



SPP *Southwest
Power Pool*

***Impact Study for Generation
Interconnection Request
GEN-2005-012***

***SPP Tariff Studies
(#GEN-2005-012)***

January, 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-2005-012. 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. This study is a restudy of GEN-2005-012 that was completed in July, 2006. The original Impact Study report studied the interconnection with Vestes V80 1.8 MW wind turbines. This report documents the response of the wind farm using Gamesa G87 2.0MW wind turbines.

Interconnection Facilities

The Impact Study determined that two (2) 34.5kV, 38MVAR capacitor banks are required to be installed in the Customer interconnection substation in order to accommodate for reactive power losses on the wind turbine collector circuits and associated transformers.

The Impact Study determined that a SVC device with a rating of 345kV, 50MVar is required in order for the request to interconnect at 400MW. This SVC device would need to be located at on the 345kV high side bus of the Customer 345/34.5kV substation. If the Customer does not wish to install this SVC device, the Customer may reduce the interconnection request to 374MW.

The need for this SVC device appears to be driven due to higher queued requests in the area of this generation interconnection request. The area cannot support the export the energy from the study project and the higher queued projects without the construction of new facilities. If all prior queued projects do not stay in the queue, or if additional facilities are built in the area of the generation, the Customer may request a restudy in which this issue may be revisited to determine the need for this device.

Estimates for the Interconnection Facilities were given in the Feasibility Study. These estimates are given again in Table 1 and Table 2. **These costs do not include any cost that might be associated with short circuit study results.** These costs and a further refinement of the facilities listed in Table 1 and Table 2 will be determined when and if a Facility Study is conducted.

Table 1: Direct Assigned Facilities

Facility	ESTIMATED COST (2006 DOLLARS)
Customer – 345-34.5 kV Substation facilities	*
Customer – Two (2) 34.5kV, 38Mvar capacitor banks in Customer substation	*
Customer – 345kV, 50Mvar static var compensator (SVC) in Customer substation	*
Customer – 345kV line between Customer substation and upgraded SUNC 345kV Spearville Substation facilities.	*
Customer - Right-of-Way for Customer Substation & Line.	*
Customer – Add interconnection metering at Spearville 345kV bus by SUNC.	\$250,000
Total	*

Note: *Estimates of cost to be determined by Customer

Table 2: Interconnection Facility Network Upgrades

Facility	ESTIMATED COST (2006 DOLLARS)
SUNC - Add 345kV bus, breaker, etc. in the Spearville Substation.	\$650,000
Total	\$650,000

