Impact Study for Generation Interconnection Request GEN–2003–005

SPP Tariff Studies
(#GEN-2003-005)

March 2009

Summary

Pursuant to the tariff and at the request of the Southwest Power Pool (SPP), S&C Electric Company (S&C) performed the following Impact Study to satisfy the Impact Study Agreement executed by the requesting customer and SPP for SPP Generation Interconnection request GEN-2003-005. 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 for GEN-2003-005 was originally studied with Vestas V80-1.8 MW turbines. This restudy analyzed the use of G.E. 1.5 MW wind turbines.

Reactive Compensation

The Customer wind farm facility was studied with the G.E. 1.5MW wind turbines with the wind var option and +/-95% power factor capability. The Impact Study has determined that are no additional static VAR requirements necessary for the operation of GEN-2003-005 with G.E. turbines. The Impact Study determined that a STATCOM or SVC device was not necessary for the studied G.E. turbines to meet FERC Order #661A low voltage ride through provisions.

Draft Report

For

Southwest Power Pool

From

S&C Electric Company

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2003-005 RESTUDY

S&C Project No. 3475

March 2, 2009

S&C Electric Company

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Report Revision History:

Date of Report	Issue	Comments
March 2, 2009	Rev. A	Draft for review and comments

EXECUTIVE SUMMARY

This system impact study was performed in response to a generation interconnection study request through the Southwest Power Pool Tariff for a 98 MW wind farm in Grady County, Oklahoma. The proposed wind project would consist of 65 General Electric 1.5 MW wind turbine generators and interconnect into a new substation to be built along the 138 kV Anadarko to Paradise transmission line owned by the Western Farmers Electric Cooperative (WFEC). The objective of this study was to determine the impact of the interconnection at 100% output power on the stability of nearby areas and prior queued projects for winter and summer peak 2008 seasonal cases and identify reactive power compensation requirements in order to successfully integrate the project into the transmission system.

Steady-state results indicate that the project will be capable of maintaining the voltage at the Point of Interconnection (POI) to Pre-Project levels for the N-1 contingencies defined by SPP. There are no additional static VAR requirements and the standard GE 1.5 MW with +/- 95% power factor control range will be sufficient. The wind project is required to monitor and control the voltage at the POI to an operating voltage set point via the GE Wind Farm Management System.

Three-phase and single-phase-to-ground faults were studied at locations specified by SPP. Transient stability cases and results are summarized in Table 1. Transient stability analysis results indicate that the project and prior queued projects will survive all fault contingencies and satisfy the FERC Order 661A provisions on low-voltage ride through (LVRT). The system is stable in all cases.

1. INTRODUCTION

This system impact study was performed in response to a generation interconnection study request through the Southwest Power Pool Tariff for a 98 MW wind farm in Grady County, Oklahoma. The proposed wind project would consist of 65 General Electric 1.5 MW wind turbine generators to be interconnected into a new substation to be built along the 138 kV Anadarko to Paradise transmission line owned by the Western Farmers Electric Cooperative (WFEC). The objective of this study was to determine the impact of the interconnection at 100% output power on the stability of nearby areas and prior queued projects for winter and summer seasonal peak 2008 cases and identify any reactive power compensation requirements in order to successfully integrate the project into the transmission system. Previously the project had been studied using 2.1 MW Suzlon S88 wind turbine generators and results indicated the need for static and dynamic reactive compensation.

2. LOAD FLOW STUDY AND RESULTS

Collector system impedance information was provided by the project developer. Each feeder/circuit is represented as aggregated generators to simplify representation in PSS/E.

Table 1: GEN-2003-005 Model Parameters

Circuit 1	Parameters
12 GE 1.5 MW wind turbine generators at 0.575 kV	12 * 1.5 MW = 18 MW 12 * 1.58 MVA = 18.95 MVA pf range = +/- 0.95
12 Pad mounted wind turbine generator transformers 0.575 / 34.5 kV transformers	12 * 1.75 MVA = 21 MVA X/R = 7.5, %IZ = 5.75 Z1 = 0.0076+ 0.0570j p.u. on 21 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.03958 + 0.02769j p.u. on 100 MVA base B1 = 0.005270 p.u. on 100 MVA base

Table 1: GEN-2003-005 Model Parameters (continued)

