnection request GEN-2006-024S. 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 Customer asked for the Impact Study to analyze two different turbine types, the Suzlon S88, 2.1 MW turbine and the Vestas V80, 1.8MW turbine. The study found that either turbine type can be installed at the site. However, because the Customer has filed this request under the small generator provisions of FERC Order 2006, the request cannot total over 20MW. Therefore the following limitations occur to each turbine.

- Vestas V80 1.8 MW turbine – Total request cannot exceed 19.8MW
- Suzlon S88 2.1 MW turbine – Total request cannot exceed 18.9 MW

Facilities

The Impact Study determined that no SVC or STATCOM device was necessary for the requested generation using either turbine type. However, it was determined that capacitors were necessary for reactive compensation at the point of interconnection. The amount of capacitors that need to be installed at the Customer's 34.5kV bus is dependent upon the turbine type the Customer eventually determines it will install. The necessary capacitor bank sizes are as follows

- Vestas V80 1.8MW turbine – 34.5kV, 10MVAR capacitor bank
- Suzlon S88 2.1MW turbine – 34.5kV, 1.1 MVAR capacitor bank

Facility estimates were given in the Feasibility Study. With the exception of the above mentioned capacitor banks, no new facilities were required by the Impact Study. The Facility estimates given in the Feasibility Study are restated below in Table 1 and Table 2. These costs will be refined if the Customer executes a Facility Study Agreement. These costs do not include facilities that may be required after a fault study analysis. This analysis will be conducted if the Customer executes a Facility Study Agreement.

Table 1: Direct Assignment Facilities

Facility	ESTIMATED COST (2006 DOLLARS)
Customer – 69-34.5 kV Substation facilities,	*
Customer – 69kV line between Customer substation and WFEC three breaker ring bus station	*
Customer – 34.5kV capacitor bank (size dependent upon turbine type)	*
Customer - Right-of-Way for Customer Substation & Line.	*
Total	*****

Note: *Estimates of cost to be determined by Customer.

Table 2: Required Interconnection Network Upgrade Facilities

Facility	ESTIMATED COST (2006 DOLLARS)
WFEC – Build 138kV three breaker ring bus substation with terminals to Buffalo, Fort Supply and the Customer substation. Facility to be initially operated at 69kV	$2,080,000
Total	**$2,080,000**