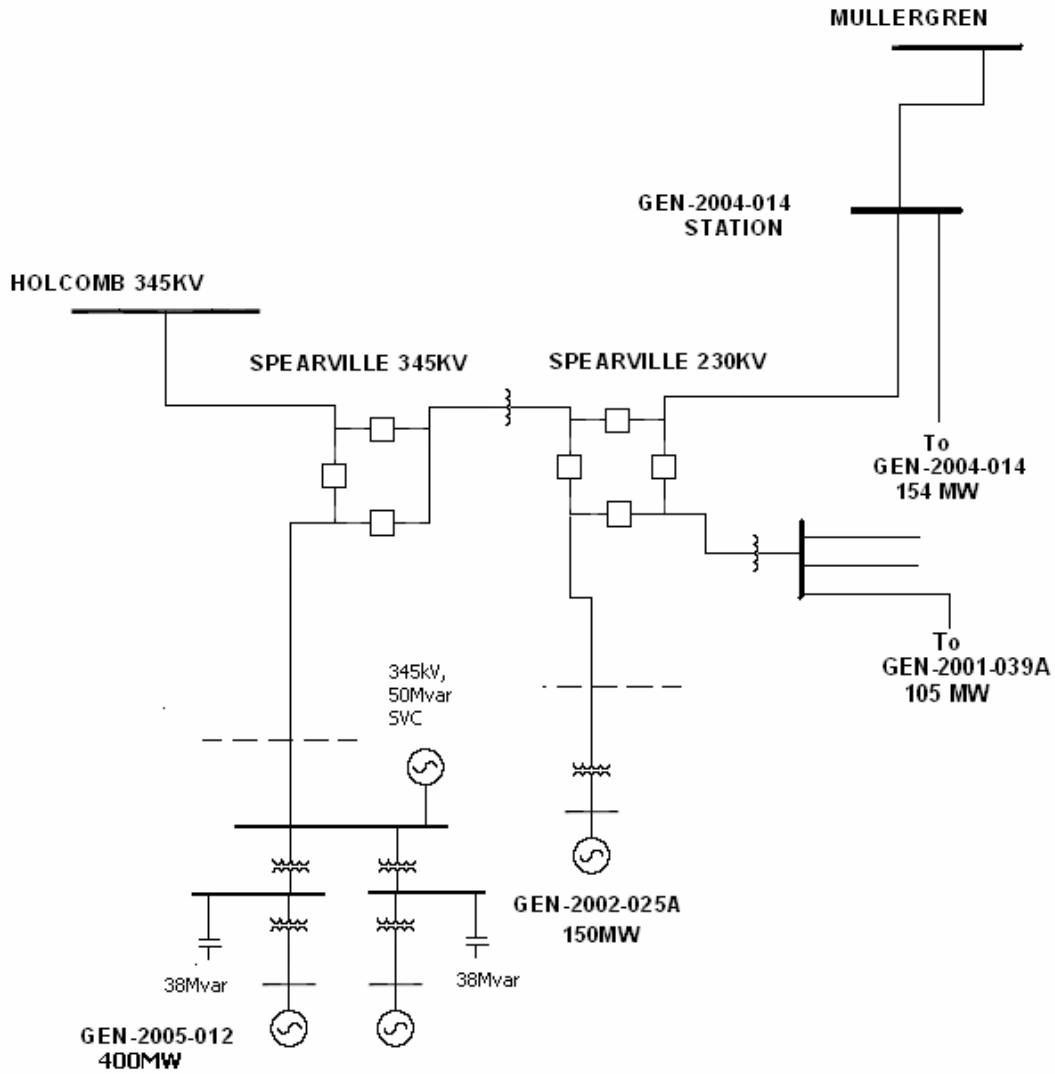


Figure 1: Proposed Interconnection
(Final substation design to be determined)

