Impact Study
For
Generation Interconnection
Request
GEN-2007-015

SPP Tariff Studies
(#GEN-2007-015)

June 2008

Summary

Pursuant to the tariff and at the request of 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-2007-015. 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.

Power Factor Requirements

The Customer has requested to study two different types of turbines, the General Electric 1.5MW wind turbine and the Vestes V82 1.65 MW wind turbine.

The General Electric wind turbines have capability of +/- 95% lead/lag power factor at the generator terminals with optional +/-90% lead/lag power factor at the generator terminal. If the Customer uses the General Electric turbines with the wind farm management system (WFMS) and the LVRT II package, no additional reactive sources, static or dynamic, are required for power factor capability or FERC Order #661A low voltage ride through (LVRT) requirements.

The Vestes V82 wind turbines have no reactive compensation capability. The V82 turbines draw reactive power during operation and have power factor correction capacitors at each turbine to compensate for losses at the generator terminals. For the Vestes V82 wind turbines to provide acceptable power factor at the point of interconnection and to meet FERC Order #661A low voltage ride through (LVRT) requirements, the Customer will be required to provide a 34.5kV, 15 Mvar staged capacitor bank and a 34.5kV, 13.75MVA STATCOM device.

Interconnection Facilities

The requirements for interconnection of the 130 MW consist of constructing a new 161 kV substation on the existing Kelly (Westar) – Humboldt (OPPD) 161 kV transmission line, owned by Westar within the state of Kansas. This substation will be located within the Kansas state boundary and will be constructed and maintained by Westar. A preliminary one-line drawing of the interconnection facilities are shown in Figure 1. The Customer did not propose a specific route of its 161 kV line to serve its 161/34.5 kV collection system facilities. It is assumed that obtaining all necessary right-of-way for construction of the Customer 161 kV transmission line and the 161/34.5 kV collector substation will not be a significant expense.

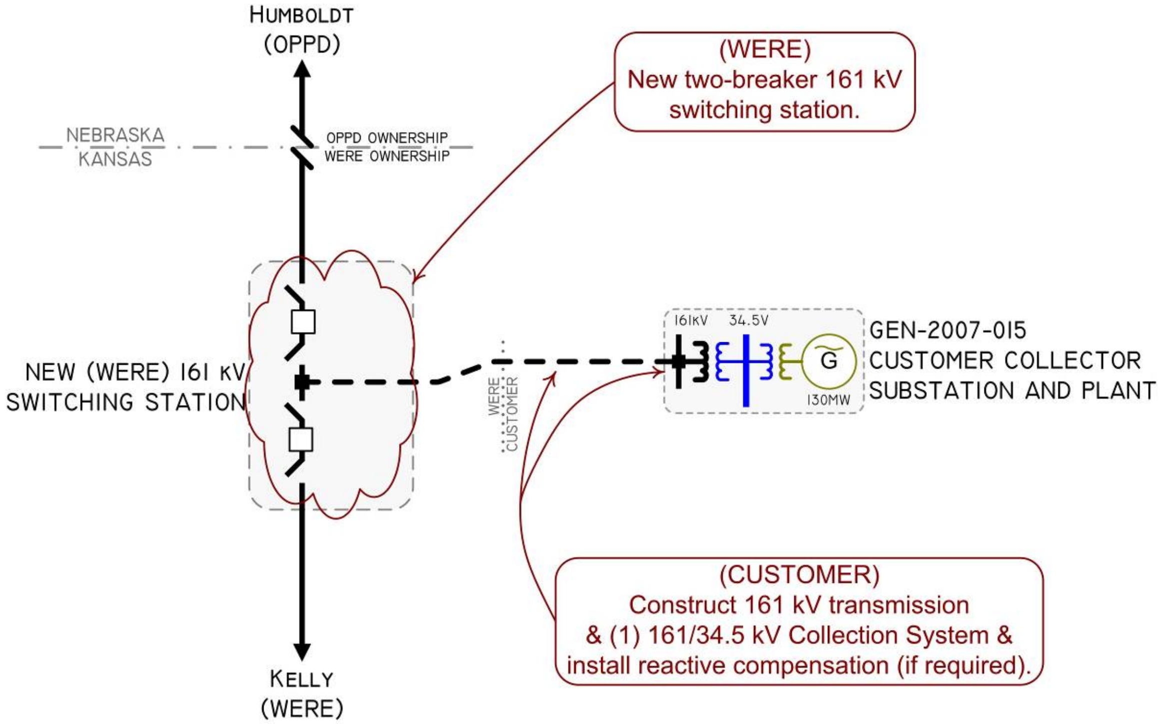

Figure 1: Proposed Method of Interconnection

(Final design to be determined)

