SPP Southwest Power Pool

System Impact Study for Generation Interconnection Request

GEN-2003-013

SPP Tariff Studies
(#GEN-2003-013)

March 2004

Executive Summary

<OMITTED TEXT> (Customer) has requested a System Impact Study under the Southwest Power Pool Open Access Transmission Tariff (OATT) for interconnection of up to a 198 MW wind powered generation facility in Stevens County, Kansas to the transmission system of Southwestern Public Service Company (SPS/Xcel Energy). The wind powered generation facility will be comprised of 132 individual 1.5MW GE 1.5s wind turbines. The requested in-service date for the 198MW facility was September 30, 2004. However, this date was considered non-feasible considering the long order and lead times for equipment and construction. The revised in-service date is December 1, 2005.

The wind powered generation facility will interconnect approximately 7 miles northeast of Hugoton, Kansas, and 2 miles east of US Highway 56. The generation facility will interconnect to the Potter to Finney 345kV line circuit J3 via a new 345kV substation. The substation configuration will be finalized during the Facility Study if the customer elects to proceed.

There were no adverse impacts to the SPS/Xcel Energy transmission system identified through the power flow and single contingency studies, provided the generation facility satisfies the power factor requirements of SPS/Xcel Energy. Induction generator installations must provide power factor control within a range of 0.95 leading to 0.95 lagging. The Producer must provide any capacitors or other devices needed to achieve this power factor performance level.[1] The GE turbines utilized for this facility have the capability of achieving this power factor requirement. However, it should be noted that the requirement is at the Point of Interconnection and not at the turbines. Losses between the facility and the Point of Interconnection may require additional compensation depending on final siting and equipment configuration. For purposes of this study, the customer 345/34.5kV transformer substation is assumed adjacent to the 345kV substation on the Potter to Finney line.

Using the machine data provided by the requestor and other information publicly available, the stability studies indicate that the SPS/Xcel Energy system will remain stable for all but one simulated fault when the 198MW wind powered generation facility is connected to the transmission system. The GE turbines were able to ride-through the 14 distinct fault simulations that were specified by SPS/Xcel Energy. However, the interaction between the GEN-2003-013 and GEN-2002-008 wind farms, which are in relatively close proximity, causes an undesirable voltage and power oscillation at both the Potter and Finney substations. New, improved models of both the GE and Vestas turbines involved may reduce or eliminate the oscillations. SPP requires that once these models are made available, the certain unstable contingencies be re-run to verify these study results and determine what equipment that GEN-2003-013 would be required to provide to mitigate the instability. Short circuit analysis for this wind powered generation facility will be performed by SPS/Xcel Energy as part of the Facility Study if the customer elects to proceed.

The total estimated cost of construction on the SPS/Xcel Energy system for this interconnection is $3.9 million. The cost includes only construction of the 345kV substation tapping the Potter to Finney line. This cost does not include any costs associated with customer facilities including the customer 345/34.5kV substation, line connecting the customer substation and the new 345kV substation or associated right-of-way.

1. *Interconnection Guidelines For Transmission Interconnected Producer-Owned Generation Greater Than 20 MW Version 2.0*, p. 24, Retrieved 02/11/2004 from http://www.xcelenergy.com/docs/corpcomm/TransmissionInterconnectionGuidelines.pdf

1. Introduction

<OMITTED TEXT> (Customer) has requested a System Impact Study under the Southwest Power Pool Open Access Transmission Tariff (OATT) for interconnecting up to a 198 MW wind powered generation facility in Stevens County, Kansas to the transmission system of Southwestern Public Service Company (SPS/Xcel Energy). The wind powered generation facility will be comprised of 132 individual 1.5MW GE 1.5s wind turbines. The requested in-service date for the 198MW facility was September 30, 2004. However, this date was considered non-feasible considering the long order and lead times for equipment and construction. The revised in-service date is December 1, 2005.

The wind powered generation facility will interconnect approximately 7 miles northeast of Hugoton, Kansas, and 2 miles east of US Highway 56. The generation facility will interconnect to the Potter to Finney 345kV line circuit J3 via a new 345kV substation. The substation configuration will be finalized during the Facility Study if the customer elects to proceed.

2. Purpose

The purpose of the Interconnection System Impact Study is to evaluate the impact of the proposed interconnection on the reliability of the Transmission System. The Interconnection System Impact Study will consider the Base Case as well as all Generating Facilities (and with respect to (iii) below, any identified Network Upgrades associated with such higher queued interconnection) that, on the date the Interconnection System Impact Study is commenced: (i) are directly interconnected to the Transmission System; (ii) are interconnected to Affected Systems and may have an impact on the Interconnection Request; (iii) have a pending higher queued Interconnection Request to interconnect to the Transmission System; and (iv) have no Queue Position but have executed an LGIA or requested that an unexecuted LGIA be filed with FERC.