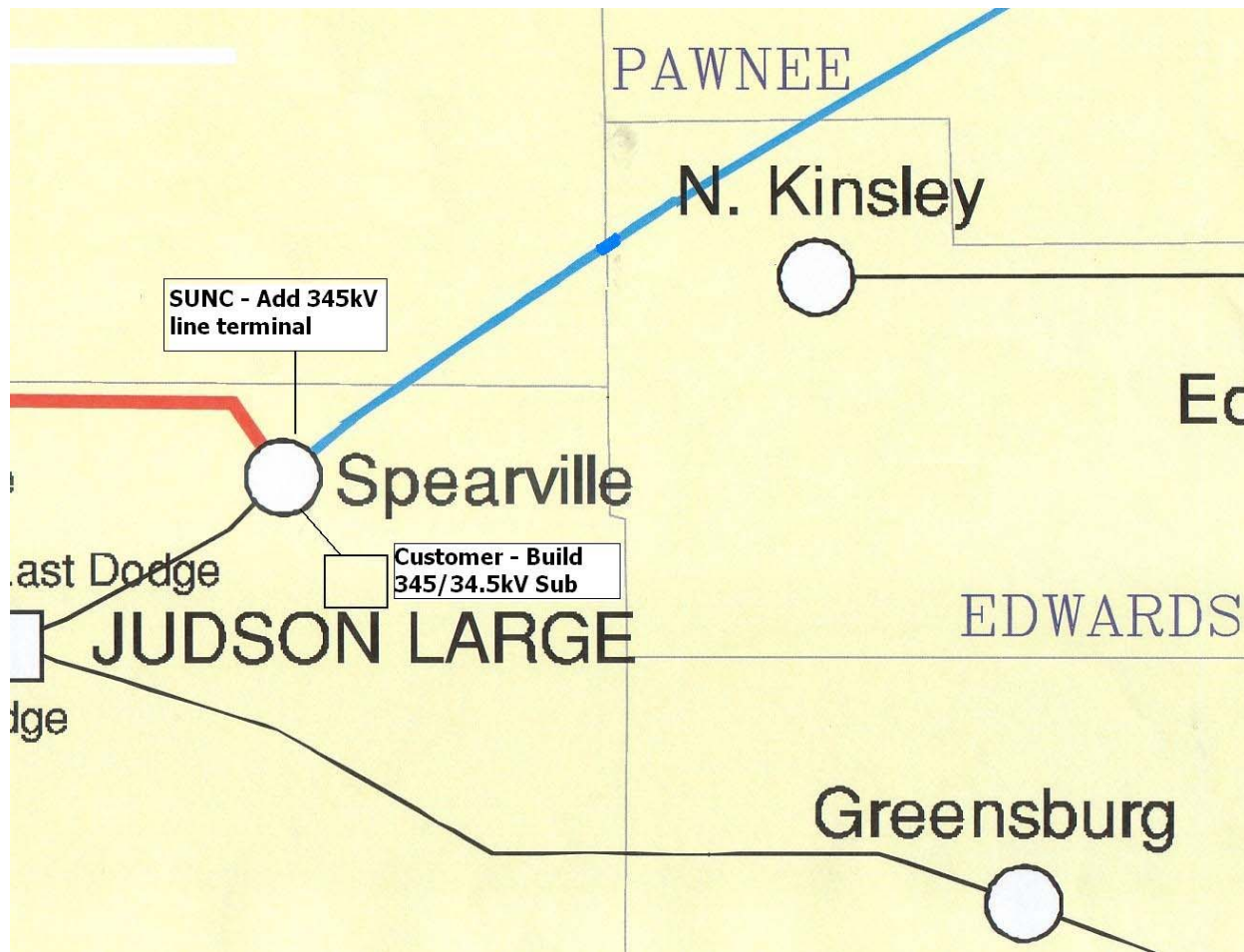


Figure 2: Map of the Area of the Proposed Interconnection

Pterra Consulting

Report No. R134-06

“Impact Study for Generation Interconnection Request GEN-2005-012”

Submitted to

The Southwest Power Pool

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‘Impact Study for Generation Interconnection Request GEN- 2005-012’

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1. Executive Summary

The Southwest Power Pool (SPP) contracted Pterra LLC (Pterra) to perform stability analyses for a proposed 400 MW wind farm plant. The plant (“the Project”) consists of 200 Gamesa G87 wind units of 2.0 MW each.

The Project is proposed to be interconnected to the Spearville 345 kV substation owned by Sunflower Electric Cooperative. *Figure 1* shows the interconnection schematic for the proposed wind farm plant.

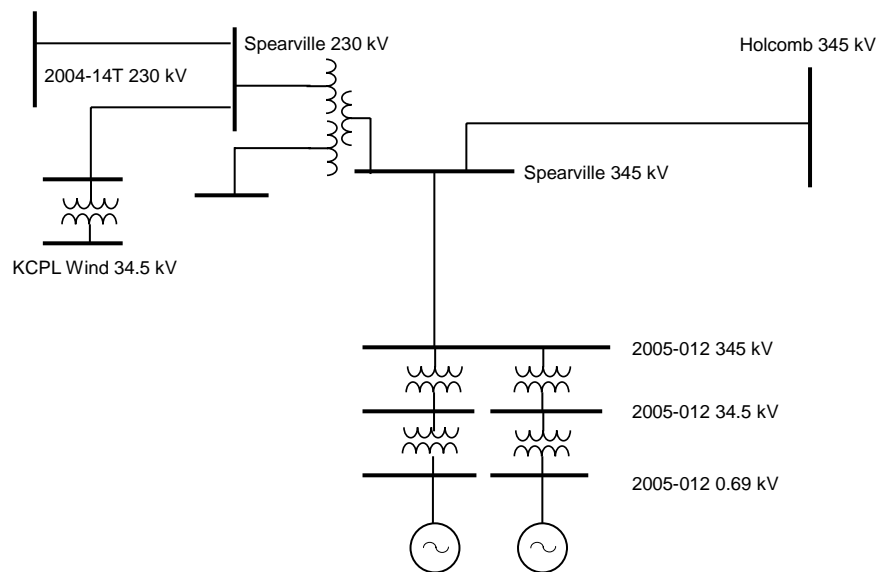


Figure 1 Interconnection Scheme for GEN-2005-012 (the Project) to SPP

Fourteen (14) contingencies were considered for the transient stability simulations which included three phase faults as well as single-line-to-ground faults at the locations defined by SPP. The simulation runs are performed for a study case at 100% MW plant dispatch with dynamic reactive compensation as required. Runs were also made to determine maximum MW without compensation.