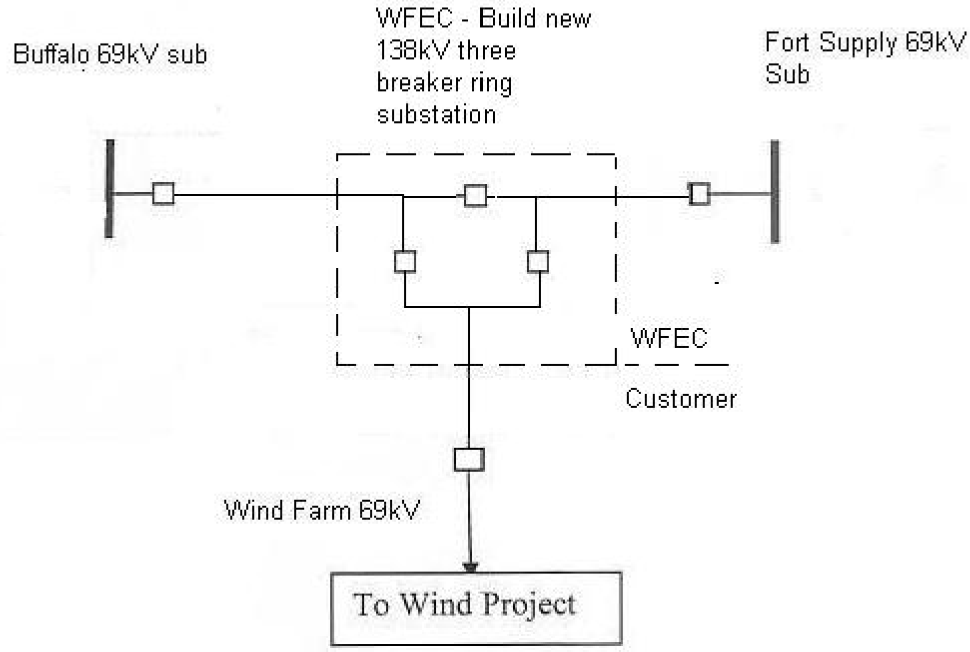

FIGURE 1. ONE-LINE OF THE INTERCONNECTION

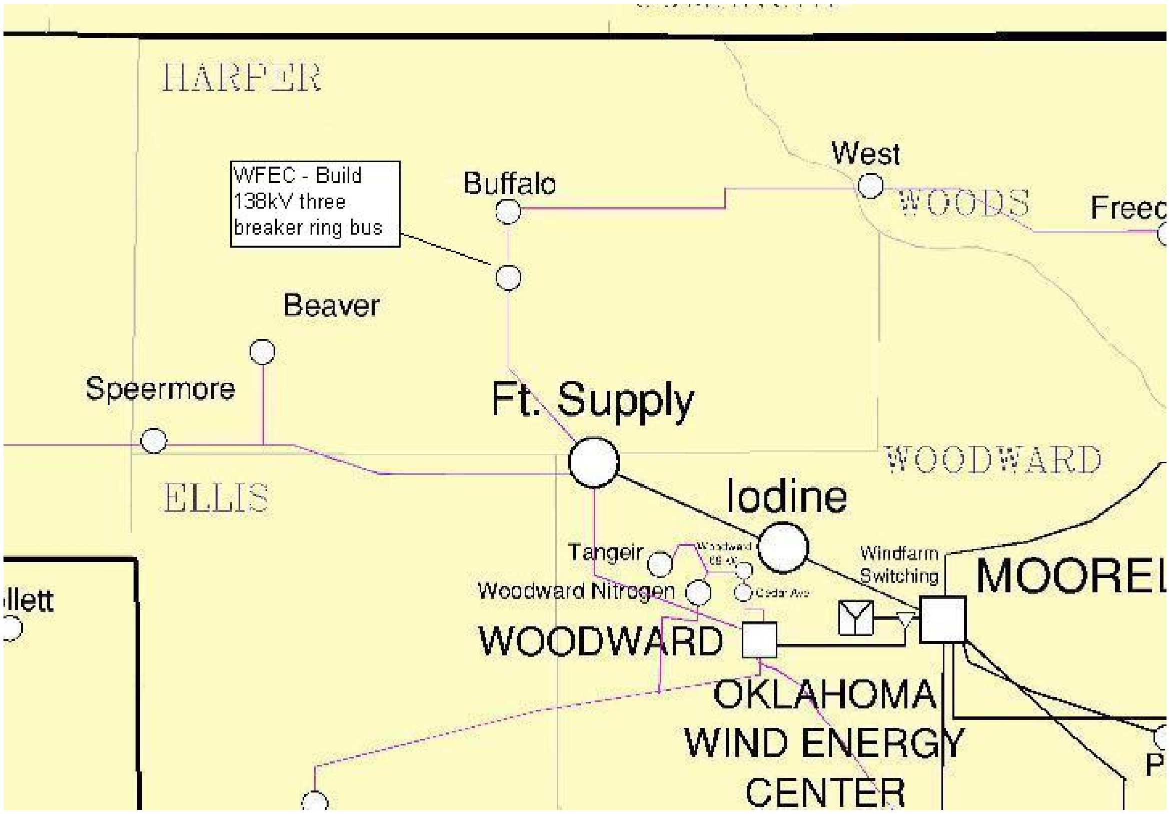

FIGURE 2. MAP OF THE LOCAL AREA

Pterra Consulting

Report No. R102-07

"Impact Study for Generation Interconnection Request GEN-2006-024"

Submitted to

The Southwest Power Pool

January 2007

Pterra

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Report No. R102-07

"Impact Study for Generation Interconnection Request GEN-2006-024"