Circuit 2	Parameters
12 GE 1.5 MW wind turbine generators at 0.575 kV	12 * 1.5 MW = 18 MW 12 * 1.58 MVA = 18.95 MVA pf range = +/- 0.95
12 Pad mounted wind turbine generator transformers 0.575 / 34.5 kV transformers	12 * 1.75 MVA = 21 MVA X/R = 7.5, %IZ = 5.75 Z1 = 0.0076+ 0.0570j p.u. on 21 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.02401 + 0.01405j p.u. on 100 MVA base B1 = 0.004950 p.u. on 100 MVA base

Circuit 3	Parameters
12 GE 1.5 MW wind turbine generators at 0.575 kV	12 * 1.5 MW = 18 MW 12 * 1.58 MVA = 18.95 MVA pf range = +/- 0.95
12 Pad mounted wind turbine generator transformers 0.575 / 34.5 kV transformers	12 * 1.75 MVA = 21 MVA X/R = 7.5, %IZ = 5.75 Z1 = 0.0076+ 0.0570j p.u. on 21 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.09549 + 0.06526j p.u. on 100 MVA base B1 = 0.006153 p.u. on 100 MVA base

Circuit 4	Parameters
11 GE 1.5 MW wind turbine generators at 0.575 kV	11 * 1.5 MW = 16.5 MW 11 * 1.58 MVA = 17.38 MVA pf range = +/- 0.95
11 Pad mounted wind turbine generator transformers 0.575 / 34.5 kV transformers	11 * 1.75 MVA = 19.25 MVA X/R = 7.5, %IZ = 5.75 Z1 = 0.0076+ 0.0570j p.u. on 21 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.03225 + 0.01246j p.u. on 100 MVA base B1 = 0.004298 p.u. on 100 MVA base

Circuit 5	Parameters
12 GE 1.5 MW wind turbine generators at 0.575 kV	12 * 1.5 MW = 18 MW 12 * 1.58 MVA = 18.95 MVA pf range = +/- 0.95
12 Pad mounted wind turbine generator transformers 0.575 / 34.5 kV transformers	12 * 1.75 MVA = 21 MVA X/R = 7.5, %IZ = 5.75 Z1 = 0.0076+ 0.0570j p.u. on 21 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.04185 + 0.01933j p.u. on 100 MVA base B1 = 0.003956 p.u. on 100 MVA base

Circuit 6	Parameters
6 GE 1.5 MW wind turbine generators at 0.575 kV	6 * 1.5 MW = 9 MW 6 * 1.58 MVA = 9.48 MVA pf range = +/- 0.95
6 Pad mounted wind turbine generator transformers 0.575 / 34.5 kV transformers	6 * 1.75 MVA = 10.5 MVA X/R = 7.5, %IZ = 5.75 Z1 = 0.0076+ 0.0570j p.u. on 21 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.13402 + 0.01942j p.u. on 100 MVA base B1 = 0.002897 p.u. on 100 MVA base

Substation	Parameters
34.5 / 138 kV main transformer	MVA ratings = 69/92/115 MVA X/R = 30 (typical) %IZ = 9 on self-cooled MVA rating Z1 = 0.00300+ 0.08995j p.u. on 69 MVA base Fixed HV tap setting = flat

2.1 Modeling of Wind Turbine Generators

The GE 2.1 MW/60 Hz wind turbine generators are variable speed doubly-fed (wound rotor) induction generators with electrical pitch control. At full load, the standard product offering can operate between 0.95 lagging (inductive) to 0.95 leading (capacitive) power factor. With an optional upgrade, the turbines can operate between 0.90 lagging to 0.90 leading power factor. Each wind turbine can be configured to work with the GE Wind Farm Management System to regulate the voltage at the Point of Interconnection (POI) to a specific setpoint.

2.2 Power Factor Requirements at the POI

The project can be successfully integrated into the transmission system with the standard GE 1.5 MW wind turbine generator. The project would be required to regulate the voltage at the POI to pre-project system intact voltage levels for N-1 contingencies specified by SPP, which are listed in Table 2. Table 3 lists the voltage level at the POI for the N-1 contingencies in the Pre-Project case. Tables 4 and 5 list the voltage level at the POI for the Post-Project case. The wind farm meets the steady-state reactive power needs of the system. Figure 2 and 3 are the power flow diagrams of the project for the summer and winter peak cases.