There are also several previously queued projects ahead of this request in the SPP Generation Interconnection queue. It was assumed for purposes of this study that not all of those projects would be in-service if this project is built. Any changes to this assumption, i.e. one or more of the previously queued projects not included in the study signing an interconnection agreement, may require a re-study of this request at the expense of the customer.

Nothing in this System Impact Study constitutes a request for transmission service or confers upon the Interconnection Customer any right to receive transmission service.

3.0 Facilities

3.1 Generating Facility

The generating facility was studied with the assumption that it would be using the GE 1.5s wind turbines. The nameplate rating of each turbine is 1.5MW (1500kW) with a machine base of 1667kVA. The turbine output voltage is 575V. The GE turbines utilize a doubly fed induction-generator with a wound rotor and slip rings. The generator synchronous speed is 1200 rpm, and a variable frequency power converter tied to the generator rotor allows the generator to operate at speeds ranging from 800 rpm to 1600 rpm. Nominal speed at 1.5MW power output is 1440 rpm and the maximum allowable non-operating rotational speed is 1680 rpm. The power converter allows the generator to produce power at a power factor of 0.9 lagging to 0.95 leading. The power factor is settable at each WTG or by the Plant SCADA system.

This power converter capability allows the turbines to have a significantly stronger voltage ride-through capability than other turbine models.

GE has provided optional equipment configurations that consist of enhanced low voltage ride through capability and improved power electronics that will improve efficiency and grid response to power fluctuations. This study was performed using the "standard" GE 1.5s wind turbine package available.

3.2 Interconnection Facility

The Customer has proposed an interconnection facility, which would connect to the SPS/Xcel Energy transmission system via a new substation located in Stevens County, Kansas on the existing Potter to Finney 345kV line circuit J3. The new substation would be configured to accept a terminal from an adjacent 345/34.5kV transformer substation that serves the wind powered generation facility.

The 345kV circuit J3 is approximately 220 miles long and connects southwest Kansas to the Amarillo, Texas area. There are no other substations along the line between these two points. However, there is a previously queued request in the SPP Interconnection queue that has requested interconnection to this same circuit J3. This request is a 240MW wind farm located on circuit J3 near the point where the transmission line crosses the Texas-Oklahoma state border. It was assumed for this study that this previously queued project, GEN-2002-008, was in-service and generating at 100% output for all scenarios. This places the GEN-2002-008 plant interconnection substation on the line between the GEN-2003-013 requested point of interconnection and the Potter substation.

4.0 <u>Analysis</u>

4.1 <u>Powerflow Analysis</u>

A powerflow analysis was conducted for the facility using modified versions of the 2004 Fall Peak and 2009 Summer Peak models. The output of the Customer's facility was offset in each model by a reduction in output of existing online SWPS generation. The in-service date of the facility is proposed to be December 2005. At the time the study was initiated, the next available stability model for simulation was the 2009 Summer Peak. During this initial analysis, a 2004 Fall Peak model was made available and was used to simulate a light load condition with the wind farms operating at full output.

The analysis of the customer's project shows that the proposed location can handle the entire 198MW of output under steady state and single contingency conditions without system upgrades in all seasons out to the end of SPP's planning horizon. The powerflow analysis does not study transient disturbances and their effects on the system.

There are several other proposed wind generation additions in the general area of the Customer's facility. It was assumed in the analysis that not all of these other projects were in service. Those previously queued projects that have advanced to nearly complete phases were included in this System Impact study.

4.1.1 <u>Powerflow Analysis Methodology</u>

The Southwest Power Pool (SPP) criteria states that: The transmission system of the SPP region shall be planned and constructed so that the contingencies as set forth in the Criteria will meet the applicable *NERC Planning Standards* for System Adequacy and Security – Transmission System Table l hereafter referred to as NERC Table l) and its applicable standards and measurements.

Using the created models and the ACCC function of PSS\E, single contingencies in the SWPS control area were applied and the resulting scenarios analyzed. This satisfies the 'more probable' contingency testing criteria mandated by NERC and the SPP criteria.

4.2 Stability Analysis

The following fault simulations were used to analyze the effects on various transmission system facilities and the wind farm.

The faults that were performed were defined by SPS and are as follows:

1. Fault on the GEN-2002-013 (90001) – Finney Switch Station (50858) 345kV line, near Finney.

   FLT_1_3_PH - 3-phase Fault
   a. Apply fault at the Finney bus (50858).
   b. Clear fault after 5 cycles by removing the line from 90001 to 50858.
   c. Wait 30 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.

2. Fault on the GEN-2002-013 (90001) – Finney Switch Station (50858) 345kV line, near Finney ***(utilizing single pole tripping–see Study Contents #8 above***).