1. Executive Summary

This report presents the stability simulation findings of the impact study of a proposed interconnection (Gen-2006-024). The analysis was conducted through the Southwest Power Pool Tariff for a 69 kV interconnection for 19.8 MW wind farm in Harper County, Oklahoma. This wind farm will be interconnected to the existing Fort Supply – Buffalo 69 kV transmission line. This line is owned by Western Farmers Electric Cooperative. The customer has asked for a study case of 100% MW output (with dynamic reactive compensation if required). The Customer has asked to study two (2) types of Wind Turbine Generators (WTGs): Suzlon S88 2.1 MW and Vestas V80 1.8 MW.

Two base cases each comprising of a power flow and corresponding dynamics database for 2011 summer and 2007 winter were provided by SPP. Transient stability simulations were conducted with the proposed wind farm in service with a full output of 19.8 MW. In order to integrate the proposed 19.8 MW wind farm in SPP system, the existing generation in the SPP footprint was re-dispatched as provided by SPP.

Sixteen (16) disturbances 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-phase 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.

In order to achieve a unity power factor at the point of the interconnection (POI), a 10 MVAR capacitor bank was placed at the 34.5 kV side of the 34.5/69 kV grid transformer for Vestas V80 1.8 MW; while for Suzlon S88 2.1 MW, 1.1 MVAR capacitor bank was used.

For both Vestas V80 1.8 MW and Suzlon S88 2.1 MW WTGs, the equivalent generators at the collector buses were modeled with under/over voltage/frequency ride through protection. The settings were in accordance with standard or default settings for each model.

With either Vestas V80 1.8 MW or Suzlon S88 2.1 MW WTGs and for peak summer and winter loading conditions, the simulations conducted in the study did not find any angular or voltage instability problems for the studied disturbances. Consequently, no dynamic reactive compensation is required.

All oscillations were well damped. The study finds that the proposed 19.8 MW wind farm project shows stable performance of SPP system for the contingencies tested on the supplied base cases.

2. Introduction

2.1 Project Overview

The proposed 19.8 MW wind farm would be interconnected into the Fort Supply – Buffalo 69kV line. Figure 1 shows the interconnection diagram of the proposed GEN-2006-024 project to the 69 kV transmission system. The detailed connection diagram of the wind farm is provided by SPP.

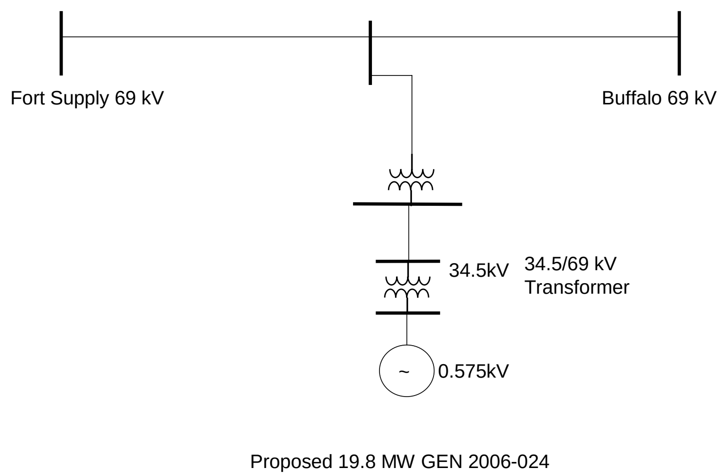

Figure 1. Interconnection Plan for GEN-2006-024 to the 69 kV System

In order to integrate the proposed 19.8 MW wind farm in SPP system, the SPP footprint is displaced to maintain current area interchange totals.