Table 2: List of Contingencies

Contingency Number	Description
INTACT	System intact
FLT13PH	Anadarko (#520814) – Wind Farm 138 kV line (N-1)
FLT33PH	Paradise (#521024) – Windfarm 138 kV line (N-1)
FLT53PH	Snyder (#521052) – Paradise (521024) 138 kV line (N-1)
FLT73PH	Snyder (#521051) – Navajo (#521009) 69kV line (N-1)
FLT93PH	Fort Cobb (#511454)– Southwestern Station (#511477) 138 kV line (N-1)
FLT113PH	Anadarko (#520814) – Southwestern Station (#511477) 138 kV line (N-1)
FLT153PH	Anadarko (#520810) – Blanchard (#520828) 69 kV line (N-1)
FLT173PH	Washita (#521089) – Anadarko (#520814) 138 kV line (N-1)
FLT193PH	Washita (#521089) – Oney (#521017) 138 kV line (N-1)
FLT213PH	Washita (#521089) – Southwest Station (#511477) 138 kV line (N-1)

Table 3: Pre-Project Voltages at the POI

Contingency Number	Voltage in p.u. Summer Peak 08	Voltage in p.u. Winter Peak 08
INTACT	1.0170	1.0230
FLT13PH	0.9598	1.0191
FLT33PH	1.0193	1.0226
FLT53PH	1.0180	1.0219
FLT73PH	1.0184	1.0245
FLT93PH	1.0162	1.0230
FLT113PH	1.0167	1.0241
FLT153PH	1.0167	1.0227
FLT173PH	1.0174	1.0243
FLT193PH	1.0169	1.0232
FLT213PH	1.0136	1.0187

Table 4: Post-Project Voltages at the POI for Summer Peak
(GE Wind Farm Management System regulating voltage at the POI to 1.017 pu)

Case	Voltage at POI (pu)	MW into POI	Power Factor at POI in %	Power Factor at WTG in %
INTACT	1.017	96.5	98.1% lagging	99.9% lagging
FLT13PH	1.017	96.6	98.1% lagging	99.4% leading
FLT33PH	1.017	96.4	100.0%	99.4% lagging
FLT53PH	1.017	96.5	96.3% lagging	99.7% lagging
FLT73PH	1.017	96.5	97.3% lagging	99.6% lagging
FLT93PH	1.017	96.5	97.0% lagging	100.0%
FLT113PH	1.017	96.5	98.7% lagging	100.0%
FLT153PH	1.017	96.5	98.6% lagging	99.9% lagging
FLT173PH	1.017	96.5	98.4% lagging	99.9% lagging
FLT193PH	1.017	96.5	98.2% lagging	99.9% lagging
FLT213PH	1.017	96.6	99.8% lagging	99.7% leading

Table 5: Post-Project Voltages at the POI for Winter Peak
(GE Wind Farm Management System regulating voltage at the POI to 1.032 pu)

Case	Voltage at POI (pu)	MW into POI	Power Factor at POI in %	Power Factor at WTG in %
INTACT	1.032	96.5	97.8% lagging	99.8% lagging
FLT13PH	1.032	96.6	97.8% lagging	99.7% leading
FLT33PH	1.032	96.5	99.9% lagging	99.9% lagging
FLT53PH	1.032	96.5	98.2% lagging	100.0%
FLT73PH	1.032	96.5	98.6% lagging	99.5% lagging
FLT93PH	1.032	96.5	96.6% lagging	99.8% lagging
FLT113PH	1.032	96.5	97.9% lagging	99.7% lagging
FLT153PH	1.032	96.5	97.3% lagging	99.9% lagging
FLT173PH	1.032	96.5	98.1% lagging	99.6% lagging
FLT193PH	1.032	96.5	97.7% lagging	99.8% lagging
FLT213PH	1.032	96.6	99.8% lagging	99.7% leading