Table 1: Direct Assignment Facilities

FACILITY	ESTIMATED COST (2007 DOLLARS)
CUSTOMER – (1) 161 kV transmission line from Customer collector substation to the new substation located on the Kelly (Westar) – Humboldt (OPPD) 161 kV transmission line.	*
WERE – Termination and interconnection of CUSTOMER 161 kV transmission line into the new 161 kV three-breaker ring bus.	$750,000
CUSTOMER – (1) 161/34.5 kV Customer collector substation facilities.	*
CUSTOMER – 34.5 kV, 15 Mvar capacitor bank(s) to be installed in the Customer 161/34.5 kV collector substation (if Vestes V82 turbines are used)	*
CUSTOMER – 34.5Kv, 13.75MVA STATCOM device (if Vestes V82 turbines are used)	*
CUSTOMER – Right-of-Way for all Customer facilities.	
TOTAL	*

* *Estimates of cost to be determined.*

Table 2: Required Interconnection Network Upgrade Facilities

FACILITY	**ESTIMATED COST** (2007 DOLLARS)
Westar – (1) 161 kV substation for GEN-2007-015 located in Kansas on the Kelly (Westar) – Humboldt (OPPD) 161 kV transmission line. Station to include breakers, switches, control relaying, high speed communications, metering and related equipment and all related structures.	$3,500,000
TOTAL	*****

*   *Estimates of cost to be determined.*

Final Report

For

Southwest Power Pool

From

S&C Electric Company

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2007-015

S&C Project No. 2923

June 12, 2008

S&C Electric Company

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Table of Contents

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Executive Summary

This system impact study was performed in response to a generation interconnection study request for a wind farm in Nemaha County, Kansas. The projected output power of the wind farm is 129 MW with GE 1.5 MW wind turbine generators or 132 MW with Vestas 1.65 MW V82 wind turbine generators. The GEN-2007-015 project will be interconnected into the existing 161 kV transmission line from Kelley (Westar) to Humboldt (Omaha Power Public District) through a new ring bus in the Westar control area. The objective of this study is to determine the impact of the interconnection on the stability of nearby areas and prior queued projects for winter peak (with facilities planned for 2008) and summer peak (with facilities planned for 2012) cases. Steady-state and dynamic studies were performed at full load.

SPP requires the project to maintain unity power factor at the POI under normal operating conditions. The GE wind turbine option will require a WFMS (Wind Farm Management System) to dynamically control the power factor setpoint of wind turbines to compensate for collector and transformation losses in response to nearby transmission grid changes and variations in wind farm production levels. The Vestas V82 wind turbine option will require the installation of 15 MVAR of MSSCs (mechanically switched shunt capacitors) in appropriately sized steps on the 34.5 kV collector bus in addition to the power factor correction capacitors located at each wind turbine generator. MSSCs and wind turbine power factor correction capacitors should be switched on/off automatically in response to transmission grid changes and variations in wind farm production levels to maintain unity power factor at the POI.

Three-phase and single-phase-to-ground faults were studied at locations specified by SPP. Dynamic stability results show that nearby areas remain stable for all fault contingencies. The interconnection will satisfy low-voltage ride through provisions in FERC Order 661A with the GE option. However, the Vestas V82 wind turbines will disconnect on high voltage relay actuation for permanent three-phase faults near the project on the GEN-2007-015 to Humboldt 161kV line. If the V82 turbines were to remain connected for the above disturbance, then the voltages at the wind farm project and nearby connected buses would become unstable. Therefore, a fast and continuously controlled reactive compensation device such as STATCON or SVC is required to keep wind turbines connected and maintain system stability.