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 in the load flow database by taking the equivalent series impedances of the different feeders connecting the wind turbines. Using this approach, the proposed 19.8 MW wind farm was modeled with 4 equivalent units (using Vetas V80 1.8 MW WTGs) and 5 equivalent units (using Suzlon S88 2.1 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. 34.5 kV feeders

2. Generating unit step up transformers
3. 69 kV/34.5 kV transformers

Two base cases each comprising of a power flow and corresponding dynamics database for 2011 summer and 2007 winter were provided by SPP. The base cases contain four (4) prior queued projects in the base case. The projects are as follows;

a. GEN-2001-014 – 94.5 MW of Suzlon 2.1 MW wind turbines
b. GEN-2001-037 – 102 MW of G.E. 1.5 MW wind turbines
c. GEN-2005-005 – 18 MW of Siemens 2.3 MW wind turbines
d. GEN-2005-008 – 120 MW of G.E. 1.5 MW wind turbines

2.2 Objective

The objective of the study is to determine the impact on system stability of connecting the proposed 19.8 MW wind farm to SPP's 69 kV transmission system.

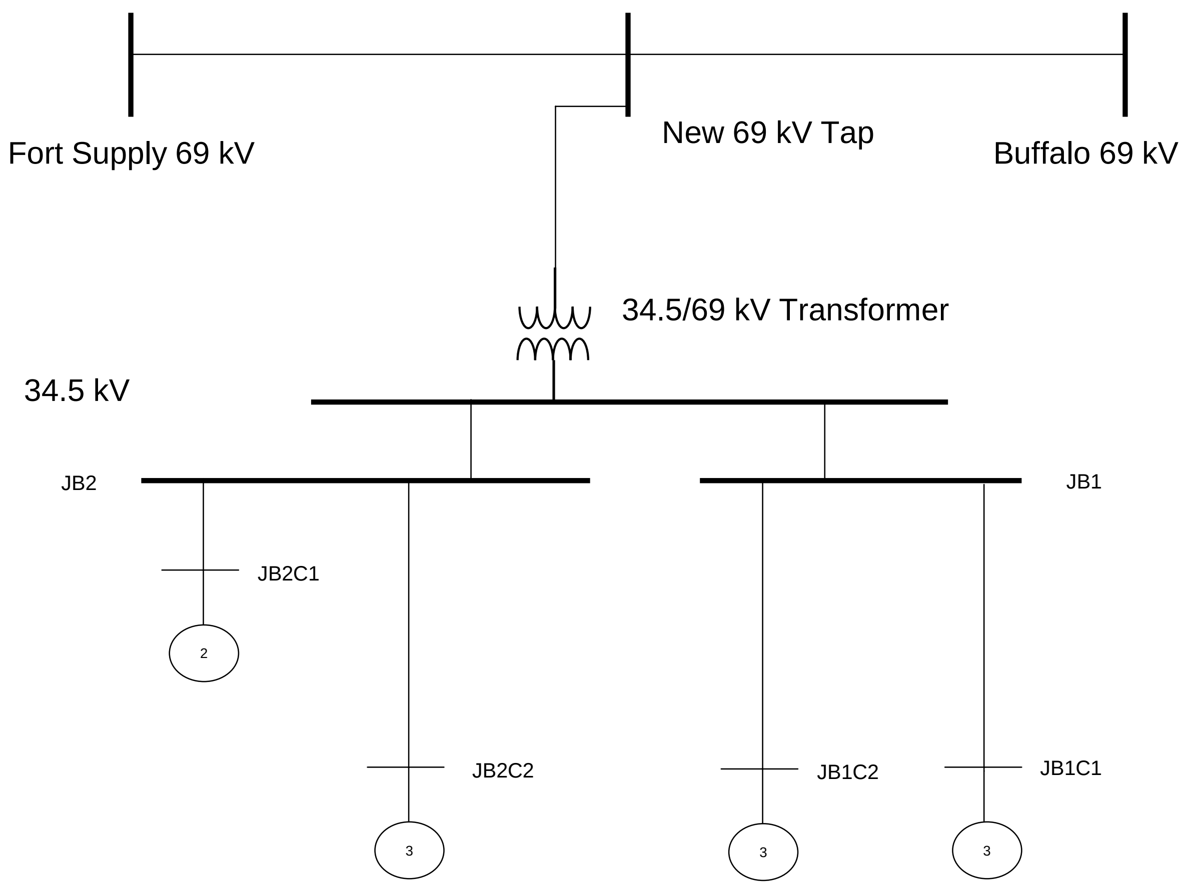

Figure 2. Wind Farm Equivalent Representation in Load Flow (Vestas V80 1.8 MW WTGs)