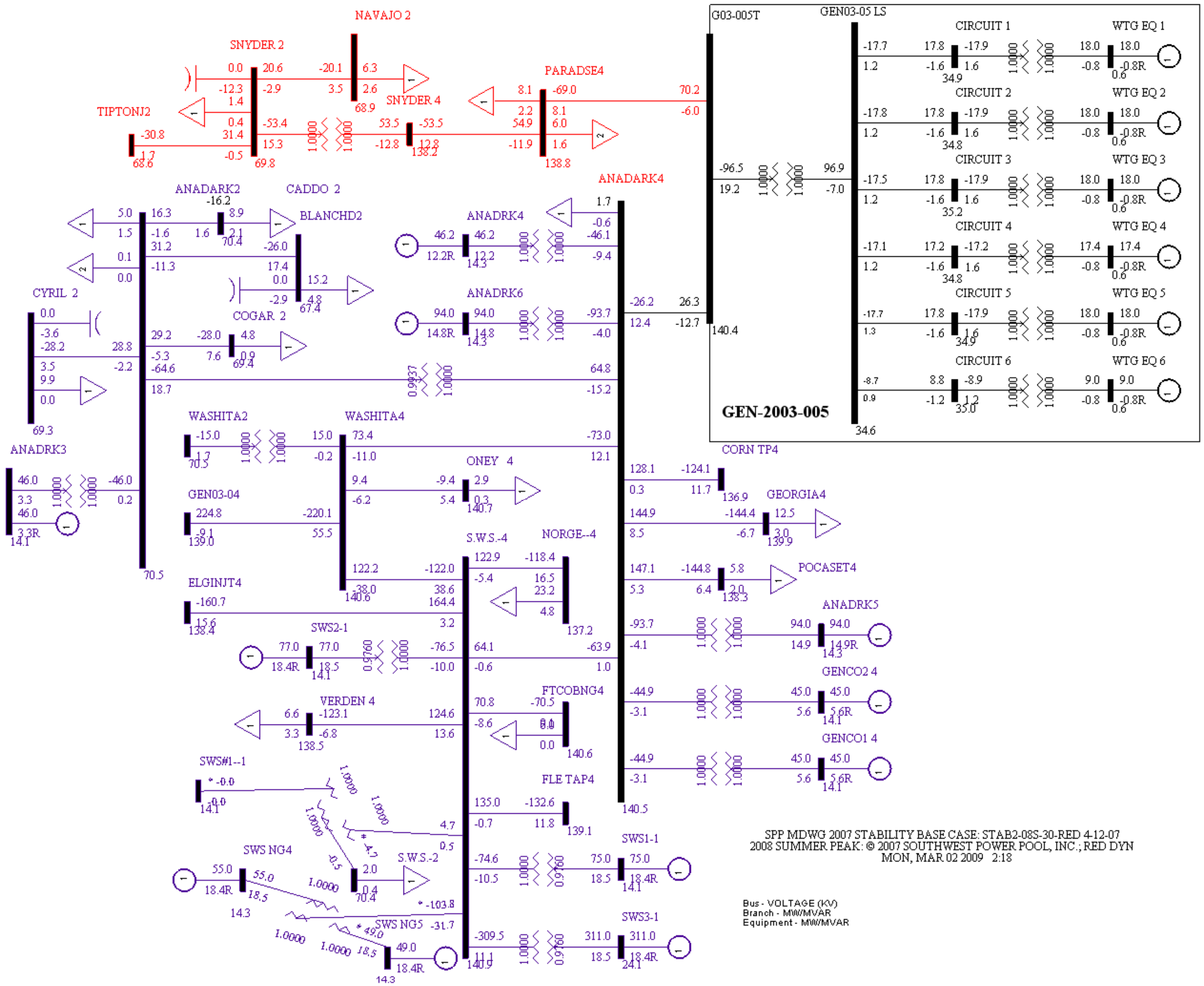

Figure 2: Power flow diagram - Summer Peak 2008

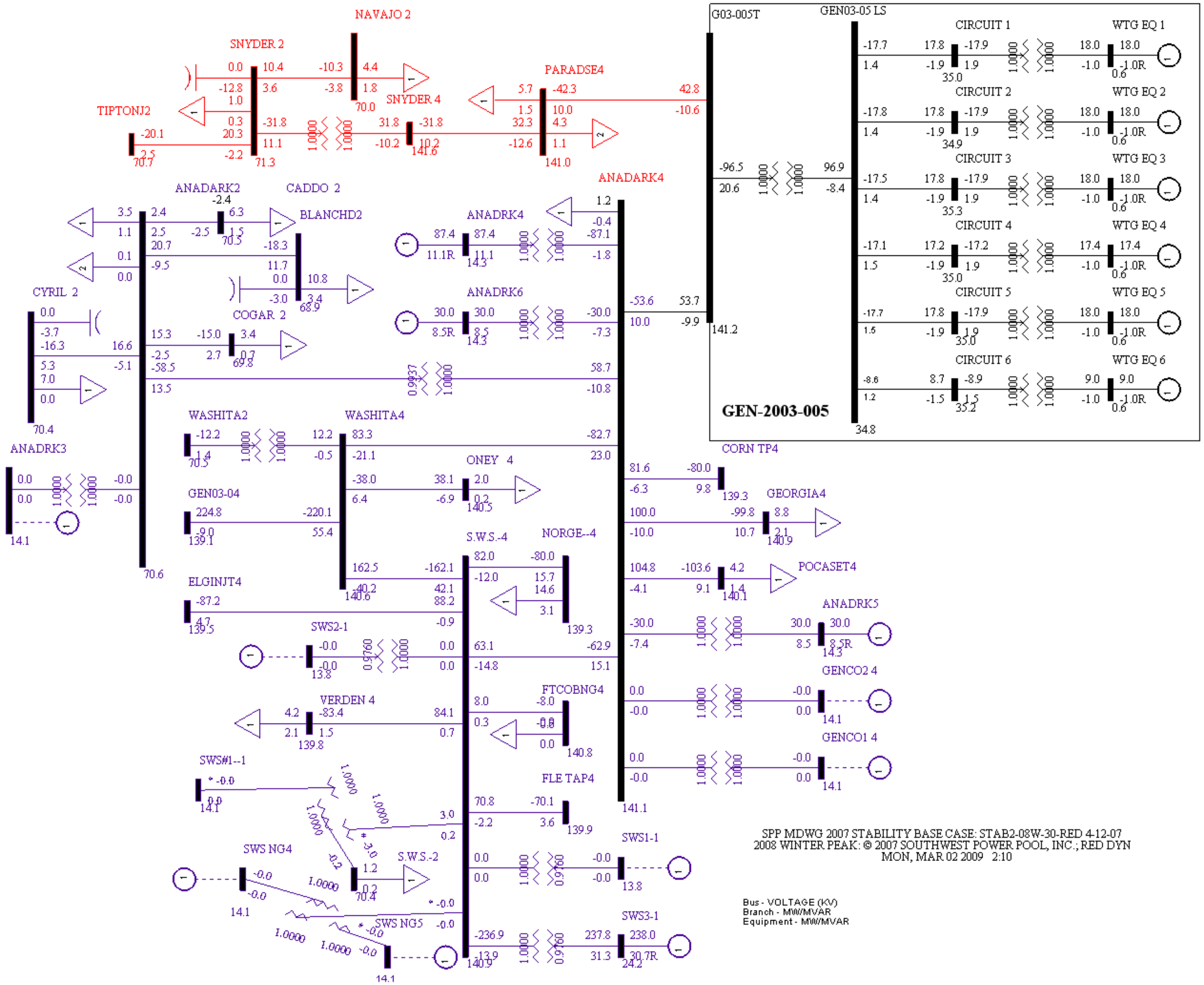

Figure 3: Power flow diagram - Winter Peak 2008

3. DYNAMIC STABILITY SIMULATIONS AND RESULTS

Dynamic simulations were performed for fault contingencies in Table 6 with and without GEN-2003-005.

Table 6: Fault Contingencies Evaluated

Cont. Number	Cont. Name	Description
1	FLT13PH	Three phase fault on Anadarko (#520814) – Wind Farm 138 kV line, near the Wind Farm, with one shot reclosing after 20 cycles followed by lockout.
2	FLT21PH	Single phase fault like FLT13PH
3	FLT33PH	Three phase fault on Paradise (#521024) – Windfarm 138 kV line, near the wind farm, with one shot reclosing after 20 cycles followed by lockout.
4	FLT41PH	Single phase fault like FLT33PH.
5	FLT53PH	Three phase fault on Snyder (#521052) – Paradise (521024) 138 kV line, near Snyder, with one shot reclosing after 20 cycles followed by lockout.
6	FLT61PH	Single phase fault like FLT53PH
7	FLT73PH	Three phase fault on Snyder (#521051) – Navajo (#521009) 69kV line, near Snyder, with one shot reclosing after 20 cycles followed by lockout.
8	FLT81PH	Single phase fault like FLT73PH
9	FLT93PH	Three phase fault on Fort Cobb (#511454)– Southwestern Station (#511477) 138 kV line, near Fort Cobb, with one shot reclosing after 20 cycles followed by lockout.
10	FLT101PH	Single phase fault like FLT93PH
11	FLT113PH	Three phase fault on Anadarko (#520814) – Southwestern Station (#511477) 138 kV line, near Southwestern Station, with one shot reclosing after 20 cycles followed by lockout
12	FLT121PH	Single phase fault like FLT113PH
13	FLT153PH	Three phase fault on Anadarko (#520810) – Blanchard (#520828) 69 kV line, near Blanchard, with one shot reclosing after 20 cycles followed by lockout.
14	FLT161PH	Single phase fault like FLT153PH..