In order to have unity power factor at the POI (Spearville 345 kV), two 35-MVAR capacitor banks are required. This assumes two step-up transformers 34.5/345 kV each with 10% reactance on 124 MVA base. The capacitor banks are located at 34.5 kV bus of each transformer.

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

The Project trips on low voltage for a single-line-to-ground fault at Spearville 345 kV in the winter 2007 case. A reduction to 374 MW would prevent this tripping.

A sensitivity was simulated for this single-line-to-ground fault at Spearville 345 kV in the winter 2007 case when two step-up transformers 34.5/345 kV (10% impedance on 124 MVA base) are connected among two 34.5 buses and the high voltage bus. In order to avoid plant tripping, a SVC of 80 MVAR connected at 345 kV is required.

The other contingencies tested indicate that the Project remains online and stable at 100% power and with no additional compensation.

2. Introduction

2.1 Project Overview

The Southwest Power Pool (SPP) contracted Pterra LLC (Pterra) to perform stability analyses for a proposed 400 MW wind power plant. The plant (“the Project”) consists of 200 Gamesa G87 wind units of 2.0 MW each. The Project is proposed to be interconnected to the Spearville 345 kV substation owned by Sunflower Electric Cooperative.

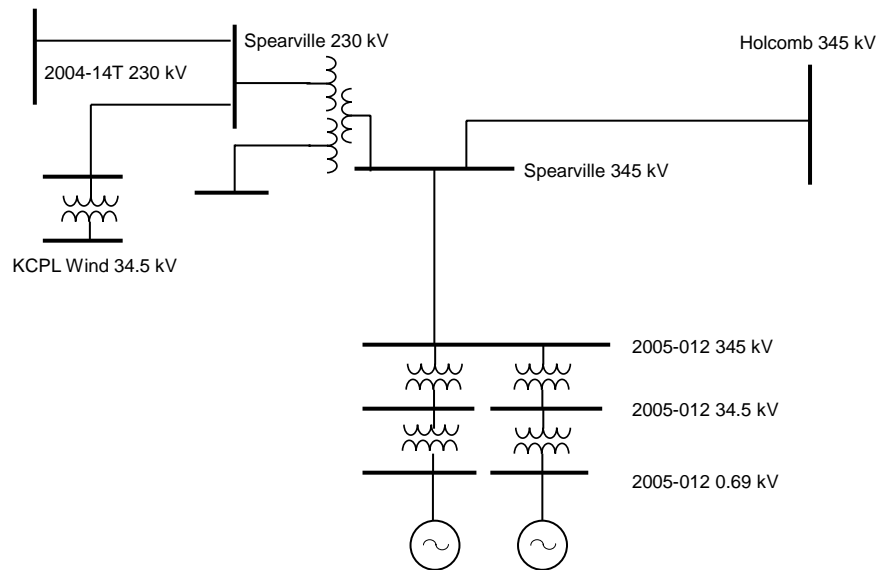


Figure 2 Interconnection Plan for GEN-2005-012 (the Project) to the SPP System

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

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

Per SPP directions, generation in AEPW, OKGE, WFEC, SPS, MIPU and KACP was scaled down to dispatch the Project in the winter 2007 and summer 2011 cases. Generation in each of the areas mentioned above was reduced by one sixth of the capability of the Project. Table 1 shows the MW allocation in each area provided by SPP.

Table 1 Re-dispatch for the Project

Winter Peak 2007		Summer Peak 2011
Area	Action	Action
AEPW	Reduced Generation by 66.66 MW	Reduced Generation by 66.66 MW
OKGE	Reduced Generation by 66.66 MW	Reduced Generation by 66.66 MW
WFEC	Reduced Generation by 66.66 MW	Reduced Generation by 66.66 MW
SPS	Reduced Generation by 66.66 MW	Reduced Generation by 66.66 MW
MIPU	Reduced Generation by 66.66 MW	Reduced Generation by 66.66 MW
KACP	Reduced Generation by 66.7 MW	Reduced Generation by 66.7 MW

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

In order to have unity power factor at the POI (Spearville 345 kV), two 35-MVAR capacitor banks are required. This assumes two step-up transformers 34.5/345 kV each with 10% reactance on 124 MVA base. The capacitor banks are located at 34.5 kV bus of each transformer.