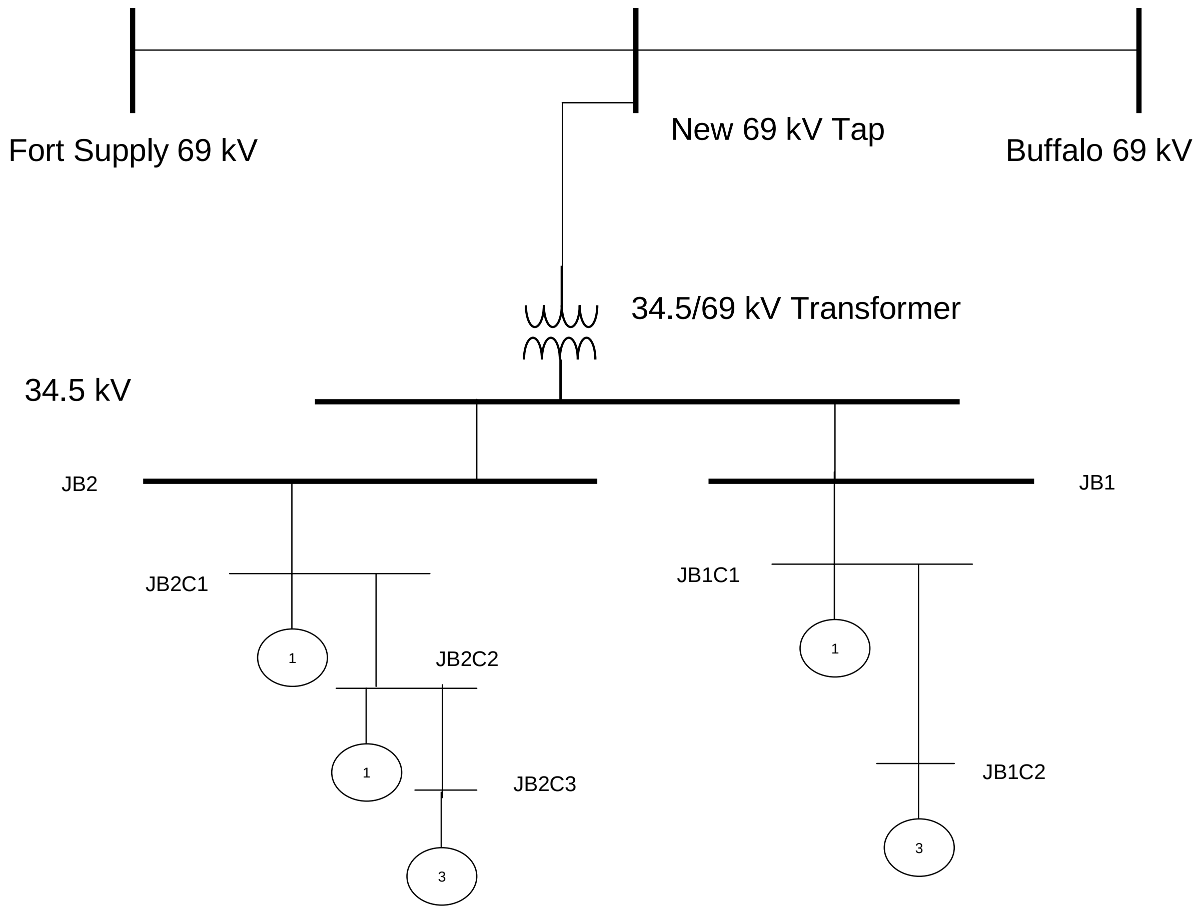

Figure 3. Wind Farm Equivalent Representation in Load Flow (Suzlon S88 2.1 MW WTGs)

3. Stability Analysis

3.1 Modeling of the Vestas V80 1.8 MW and Suzlon S88 2.1 MW WTGs

Equivalents for the wind turbine and generator step-up (GSU) transformer in the load flow case were modeled. For the stability simulations, the Vestas V80 1.8 MW wind turbine generators were modeled using the latest Vestas V80 1.8 MW wind turbine model set. Table 1 shows Vestas V80 1.8 MW wind generator data.