   FLT_2_1_PH - 1-phase Fault
   a. Apply fault at the Finney bus (50858).
   b. Clear fault after 5 cycles by tripping one phase on the line from 90001 to 50858.
   c. Wait 30 cycles, and then re-close the phase in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

3. Fault on the GEN-2002-008 (66661) – Potter County (50888) 345kV line, near Potter County.

   FLT_3_3_PH - 3-phase Fault
   a. Apply fault at the Potter County bus (50888).
   b. Clear fault after 5 cycles by removing the line from 50888 to 66661.
   c. Wait 30 cycles, and then re-close line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip line in (b) and remove fault.

4. Fault on the GEN-2002-008 (66661) – Potter County (50888) 345kV line, near Potter County ***(utilizing single pole tripping– see Study Contents #8 above***).

   FLT_4_1_PH - 1-phase Fault
   a. Apply fault at the Potter bus (50888).
   b. Clear fault after 5 cycles by tripping one phase on the line from 66661 to 50888.
   c. Wait 30 cycles, and then re-close the phase in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

5. Fault on the GEN-2002-008 (66661) – GEN-2003-013 (90001) 345kV line, at the midpoint of the line.

   FLT_5_3_PH - 1-phase Fault

   a. Apply fault at the midpoint of the line (99996).
   b. Clear fault after 5 cycles by tripping the line from 66661 to 90001.
   c. Wait 30 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. Fault on the GEN-2002-008 (66661) – GEN-2003-013 (90001) 345kV line, at the midpoint of the line ***(utilizing single pole tripping– see Study Contents #8 above***).

   FLT_6_1_PH - 1-phase Fault

   a. Apply fault at the midpoint of the line (99996).
   b. Clear fault after 5 cycles by tripping one phase on the line from 66661 to 90001.
   c. Wait 30 cycles, and then re-close the phase in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

7. Fault on the Grapevine (50827) – Elk City (54153) 230 kV line, near Grapevine.

   FLT_7_3_PH - 3-phase Fault

   a. Apply fault at the Grapevine bus (50827).
   b. Clear Fault after 5 cycles by removing line from 50827 – 54153.
   c. Wait 20 cycles, and then re-close line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

8. Fault on the Grapevine (50827) – Elk City (54153) 230 kV line, near Grapevine.

   FLT_8_1_PH - 1-phase Fault

   a. Apply fault at the Grapevine bus (50827).
   b. Clear Fault after 5 cycles by removing line from 50827 – 54153.
   c. Wait 20 cycles, and then re-close line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

9. Fault on the Potter County (50887) – Plant X (51419) 230kV line, near Plant X.

   FLT_9_3_PH - 3-phase Fault

   a. Apply fault at the Plant X bus (51419).
   b. Clear Fault after 5 cycles by removing line from 50887 – 51419.
   c. Wait 20 cycles, and then re-close line in (b) into the fault.
   d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

10. Fault on the Potter County (50887) – Plant X (51419) 230kV line, near Plant X.

FLT_10_1_PH - 1-phase Fault

a. Apply fault at the Plant X bus (51419).
b. Clear Fault after 5 cycles by removing line from 50887 – 51419.
c. Wait 20 cycles, and then re-close line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

11. Fault on the Pringle Interchange (50652) – Blackhawk (50718) 115kV line, near Blackhawk.

FLT_11_3_PH - 3-phase Fault

a. Apply fault at the Blackhawk bus (50718).
b. Clear Fault after 5 cycles by removing line from 50652 – 50718.
c. Wait 20 cycles, and then re-close line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

12. Fault on the Pringle Interchange (50652) – Blackhawk (50718) 115kV line, near Blackhawk.

FLT_12_1_PH - 1-phase Fault

a. Apply fault at the Blackhawk bus (50718).
b. Clear Fault after 5 cycles by removing line from 50652 – 50718.
c. Wait 20 cycles, and then re-close line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

13. Fault on the Wolfforth Interchange (51762) – Terry County (51830) 115kV line, near Terry County.

FLT_13_3_PH - 3-phase Fault

a. Apply fault at the Terry County bus (51830).
b. Clear Fault after 5 cycles by removing line from 51762 – 51830.
c. Wait 20 cycles, and then re-close line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

14. Fault on the Wolfforth Interchange (51762) – Terry County (51830) 115kV line, near Terry County.

FLT_14_1_PH - 1-phase Fault

a. Apply fault at the Terry County bus (51830).
b. Clear Fault after 5 cycles by removing line from 51762 – 51830.
c. Wait 20 cycles, and then re-close line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

The above cases were run for the following conditions:

2009 Summer Peak (Max loading conditions)
System base case with Wind farm idled (0MW)
Wind farm output at 198MW with voltage control enabled
Wind farm output at 198MW with power factor control enabled (PF set to 0.95 lag)
Wind farm output at 198MW with power factor control enabled (PF set to 0.95 lead)
Wind farm output at 99 MW with voltage control enabled