A STATCON located at the 34.5 kV collector bus with minimum 3.5-second short-time rating of 13.75 MVA and ±5 MVAR continuous rating will satisfy the requirements of keeping wind turbines connected and maintaining system stability.

The size of STATCON will depend on the device; therefore, a sizing study using device specific dynamic models must demonstrate that the proposed device will meet the short-time requirement and help to keep the project connected and maintain system stability.

1. Introduction

This system impact study was performed in response to a generation interconnection study request for a wind farm in Nemaha County, Kansas. The projected output power of the wind farm is 129 MW with GE 1.5 MW wind turbine generators or 132 MW with Vestas 1.65 MW V82 wind turbine generators. The GEN-2007-015 project will be interconnected into the existing 161 kV transmission line from Kelley (Westar) to Humboldt (Omaha Power Public District) through a new ring bus in the Westar control area.

The objective of this study is to determine the impact of the interconnection at rated output power on the stability of nearby areas and prior queued projects during winter peak (with facilities planned for 2008) and summer peak (with facilities planned for 2012).

2. Load Flow Model

The customer provided a collector system layout and impedance information. Each feeder is represented as aggregated generators to simplify representation in PSS/E. Transformer fixed taps were selected after looking at operating voltages within the wind farm.

Table 1: GEN-2007-015 load flow parameters with GE 1.5 MW turbines

Feeder 1	Parameters
18 GE 1.5 MW wind turbine generators at 0.575 kV	18 * 1.5 MW = 27 MW 18 * 1.667 MVA = 30 MVA Power factor at 0.575 kV bus: 0.985 lagging
18 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	18 * 1.75 MVA = 31.5 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 31.5 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.05568 +0.09466j p.u. on 100 MVA base B1 = 0.008748 p.u. on 100 MVA base

Feeder 2	Parameters
18 GE 1.5 MW wind turbine generators at 0.575 kV	18 * 1.5 MW = 27 MW 18 * 1.667 MVA = 30 MVA Power factor at 0.575 kV bus: 0.985 lagging
18 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	18 * 1.75 MVA = 31.5 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 31.5 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.06748 +0.13319j p.u. on 100 MVA base B1 = 0.01225 p.u. on 100 MVA base

Table 1: GEN-2007-015 load flow parameters with GE 1.5 MW turbines (Continued)

Feeder 3	Parameters
18 GE 1.5 MW wind turbine generators at 0.575 kV	18 * 1.5 MW = 27 MW 18 * 1.667 MVA = 30 MVA Power factor at 0.575 kV bus: 0.985 lagging
18 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	18 * 1.75 MVA = 31.5 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 31.5 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.06925 +0.13245j p.u. on 100 MVA base B1 = 0.01182 p.u. on 100 MVA base

Feeder 4	Parameters
17 GE 1.5 MW wind turbine generators at 0.575 kV	17 * 1.5 MW = 25.5 MW 17 * 1.667 MVA = 28.34 MVA Power factor at 0.575 kV bus: 0.985 lagging
17 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	17 * 1.75 MVA = 29.75 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 29.75 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.08444 +0.17545j p.u. on 100 MVA base B1 = 0.01316 p.u. on 100 MVA base

Feeder 5	Parameters
15 GE 1.5 MW wind turbine generators at 0.575 kV	15 * 1.5 MW = 22.5 MW 15 * 1.667 MVA = 25.0 MVA Power factor at 0.575 kV bus: 0.985 lagging
15 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	15 * 1.75 MVA = 26.25 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 26.25 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.06501 +0.09411j p.u. on 100 MVA base B1 = 0.01108 p.u. on 100 MVA base

Substation	Parameters
34.5 / 161 kV main transformer	MVA ratings = 85/113/141 MVA X/R = 30 (typical) %IZ = 10 on self-cooled MVA rating Z1 = 0.00316+ 0.09495j p.u. on 85 MVA base Fixed HV tap setting = 5% above (169.05 kV)