Cont. Number	Cont. Name	Description
15	FLT173PH	Three phase fault on Washita (#521089) – Anadarko (#520814) 138 kV line, near Anadarko, with one shot reclosing after 20 cycles followed by lockout.
16	FLT181PH	Single phase fault like FLT173PH
17	FLT193PH	Three phase fault on Washita (#521089) – Oney (#521017) 138 kV line, near Oney, with one shot reclosing after 20 cycles followed by lockout.
18	FLT201PH	Single phase fault like FLT193PH
19	FLT213PH	Three phase fault on Washita (#521089) – Southwest Station (#511477) 138 kV line, near Washita, with one shot reclosing after 30 cycles.
20	FLT221PH	Single phase fault like FLT213PH

Single line to ground faults were simulated in a manner consistent with currently accepted practices, that is to assume that a single line to ground will cause a voltage drop at the fault location of 60% of nominal.

Control areas monitored:

- Southwest Public Service
- Oklahoma Gas and Electric
- Western Farmers Electric Cooperative
- AEP West, Sunflower Electric Cooperative

Prior queued projects monitored:

- Blue Canyon Wind Farms
- Weatherford Wind Farm
- GEN-2002-005
- GEN-2006-035

3.1. Stability Criteria

Disturbances including three-phase and single-phase to ground faults should not cause synchronous and asynchronous plants to become unstable or disconnect from the transmission grid.

The criterion for synchronous generator stability as defined by NERC is:

“Power system stability is defined as that condition in which the difference of the angular positions of synchronous machine rotor becomes constant following an aperiodic system disturbance.”

Voltage magnitudes and frequencies at terminals of asynchronous generators should not exceed magnitudes and durations that will cause protection elements to operate. Furthermore, the response after the disturbance needs to be studied at the terminals of the machine to insure that there are no sustained oscillations in power output, speed, frequency, etc.

Voltage magnitudes and angles after the disturbance should settle to a constant and reasonable operating level. Frequencies should settle to the nominal 60 Hz power frequency.

3.2. Modeling of Wind Turbine Generators

PSS/E Wind package issue 2.0.0 dated February 2006 was used for the dynamic stability analysis with PSS/E version 30.2.1. Voltage and frequency relay settings are summarized in Table 7.

Table 7: GE 1.5 MW wind turbine generator trip settings

Relay type	Description	Trip setting and time delay	Units
Undervoltage (27-1)	Relay trips if |Vbus|<	0.85	Pu
	for t =	10.0	S
Undervoltage (27-2)	Relay trips if |Vbus|<	0.75	Pu
	for t =	1.0	S
Undervoltage (27-3)	Relay trips if |Vbus|<	0.70	Pu
	for t =	0.625	S
Undervoltage (27-4)	Relay trips if |Vbus|<	0.15	Pu
	for t =	0.625	S
Overvoltage (59-1)	Relay trips if |Vbus|>	1.1	Pu
	for t =	1.0	S
Overvoltage (59-2)	Relay trips if |Vbus|>	1.15	Pu
	for t =	0.1	S
Overvoltage (59-3)	Relay trips if |Vbus|>	1.3	Pu
	for t =	0.02	S
Underfrequency (81U-1)	Relay trips if Fbus <	57.5	Hz
	for t =	10.0	S
Underfrequency (81U-2)	Relay trips if Fbus <	56.5	Hz
	for t =	0.02	S
Overfrequency (81O-1)	Relay trips if Fbus >	61.5	Hz
	for t =	30.0	S
Overfrequency (81U-2)	Relay trips if Fbus >	62.5	Hz
	for t =	0.02	S

3.3. Pre-Project Simulation Results

Non-disturbance runs of 10 seconds were carried out on Winter Peak 2008 and Summer Peak 2008 base cases to verify proper initialization of dynamic models and to check steady-state conditions.