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

- a. Gray County Wind Farm -110 MW consisting of (167) Vestas V47 turbines.

- b. GEN-2001-039A – 115kV Wind Farm – 105 MW consisting of Clipper wind turbines. If this model gives problems, please change to a CIMTR3 model.
- c. GEN-2002-025A – Spearville 230kV Wind Farm – 150 MW wind farm consisting of (100) GE turbines.
- d. GEN-2004-014 – North Kinsley 230/115kV wind farm – 154 MW consisting of (77) Gamesa turbines.

2.2 Objective

The objective of the study is to determine the impact on system stability of connecting the Project to SPP's 345 kV transmission system. The stability results also included 100% power runs with dynamic compensation, and reduced stability runs to determine the maximum MW with no upgrades.

3. Stability Analysis

3.1 Modeling of the Wind Turbines

The wind farm was modeled with Gamesa G87 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 Λ , performance coefficient etc.,
7. Model to read the turbine C_p 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 current standard ride-through capability available is reflected in the Gamesa wind turbine model package as shown in Table 2 and Table 3 for frequency and voltage, respectively. These standard settings were used in the study.

Table 2: 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 3. 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 G87 2.0 MW WTG Parameters

Data for the Gamesa G87 2.0 MW WTG and generator step-up transformer are shown in Table 4.

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 4. Gamesa G87 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

Fourteen (14) contingencies were considered for the transient stability simulations which included three phase faults as well as single-line-to-ground faults at the locations defined by SPP.

Single-line-to-ground faults were simulated by applying fault impedance to the positive sequence network at the fault location to represent the effect of the negative and zero sequence networks on the positive sequence network. The fault impedance was computed to give a positive sequence voltage at the specified fault location of approximately 60-65 % of pre-fault voltage.

Because of numerical simulation problems, the dynamic model for GEN-2001-039A 115 kV consisting of Clipper wind turbines was changed to CIMTR3.

Table 5 shows the list of simulated contingencies. SPP provided the fault clearing time and the time delay before re-closing for all the study contingencies.

Table 5 List of Simulated Contingencies and Result Summary of Dynamic Response for 2007 Winter Peak and 2011 Summer Peak Scenarios

No	Contingency	Description	Winter Peak 2007	Summer Peak 2011
1	FLT13PH	3 phase fault on the Spearville (56469) to Holcomb (56449) 345 kV line, near Spearville.	Stable	Stable
2	FLT21PH	<i>Single phase fault and sequence like Cont. No. 1</i>	Stable	Stable
3	FLT33PH	3 phase fault on the Holcomb (56449) to Finney (50858) 345 kV line, near Holcomb.	Stable	Stable
4	FLT43PH	3 phase fault on the Spearville 345kV bus	Stable	Stable
5	F05-3PH	3-phase fault at Mullergren on 230 kV line to Spearville	Stable	Stable
6	F05-SLG	SLG fault at Mullergren on 230 kV line to Spearville, Breaker failure at Mullergren, [CB6012]	Stable	Stable
7	F06-3PH	3-phase fault at Spearville on 230 kV line to Mullergren	Stable	Stable
8	F06-SLG	SLG fault at Spearville on 230 kV line to Mullergren, Breaker failure at Mullergren, [CB6012]	Stable	Stable
9	F07-3PH	3-phase fault at North Judson Large on 115 kV line to Spearville	Stable	Stable
10	F07-SLG	SLG fault at North Judson Large on 115 kV line to Spearville Breaker failure at North Judson Large, [CB3071]	Stable	Stable
11	F08-3PH	3-phase fault at Judson Large on 115 kV line to GEN-2001-039A Tap	Stable	Stable
12	F08-SLG	SLG fault at Judson Large on 115 kV line to GEN-2001-039A Tap Breaker failure at Judson Large, [CB3629]	Stable	Stable
13	F09-3PH	3-phase fault at GEN-2001-039A on 115 kV line to Greensburg	Stable	Stable
14	F09-SLG	SLG fault at GEN-2001-039A on 115 kV line to Greensburg Breaker failure at Medicine Lodge, [CB3102]	Stable	Stable

3.6 Simulation Results and Conclusion

Stability simulations were performed with a 0.5-second steady-state run followed by the appropriate disturbance as described in Table 5. Simulations were run for 20-second duration and plotted for 5 seconds. Absolute angles, plant terminal voltages and power, bus voltages and frequencies are plotted for buses in monitored areas: MIDW, WERE, WEPL AND SUNC. Simulation plots are provided in a separate CD-ROM.