Table 2: GEN-2007-015 load flow parameters with Vestas V82 turbines

Feeder 1	Parameters
16 GE 1.65 MW wind turbine generators at 0.6 kV	16 * 1.65 MW = 26.4 MW 16 * 1.81625 MVA = 29.06 MVA Reactive power absorption = 11.39 MVAR
Switched shunt capacitor banks at the 600V bus provided by Vestas	13.08 MVAR at 1 pu voltage, at full load
16 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	16 * 1.75 MVA = 28 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 28 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.05613 +0.10121j p.u. on 100 MVA base B1 = 0.008474 p.u. on 100 MVA base

Feeder 2	Parameters
16 GE 1.65 MW wind turbine generators at 0.6 kV	16 * 1.65 MW = 26.4 MW 16 * 1.81625 MVA = 29.06 MVA Reactive power absorption = 11.39 MVAR
Switched shunt capacitor banks at the 600V bus provided by Vestas	13.08 MVAR at 1 pu voltage, at full load
16 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	16 * 1.75 MVA = 28 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 28 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.07522 +0.15974j p.u. on 100 MVA base B1 = 0.01336 p.u. on 100 MVA base

Feeder 3	Parameters
17 GE 1.65 MW wind turbine generators at 0.6 kV	17 * 1.65 MW = 28.05 MW 17 * 1.81625 MVA = 30.88 MVA Reactive power absorption = 12.09 MVAR
Switched shunt capacitor banks at the 600V bus provided by Vestas	13.89 MVAR at 1 pu voltage, at full load
17 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	17 * 1.75 MVA = 29.75 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 29.75 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.06372 +0.1274j p.u. on 100 MVA base B1 = 0.011026 p.u. on 100 MVA base

Table 2: GEN-2007-015 load flow parameters with Vestas 1.65 M turbines (Continued)

Feeder 4	Parameters
15 GE 1.65 MW wind turbine generators at 0.6 kV	15 * 1.65 MW = 24.75 MW 15 * 1.81625 MVA = 27.24 MVA Reactive power absorption = 10.74 MVAR
Switched shunt capacitor banks at the 600V bus provided by Vestas	12.26 MVAR at 1 pu voltage, at full load
15 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	15 * 1.75 MVA = 26.25 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 26.25 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.08378 +0.1706j p.u. on 100 MVA base B1 = 0.01266 p.u. on 100 MVA base

Feeder 5	Parameters
16 GE 1.65 MW wind turbine generators at 0.6 kV	16 * 1.65 MW = 26.4 MW 16 * 1.81625 MVA = 29.06 MVA Reactive power absorption = 11.39 MVAR
Switched shunt capacitor banks at the 600V bus provided by Vestas	13.08 MVAR at 1 pu voltage, at full load
16 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	16 * 1.75 MVA = 28 MVA X/R = 10 %IZ = 6 Z1 = 0.00597 + 0.0597j p.u. on 28 MVA base
Equivalent 34.5 kV collector system	Z1 = 0.05194 +0.08124j p.u. on 100 MVA base B1 = 0.008644 p.u. on 100 MVA base

Substation	Parameters
34.5 / 161 kV main transformer	MVA ratings = 85/113/141 MVA X/R = 30 (typical) %IZ = 10 on self-cooled MVA rating Z1 = 0.00316+ 0.09495j p.u. on 85 MVA base Fixed HV tap setting = 5% above (169.05 kV)

2.1. Modeling of Wind Turbine Generators in Load Flow

General Electric 1.5 MW Wind Turbine Generators

Step up 0.575/34.5 kV transformers and aggregated generators were added automatically by an IPLAN. Transformer parameters were modified with the customer provided specifications for 0.6/34.5 kV transformers. The power factor at each wind turbine generator was manually set to 0.985 lagging (capacitive) to meet unity power factor at the POI. The GE wind turbine option will require a WFMS (Wind Farm Management System) to dynamically control the power factor setpoint of wind turbines to compensate for collector and transformation losses in response to nearby transmission grid changes and variations in wind farm production levels.

Vestas V82 - 1.65 MW Wind Turbine Generators

Step up 0.6/34.5 kV transformers and generators were added automatically by the Vestas V82 IPLAN. Each turbine consumes 740 kvar at full load. Power factor correction capacitors, 817.2 kvar in total, are provided at each turbine. The wind farm requires 15 MVAR of mechanically switched shunt capacitors at the 34.5 kV collector bus to compensate for collector and transformation losses. MSSCs and wind turbine power factor correction capacitors should be switched on/off automatically in response to transmission grid changes and variations in wind farm production levels.