Table 1. Vestas V80 1.8 MW Wind Generator Data

Parameter	Value
BASE KV	0.690
WTG MBASE	2.0
TRANSFORMER MBASE	1.85
TRANSFORMER R ON TRANSFORMER BASE	0.0000
TRANSFORMER X ON TRANSFORMER BASE	0.075
GTAP	1.0
PMAX	1.8
PMIN	0.0
RA	0.0048897
LA	0.12602
LM	6.8399
R_ROT_MACH MINIMUM VALUE (ROTOR+EXTERNAL) RESIS.=ROTOR R	0.004419
R_ROT_MAX MAXIMUM (ROTOR+EXTERNAL) RESIS.=R2+R2@10%SLIP	0.109941
L1	0.18084

Table 2 shows Suzlon S88 2.1 MW wind generator data.

Table 2. Suzlon S88 2.1 MW Wind Generator Data

Parameter	Value
Power Base (VA)	2.1
Stator Voltage Base (KV)	0.6
Rotor Voltage Base (KV)	3.3
Stator Impedance Base (Ohm)	0.1714
Rotor Impedance Base (Ohm)	5.1857
Stator Current Base (KA)	2.0207
Rotor Current Base (KA)	0.3674
Rs (Ohm)	0.0027
Xs (Ohm)	0.0536
Xm (Ohm)	2.6
Rr (Ohm)	0.0034
Xr (Ohm)	0.0564

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

Table 3. Over/Under Frequency Relay Settings for Vestas V80 1.8 MW WTG

Frequency Settings in Hertz	Time Delay in Seconds	Breaker time in Seconds
F ≤ 52.5	0.2	0.08
55.5 < F ≤ 57.0	2.0	0.08
63.0 > F ≥ 62.0	90.0	0.08
F ≥ 62.5	0.2	0.08

Table 4. Over/Under Voltage Relay Settings for Vestas V80 1.8 MW WTG

Voltage Settings Per Unit	Time Delay in Seconds	Breaker time in Seconds
V ≤ 0.15	0.35	0.08
0.15 < V ≤ 0.75	2.65	0.08
0.75 < V ≤ 0.85	10.0	0.08
0.85 < V ≤ 0.90	300	0.08
V ≥ 1.10	60	0.08
1.10 > V ≥ 1.15	60	0.08
1.15 > V ≥ 1.2	2.0	0.08
1.2 > V ≥ 1.25	0.08	0.08

Table 5. Over/Under Frequency Relay Settings for Suzlon S88 2.1 MW WTG

Frequency Settings in Hertz	Time Delay in Seconds
$F \leq 57.0$	0.2
$F \geq 63.0$	0.2

Table 6. Over/Under Voltage Relay Settings for Suzlon S88 2.1 MW WTG

Voltage Settings Per Unit	Time Delay in Seconds
$V \leq 0.15$	0.08
$0.15 < V \leq 0.40$	0.70
$0.40 < V \leq 0.60$	1.60
$0.60 < V \leq 0.80$	2.80
$0.80 < V \leq 0.90$	60
$V \geq 1.15$	60
$1.15 > V \geq 1.2$	0.08

3.2 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 wind turbine 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.