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

The Project trips due to high frequency relay protection in two contingencies involving three-phase faults at Spearville 345 kV. This occurs in both the summer and winter peak cases. Because the tripping was not caused by a low voltage relay, the addition of an SVC device was not considered. If the high frequency and high voltage relays are disabled but keeping the low voltage ride-through relays in service, the project remains on-line. Hence, these are indicated as “stable” in Table 5.

The Project trips on low voltage for a single-line-to-ground fault at Spearville 345 kV in the winter 2007 case. A reduction to 374 MW would prevent this tripping.

A sensitivity was simulated for this single-line-to-ground fault at Spearville 345 kV in the winter 2007 case when two step-up transformers 34.5/345 kV (10% impedance on 124 MVA base) are connected among two 34.5 buses and the high voltage bus. In order to avoid plant tripping, a SVC of 80 MVAR connected at 345 kV is required and the high voltage relay was disabled.

The other contingencies tested indicate that the Project remains online and stable at 100% power and with no additional compensation.

Some monitored plants trip in certain contingencies. Tables 6 and 7 show the summary of plant tripping for summer 2011 Case and winter 2007 Case, respectively.

Table 6 Summary of Plant Tripping for summer 2011 Case

Summer 2011 Contingency	Project (Gamesa WTGs)	Gray County Vestas	Gen-2001-039 Clipper	Spearville 230 kV GE	Gen-2004-014 Gamesa	Other
1 (High frequency relay disabled for the project)	-----	Trips	-----	Trips	-----	-----
2	-----	-----	-----	-----	Trips On Low Voltage	-----

Summer 2011 Contingency	Project (Gamesa WTGs)	Gray County Vestas	Gen-2001-039 Clipper	Spearville 230 kV GE	Gen-2004-014 Gamesa	Other
3	-----	-----	-----	-----	-----	-----
4 (High frequency and high voltage relay disabled for the project)	-----	Trips	-----	-----	-----	-----
5	-----	-----	-----	-----	-----	-----
6	-----	-----	-----	-----	-----	-----
7	-----	-----	-----	Trips	-----	-----
8	-----	-----	-----	-----	-----	-----
9	-----	Trips	-----	-----	-----	-----
10	-----	Trips	-----	-----	-----	-----
11	-----	Trips	Trips	-----	-----	-----
12	-----	Trips	Trips	-----	-----	Judson Large Plant @ Bus 58770 Trips
13	-----	Trips	Trips	-----	-----	-----
14	-----	-----	-----	-----	-----	-----

Note: Where there is no indication in Tables 6 and 7 the unit remains in service.

Table 7 Summary of Plant Tripping for winter 2007 Case

Winter 2007 Contingency	Project (Gamesa WTGs)	Gray County Vestas	Gen-2001-039 Clipper	Spearville 230 kV GE	Gen-2004-014 Gamesa	Other
1 (High frequency and high voltage relay disabled for the project)	-----	Trips	Trips	Trips	Trips	-----
2 (With SVC 80 MVAR at 345 kV and high voltage relay disabled for the project)	-----	-----	Trips	-----	Trips	-----
2A (Plant reduced to 374 MW.)	-----	-----	Trips	-----	-----	-----

Winter 2007 Contingency	Project (Gamesa WTGs)	Gray County Vestas	Gen- 2001- 039 Clipper	Spearville 230 kV GE	Gen- 2004- 014 Gamesa	Other
3	-----	-----	-----	-----	-----	-----
4 (High frequency relay disabled for the project)	-----	-----	-----	-----	-----	-----
5	-----	-----	-----	-----	-----	-----
6	-----	-----	-----	-----	-----	-----
7	-----	-----	-----	Trips	-----	-----
8	-----	-----	-----	-----	-----	-----
9	-----	Trips	Trips	-----	Trips	-----
10	-----	Trips	Trips	-----	Trips	-----
11	-----	Trips	Trips	-----	-----	-----
12	-----	Trips	Trips	-----	Trips	Judson Large Plant @ Bus 58770 Trips
13	-----	Trips	Trips	-----	Trips	-----
14	-----	-----	Trips	-----	-----	-----

Appendix A. Simulation Plots

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