Nearby areas are stable for the fault contingencies in Table 6 in winter 2008 and summer 2008 peak cases.

Pre-project study results are summarized in Table 8 for fault contingencies in Table 6.

3.4. Post-Project Simulation Results

Non-disturbance runs of 10 seconds were carried out on Winter Peak 2008 and Summer Peak 2008 base cases to verify proper initialization of dynamic models and valid power flow cases after the addition of the project.

Nearby areas are stable for the fault contingencies in Table 6 in winter 2008 and summer 2008 peak cases.

The project can be successfully integrated with the transmission system using the GE 1.5 MW wind turbine generators.

Post-project study results are summarized in Table 8 for fault contingencies in Table 6.

Table 8: Summary of Transient Stability Analysis Results

Case No.	*Description*	Summer Peak 2008		Winter Peak 2008	
		Pre-project	Post-project	Pre-project	Post-project
1	Three phase fault on Anadarko (#520814) – Wind Farm 138 kV line, near the Wind Farm	STABLE	STABLE	STABLE	STABLE
2	Single phase fault like FLT13PH	STABLE	STABLE	STABLE	STABLE
3	Three phase fault on Paradise (#521024) – Windfarm 138 kV line, near the wind farm	STABLE	STABLE	STABLE	STABLE
4	Single phase fault like FLT33PH.	STABLE	STABLE	STABLE	STABLE
5	Three phase fault on Snyder (#521052) – Paradise (521024) 138 kV line, near Snyder	STABLE	STABLE	STABLE	STABLE
6	Single phase fault like FLT53PH	STABLE	STABLE	STABLE	STABLE
7	Three phase fault on Snyder (#521051) – Navajo (#521009) 69kV line, near Snyder	STABLE	STABLE	STABLE	STABLE
8	Single phase fault like FLT73PH	STABLE	STABLE	STABLE	STABLE
9	Three phase fault on Fort Cobb (#511454)– Southwestern Station (#511477) 138 kV line, near Fort Cobb	STABLE	STABLE	STABLE	STABLE
10	Single phase fault like FLT93PH	STABLE	STABLE	STABLE	STABLE

Case No.	Description	Summer Peak 2008		Winter Peak 2008	
		Pre-project	Post-project	Pre-project	Post-project
11	Three phase fault on Anadarko (#520814) – Southwestern Station (#511477) 138 kV line, near Southwestern Station	STABLE	STABLE	STABLE	STABLE
12	Single phase fault like FLT113PH	STABLE	STABLE	STABLE	STABLE
13	Three phase fault on Anadarko (#520810) – Blanchard (#520828) 69 kV line, near Blanchard	STABLE	STABLE	STABLE	STABLE
14	Single phase fault like FLT153PH..	STABLE	STABLE	STABLE	STABLE
15	Three phase fault on Washita (#521089) – Anadarko (#520814) 138 kV line, near Anadarko	STABLE	STABLE	STABLE	STABLE
16	Single phase fault like FLT173PH	STABLE	STABLE	STABLE	STABLE
17	Three phase fault on Washita (#521089) – Oney (#521017) 138 kV line, near Oney	STABLE	STABLE	STABLE	STABLE
18	Single phase fault like FLT193PH	STABLE	STABLE	STABLE	STABLE
19	Three phase fault on Washita (#521089) – Southwest Station (#511477) 138 kV line, near Washita, with one shot reclosing after 30 cycles.	STABLE	STABLE	STABLE	STABLE
20	Single phase fault like FLT213PH	STABLE	STABLE	STABLE	STABLE

4. CONCLUSIONS AND RECOMMENDATIONS

1. The project can be successfully integrated into the transmission system at the proposed point of interconnection provided that the GE wind turbine generators can be used to control the voltage at the POI via the GE Wind Farm Management System. There is no need for additional capacitor or reactor banks. The standard GE 1.5 MW wind turbine generator with +/- 0.95 power factor range can sufficiently provide the lagging and leading power factor required to maintain an adequate voltage schedule at the POI provided it does not exceed.

2. The reactive power output of the GE turbines will help satisfy the FERC Order 661A provisions on low-voltage ride through (LVRT). There is no need for additional dynamic reactive compensation.