2004 Fall Peak (Light loading conditions)*
System base case with Wind farm idled (0MW)
Wind farm output at 198MW with voltage control enabled
Wind farm output at 198MW with power factor control enabled (PF set to 0.95 lag)
Wind farm output at 198MW with power factor control enabled (PF set to 0.95 lead)
Wind farm output at 99 MW with voltage control enabled

*Note: A 2004 Fall Peak stability case was used for stability analysis only to determine wind farm generator response in a light load case with minimal large, baseload generation units online. The reason for using a 2004 Fall season case is due to limited stability model availability. The 2004 Fall Peak case should model approximately the response for the same season in later years. The only differences would arise from network changes (ex. construction) and load levels (ex. load growth).

4.2.1 <u>Dynamic Modeling of the Wind Powered Generation Facility</u>

The rated output of the generation facility is 198MW, comprised of 132 GE 1.5s wind turbines. The base voltage of the GE turbine is 575 V, and a generator step up transformer (GSU) of 1.75MVA connects each unit to the high side of 34.5kV. The rated power output of each turbine is 1.5MW while the actual power output depends on the wind.

In performing a system impact study, existing on-line generation in the local control area is displaced by the addition of the generator in order to preserve control area interchange schedules in the model. Adjustment of the control area dispatch is performed with input from the Transmission Owner to accurately model unit commitments and availability.

The generating facility substation will consist of three (3) 42MVA 115kV/34.5kV transformers connected in parallel. From the preliminary one-lines received from the customer, on the 34.5kV side of each transformer, 6 feeder circuits will extend into the generating facility. Each feeder will connect to a collection substation that will in turn consist of 3 collection circuits. Each collection circuit will consist of 7 or 8 turbines each. Each turbine then has its own pad-mounted transformer rated 575V/34.5kV and 1.75MVA. Please see the one-line drawing (Figure 1) attached to this document.

The actual parameters (R, X and B) of the 34.5kV collector circuits are calculated based on the data provided by the customer and assumptions of typical conductor characteristics. This information is useful in estimating the impedance of the collection and feeder systems. The cable impedance characteristic table is as follows:

Cable Impedance Characteristic Table				
Cardinal	1000 ACSR	RAC=0.0186 Ohm/1000'	XL=0.0737 Ohm/1000'	XC=0.0168 Mohm-1000'
MV-105	1/0 Cu Shielded	RAC=0.1060 Ohm/1000'	XL=0.0500 Ohm/1000'	XC=0.0483 Mohm-1000'

4.2.2 Machine Dynamics Data

The GE 1.5s wind turbine generators utilize a doubly fed induction-generator with a wound rotor and slip rings. The generator synchronous speed is 1200 rpm, and a variable frequency power converter tied to the generator rotor allows the generator to operate at speeds ranging from 800 rpm to 1600 rpm. Nominal speed at 1.5MW power output is 1440 rpm and the maximum allowable non-operating rotational speed is 1680 rpm. The power converter allows the generator to produce power at a power factor of 0.9 lagging to 0.95 leading. The power factor is settable at each WTG or by the Plant SCADA system.

Shaw Power Technologies Inc. (PTI) has produced a GE 1.5s turbine model package for use on their PSS/E simulation software. This package was obtained from PTI and was used exclusively in modeling this wind farm. Since the analysis of this study has been completed, a new, improved GE wind turbine model package has been released by PTI.

The PTI model package consists of an IPLAN program that creates the dynamic stability data for the wind farm based on inputs from the user. The user is able to choose how the wind farm is dispatched (via a wind speed data set or dispatched directly), whether the turbines will be set to a specific voltage or power factor setpoint, and the protection schemes for the turbines (both frequency and voltage).

The wind farm was dispatched directly by the program to the level specified (100% rated power and 50% rated power). It was also assumed that all turbines located in the farm were in-service (50% rated power means that all 100 turbines were generating at 50% rated power). The wind farm was also set to adjust for a voltage setpoint and alternatively a power factor setpoint to investigate the behavior of the farm for the various fault situations. The default protection schemes embedded in the PTI model package were utilized for the farm. Improved default protection schemes are a part of the new, improved GE wind turbine model package from PTI.

4.2.3 Turbine Protection Schemes

The GE turbines utilize an undervoltage/overvoltage protection scheme and an underfrequency/overfrequency protection scheme. The various protection schemes are designed to protect the wind turbines in the case of system disturbances that can cause damage to the mechanical systems or power electronics on board the turbine. Generally, the protection schemes will disconnect the generator from the electric grid if the sampled frequency or voltage is outside of a specified band for a specified amount of time.

The new Low Voltage Ride Through (LVRT) option for the GE wind turbines was not modeled in the analysis of this request. The new LVRT option allows the wind turbines to experience grid voltages as low as 0.15pu for up to 0.5 seconds.