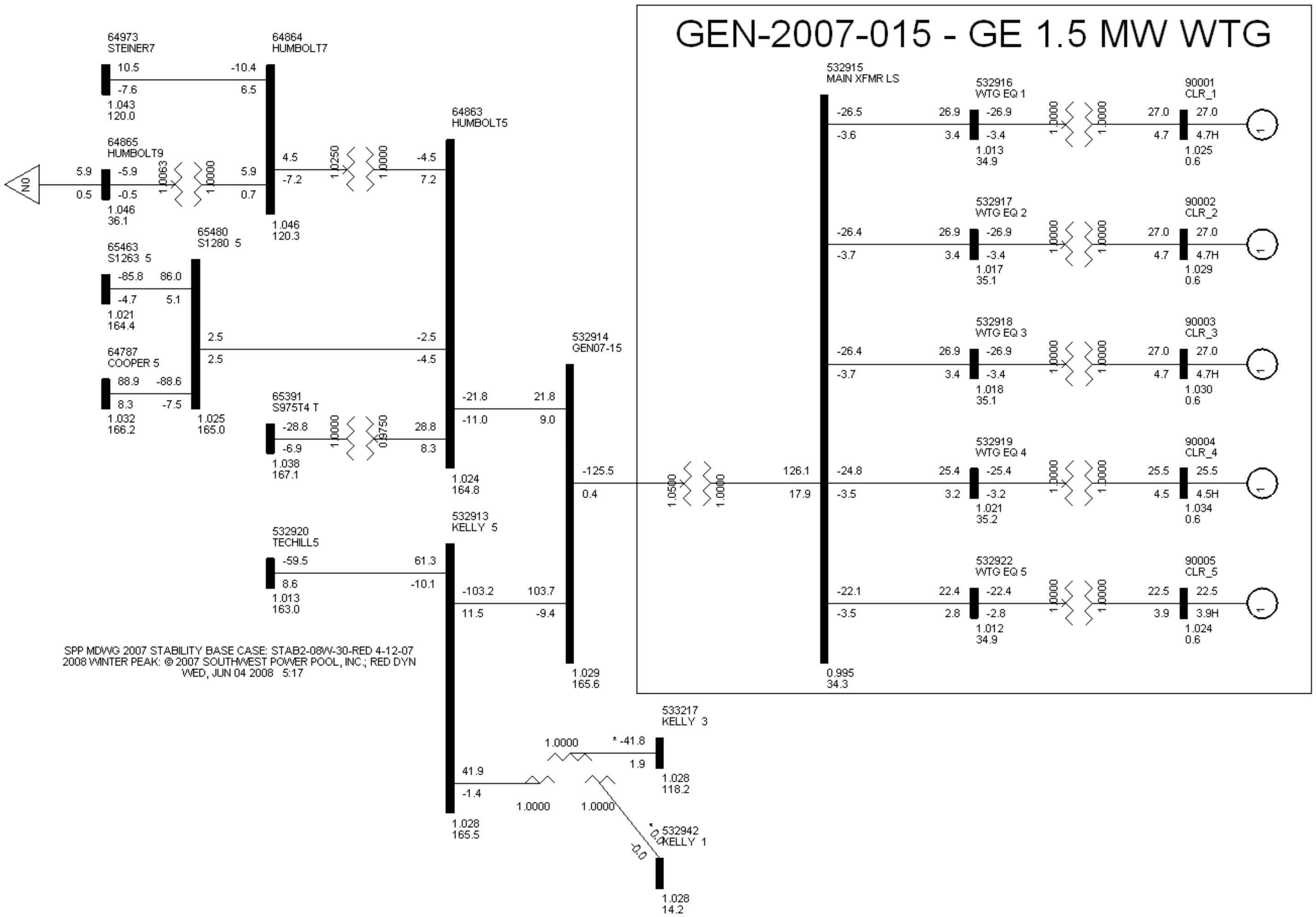

Figure 1: GEN-2007-015 and nearby buses for winter peak 2008 with GE 1.5 MW turbines