3.3 Contingencies Simulated

Sixteen (16) disturbances 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

Cont. No.	Cont. Name	Description
1	FLT13PH	3 phase fault on the Wind Farm (20) to Buffalo (55835) 69 kV line, near the Wind Farm. a. Apply fault at the Wind Farm bus. b. Clear fault after 5 cycles by tripping the line from Wind Farm - Buffalo. 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	3 phase fault on the Wind Farm (20) to Fort Supply (55919) 69 kV line, near the Wind Farm. a. Apply fault at the Wind Farm bus. b. Clear fault after 5 cycles by tripping the line from Wind Farm – Fort Supply. 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	3 phase fault on the Fort Supply (55920) to Iodine (55957) 138 kV line, near Fort Supply. a. Apply fault at the Fort Supply bus. b. Clear fault after 5 cycles by tripping the line from Fort Supply-Iodine. 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.
6	FLT61PH	*Single phase fault and sequence like Cont. No. 5*
7	FLT73PH	3 phase fault on the Mooreland (55999) to Morewood Switch (56001) 138 kV line, near Moorewood Switch. a. Apply fault at the Moorewood Switch bus. b. Clear fault after 5 cycles by tripping the line from Mooreland-Moorewood. 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.
8	FLT81PH	*Single phase fault and sequence like Cont. No. 7*
9	FLT93PH	3 phase fault on the Fort Supply autotransformer (55920-55919) on the 69kV bus a. Apply fault at the Fort Supply 69kV bus. b. Clear fault after 5 cycles by tripping the autotransformer.

Cont. No.	Cont. Name	Description
10	FLT101PH	*Single phase fault and sequence like Cont. No. 9*
11	FLT113PH	3 phase fault on the Fort Supply (55919) to Woodward (56096) 69 kV line, near Fort Supply. a. Apply fault at the Fort Supply bus. b. Clear fault after 5 cycles by tripping the line from Fort Supply-Woodward. 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.
12	FLT121PH	*Single phase fault and sequence like Cont. No.11*
13	FLT133PH	3 phase fault on the Woodward (54785) – Iodine (OG&E) (54796) 138kV line near Woodward. a. Apply fault at the Woodward bus. b. Clear fault after 5 cycles by tripping the line from Woodward-Iodine. 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	3 phase fault on the Mooreland (55999) – Taloga 138kV line near Mooreland. a. Apply fault at the Mooreland bus. b. Clear fault after 5 cycles by tripping the line from Mooreland-Taloga. 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.
16	FLT161PH	*Single phase fault and sequence like Cont. No.15*

3.4 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. Based on the obtained simulation results, the system remained stable for all the simulated faults with the proposed 19.8 MW wind farm project in service. All oscillations were well damped. The study finds that the proposed 19.8 MW 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) show stable performance of SPP system.

For the two base cases studied and for the two types of WTGs, a complete set of the transient stability plots for rotor angle, speed, frequency, and voltages for the monitored buses in SPP for the simulated (16) disturbances with the proposed 19.8 MW wind farm in service, are in an electronic format on the accompanying CD.

With either Vestas V80 1.8 MW or Suzlon S88 2.1 MW WTGs and for peak summer and winter loading conditions, the simulations conducted in the study did not find any angular or voltage instability problems for the studied disturbances. Consequently, no dynamic reactive compensation is required.

All oscillations were well damped. The study finds that the proposed 19.8 MW wind farm project shows stable performance of SPP system for the contingencies tested on the supplied base cases.

4. Conclusion

The stability simulation findings of the impact study of a proposed interconnection (Gen-2006-024) were presented in this report. The analysis was conducted through the Southwest Power Pool Tariff for a 69 kV interconnection for 19.8 MW wind farm in Harper County, Oklahoma. This wind farm will be interconnected to the existing Fort Supply – Buffalo 69kV transmission line. This line is owned by Western Farmers Electric Cooperative. The customer has asked for a study case of 100% MW output (with dynamic reactive compensation if required). The customer has asked for a study case of 100% MW output (with dynamic reactive compensation if required). The Customer has asked to study two (2) types of Wind Turbine Generators (WTGs): Suzlon S88 2.1 MW and Vestas V80 1.8 MW.

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