The voltage protection scheme is outlined in Table 1 below:

Voltage	Time Limit
1.3000pu +	1.2 cycles (0.02s)
1.1500pu -- 1.299pu	6 cycles (0.1s)
1.1499pu – 1.1000pu	12 cycles (0.2s)
1.0999pu – 0.9001pu	Continuous Operation
0.9000pu -- 0.8001pu	36000 cycles (10min) *Assumed Continuous Operation
0.8000pu – 0.7001pu	600 cycles (10.0s)
0.7000pu – 0.3001pu	60 cycles (1.0s)
0.3000pu – 0.0000pu	1.2 cycles (0.02s)

Table 1: GE 1.5s Turbine Voltage Protection

The frequency protection scheme is outlined in Table 2 below:

Frequency	Time Limit
61.7000Hz +	1.2 cycles (0.02s)
61.6999Hz -- 61.500Hz	1800 cycles (30.0s)
61.4999Hz -- 58.5001Hz	Continuous Operation
58.5000Hz – 57.9001Hz	450 cycles (7.5s)
57.9000Hz – 57.4001Hz	45 cycles (0.75s)
56.9000Hz – 56.5001Hz	7.2 cycles (0.12s)
56.5000Hz – 0.0000Hz	1.2 cycles (0.02s)

Table 2: GE 1.5s Turbine Frequency Protection

4.3 Stability Results

The wind farm and the surrounding transmission system appear to remain stable for all faults applied and for all scenarios analyzed except for Fault 2_1PH, a single phase fault on the line between the GEN-2003-013 wind farm and Finney. Further discussion of this fault and the observed instability occurs in the following section. For the other faults, this wind farm did not trip and voltage and frequency appear to recover nicely for all cases and scenarios. Speeds of machines in the SPS area and the wind farm appear to remain within limits. The GEN-2002-008 wind farm did experience tripping for certain faults on the Potter to Finney 345kV line, but this did not translate into problems for the GEN-2003-013 wind farm or the rest of the surrounding system except for Fault 2_1PH. All cases and scenarios are tabulated below:

2004 Fall Peak Case:

2004 Fall Peak Case: ***Fault Case/Scenario***	Base case	198MW (Voltage Control Enabled)	198MW (Power Factor Control set to 0.95 leading)	198MW (Power Factor Control set to 0.95 lagging)	99MW (Voltage Control Enabled)
FLT_1_3_PH	0	0	---	0	0
FLT_2_1_PH	---	---	---	---	---
FLT_3_3_PH	0	0	0	0	0
FLT_4_1_PH	@ (2)	@ (6)	@ (14)	@ (4)	---
FLT_5_3_PH	0	0	0	0	0
FLT_6_1_PH	---	---	---	---	---
FLT_7_3_PH	---	---	---	---	---
FLT_8_1_PH	---	---	---	---	---
FLT_9_3_PH	---	---	---	---	---
FLT_10_1_PH	---	---	---	---	---
FLT_11_3_PH	---	---	---	---	---
FLT_12_1_PH	---	---	---	---	---
FLT_13_3_PH	---	---	---	---	---
FLT_14_1_PH	---	---	---	---	---

O = entire equivalent GEN-2002-008 wind farm tripped due to low voltage
@ (x) = (x) number of equivalent GEN-2002-008 wind turbines tripped for low voltage
--- = none of the online wind farms tripped

2009 Summer Peak Case:

2009 Summer Peak Case: ***Fault Case/Scenario***	Base case	198MW (Voltage Control Enabled)	198MW (Power Factor Control set to 0.95 leading)	198MW (Power Factor Control set to 0.95 lagging)	99MW (Voltage Control Enabled)
FLT_1_3_PH	0	0	0	0	0
FLT_2_1_PH	---	---	---	---	---
FLT_3_3_PH	0	0	0	0	0
FLT_4_1_PH	---	0	0	0	0
FLT_5_3_PH	0	0	0	0	0
FLT_6_1_PH	---	---	---	---	---
FLT_7_3_PH	---	---	---	---	---
FLT_8_1_PH	---	---	---	---	---
FLT_9_3_PH	---	---	---	---	---
FLT_10_1_PH	---	---	---	---	---
FLT_11_3_PH	---	---	---	---	---
FLT_12_1_PH	---	---	---	---	---
FLT_13_3_PH	---	---	---	---	---
FLT_14_1_PH	---	---	---	---	---

O = entire equivalent GEN-2002-008 wind farm tripped due to low voltage
--- = none of the online wind farms tripped

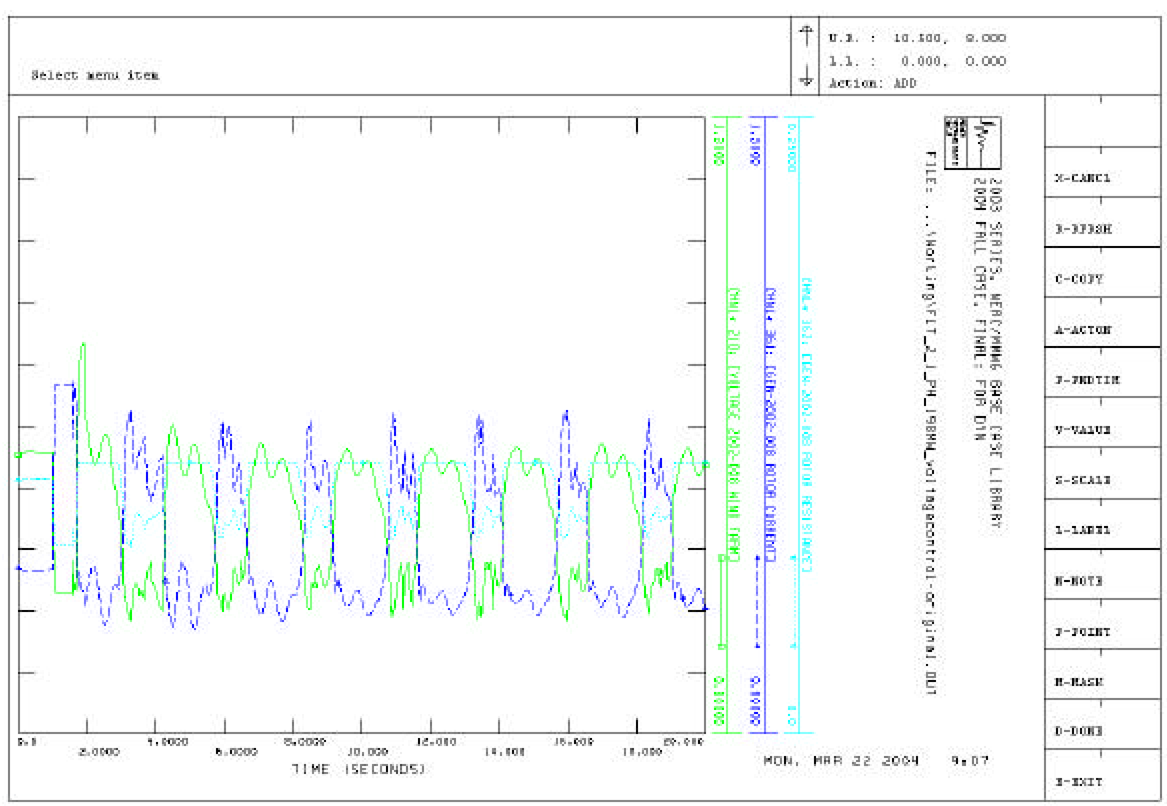
All scenarios/faults were run to a period of 20.0 seconds to verify that the wind turbines achieved stable operation.

Other wind farms modeled in the case (GEN-2002-006, -008, and –009), which have higher queue priority than this request, were modeled in these two seasons. The only wind farm to experience tripping was the GEN-2002-008 wind farm located on the same line as this GEN-2003-013 request. The GEN-2002-008 wind farm consists of the Vestas V80 turbines that utilize a significantly different technology than the GE machines. However, these faults were considered close-in faults to the wind farms and thus it was expected that either or both of these farms would possibly trip due to the fault. The remaining system and the GEN-2003-013 wind farm remained stable and online regardless of the tripping of the other wind farm except for Fault 2_1PH discussed in the following section.

4.3.1 Instability for Fault 2_1PH (Single phase fault at Finney)

Voltage instability was observed at both the GEN-2003-013 wind farm and the GEN-2002-008 wind farm for the single-phase fault at Finney. This fault simulation consisted of grounding one phase of the 345kV line by applying a fault at the Finney 345kV bus at time=1.0 seconds. Tripping on this 345kV line consists of single-pole tripping which allows only the affected phase to be tripped initially during the first clearing. This tripping scheme is an attempt to keep the phase angle spread between Southwest Kansas and North Texas from becoming too large. The tripped phase has reclosing that connects the line back into the fault. Second clearing of the fault removes all 3 phases from service.

During the fault simulation, as the voltage drops, the GEN-2002-008 wind farm rotor protection system engages the external rotor resistance intended to protect the generator rotor. The fault is cleared after 5 cycles by opening the affected phase. The voltage remains steady at both farms for the next 30 cycles until the grounded phase is closed back into the fault. After 5 more cycles, all 3 phases of the line between the GEN-2003-013 wind farm and Finney are opened. This results in a rapid rise in the voltage at both wind farms. The voltage experienced at the GEN-2002-008 wind farm causes overvoltage tripping of the power factor correction capacitors on the Vestas turbines at the GEN-2002-008 wind farm. This results in more vars being consumed by the farm and thus a drop in the voltage and a corresponding rise in the rotor current. The rise in the rotor current again causes the rotor current protection resistors to engage and reduce the voltage further. The reduced voltage reduces the var consumption of the farm and the voltage increases again. As the voltage rises and declines with the switching in and out of the rotor protection resistance, the voltage and power oscillates at the GEN-2002-008 wind farm. The voltage oscillation is between approximately 0.9pu and 1.03pu. This is further aggravated by the addition of the GEN-2003-013 wind farm with its active var control devices. The aggravation is the greatest when the GE turbines are set to regulate the voltage to a specific setpoint.



This same oscillatory response is present when only the GEN-2002-008 wind farm is connected to the 345kV line. However, the magnitude of the oscillation is very small compared to the scenario where both wind farms are connected simultaneously. When the GEN-2002-008 wind farm is connected alone, the voltage and power oscillation from the farm is not felt at either Potter or Finney substations at either end of the line. With both wind farms connected simultaneously, the voltage and power oscillations are felt at both Potter and Finney substations.

With close coordination of both wind farm operators, the wind farms controls could possibly be adjusted such that this sort of oscillatory response is either minimized or eliminated. One method of eliminating the oscillatory response is to trip the GEN-2003-013 wind farm when all 3 phases of the line between Finney and the GEN-2003-013 wind farm are opened. This will essentially eliminate the interaction between the two wind farm controls and reduce the oscillatory response of the GEN-2002-008 wind farm. It is likely that all or some of the power factor correction capacitors will trip even if the GEN-2003-013 wind farm is removed from the system after the fault. However, the magnitudes of the oscillations at the GEN-2002-008 wind farm would be of small enough size that they would not be felt on the rest of the SPS transmission system.

If the GEN-2002-008 wind farm is either not operating or is not built, then the oscillations mentioned above are not present in the fault simulations.

It is also possible that a Dynamic Reactive Support device, such as a SVC or DVAR, could be implemented to provide supplemental reactive support such that the oscillations mentioned above are either minimized or eliminated. Any additional equipment or facilities required to mitigate the instability would be the responsibility of the GEN-2003-013 request.

> **Note:** Since the analysis of this study was completed, a new, improved GE wind turbine model package was release by PTI. There is also a new, improved Vestas wind turbine model that will be made available soon. This Vestas model is still in testing. After discussion with PTI, SPP will require that when this new Vestas model is ready for public use, the selected unstable contingencies from this study be re-run with the new models (both GE and Vestas). Improved model packages may show that no instability would occur. The new GE model would include the enhanced LVRT package currently available.

5.0 Conclusion

Certain stability concerns presently exist for the GEN-2003-013 wind farm as proposed and studied. Due to the close electrical proximity of this wind farm to a previously studied, higher queued wind farm (GEN-2002-008), there are oscillatory responses to a single-phase fault on the line to which both of these wind farms are interconnected. Close coordination between both wind farm developers and equipment manufacturers will be required to ensure that the equipment is being modeled correctly and controls are adjusted correctly. Once the equipment has been configured at its optimum settings, further study should be done to investigate whether the problem has been corrected or if further action or equipment is required.

At this time, there are no recommendations for further transmission facilities that would be required for interconnection. However, SPP requires that when new, improved models of the Vestas (GEN-2002-008) wind turbines are made available, selected unstable contingencies be re-run to verify the results of this study and determine if additional equipment is required by GEN-2003-013 to mitigate the instability. When deliverability of the wind farm's power is studied, additional transmission facilities may also be required.

The minimum cost of interconnecting the Customer project is $3.9 million. However, as stated earlier, some previously queued projects were assumed to not be in service in this System Impact Study. If any of those projects are constructed, then this System Impact Study may have to be revisited, at SPP's sole discretion, to determine the impacts of this customer's project on other SPS transmission facilities. It should be noted that the models used for simulation do not contain all SPP transmission service. The models do contain all the firm transmission service included by the transmission owners in their model updates for SPP's planning models. These costs also do not take into account any breaker duty ratings or settings. The short circuit analysis will be performed as part of the Facility Study performed by SPS if the customer elects to have the study performed.

The costs do not include any costs associated with the deliverability of the energy to final customers. These costs are determined by separate studies if the Customer requests transmission service through Southwest Power Pool's OASIS.

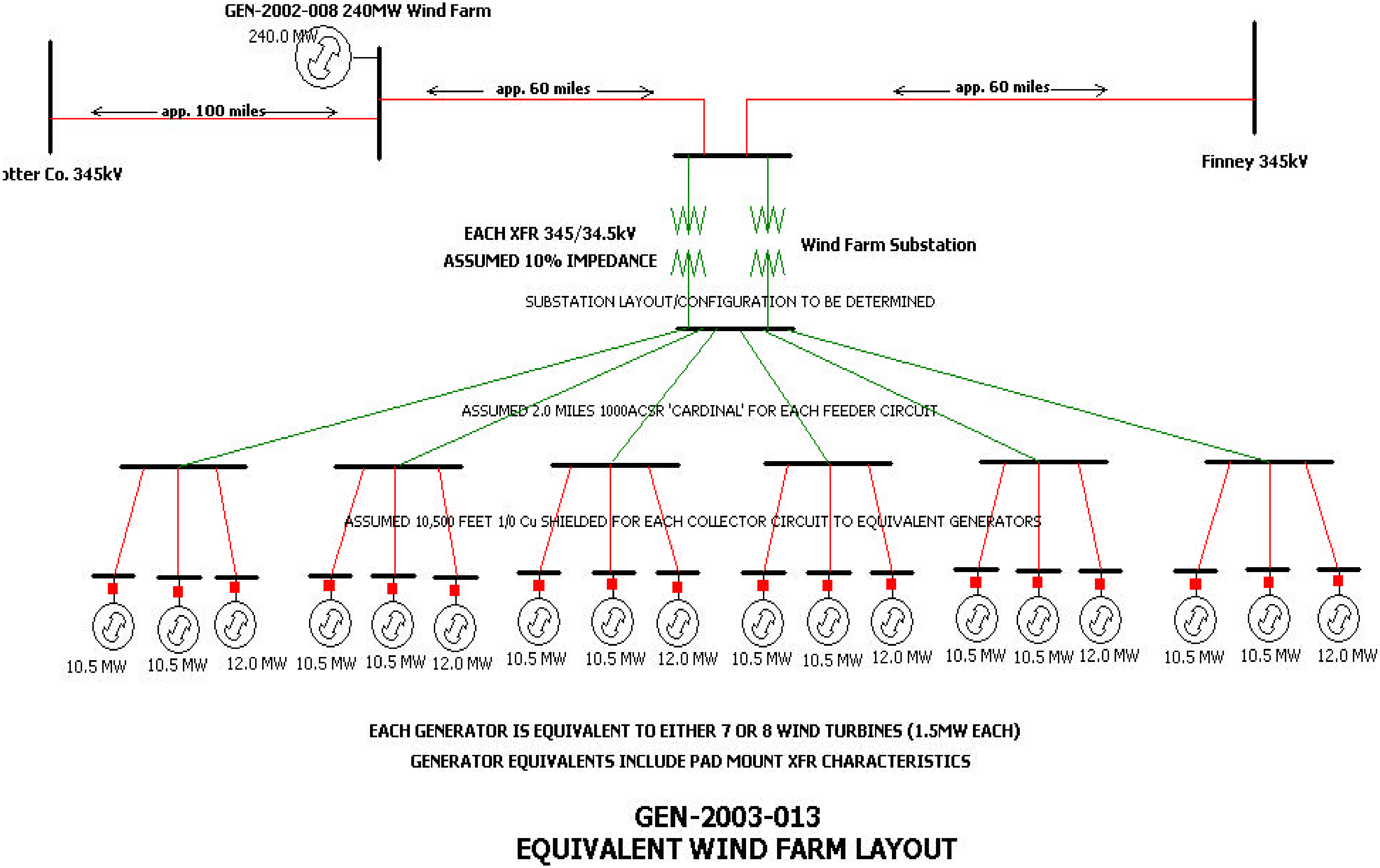

GEN-2002-008 240MW Wind Farm
240.0 MW
app. 100 miles
app. 60 miles
app. 60 miles
otter Co. 345kV
Finney 345kV
EACH XFR 345/34.5kV
ASSUMED 10% IMPEDANCE
Wind Farm Substation
SUBSTATION LAYOUT/CONFIGURATION TO BE DETERMINED
ASSUMED 2.0 MILES 1000ACSR 'CARDINAL' FOR EACH FEEDER CIRCUIT
ASSUMED 10,500 FEET 1/0 Cu SHIELDED FOR EACH COLLECTOR CIRCUIT TO EQUIVALENT GENERATORS
10.5 MW 10.5 MW 12.0 MW 10.5 MW 10.5 MW 12.0 MW 10.5 MW 10.5 MW 12.0 MW 10.5 MW 10.5 MW 12.0 MW 10.5 MW 10.5 MW 12.0 MW 10.5 MW 10.5 MW 12.0 MW
EACH GENERATOR IS EQUIVALENT TO EITHER 7 OR 8 WIND TURBINES (1.5MW EACH)
GENERATOR EQUIVALENTS INCLUDE PAD MOUNT XFR CHARACTERISTICS
GEN-2003-013
EQUIVALENT WIND FARM LAYOUT

Figure 1