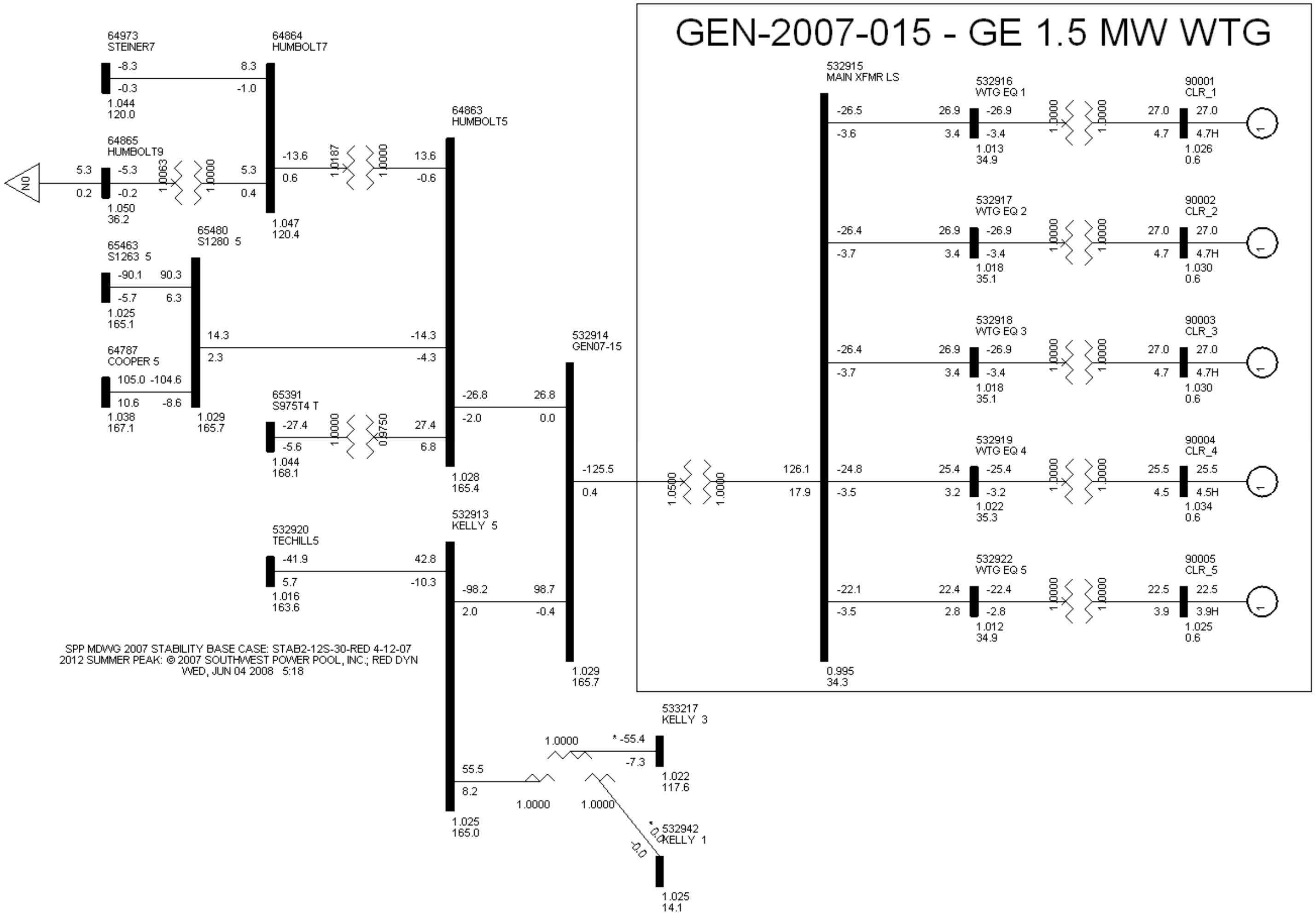

Figure 2: GEN-2007-015 and nearby buses for summer peak 2012 with GE 1.5 MW turbines

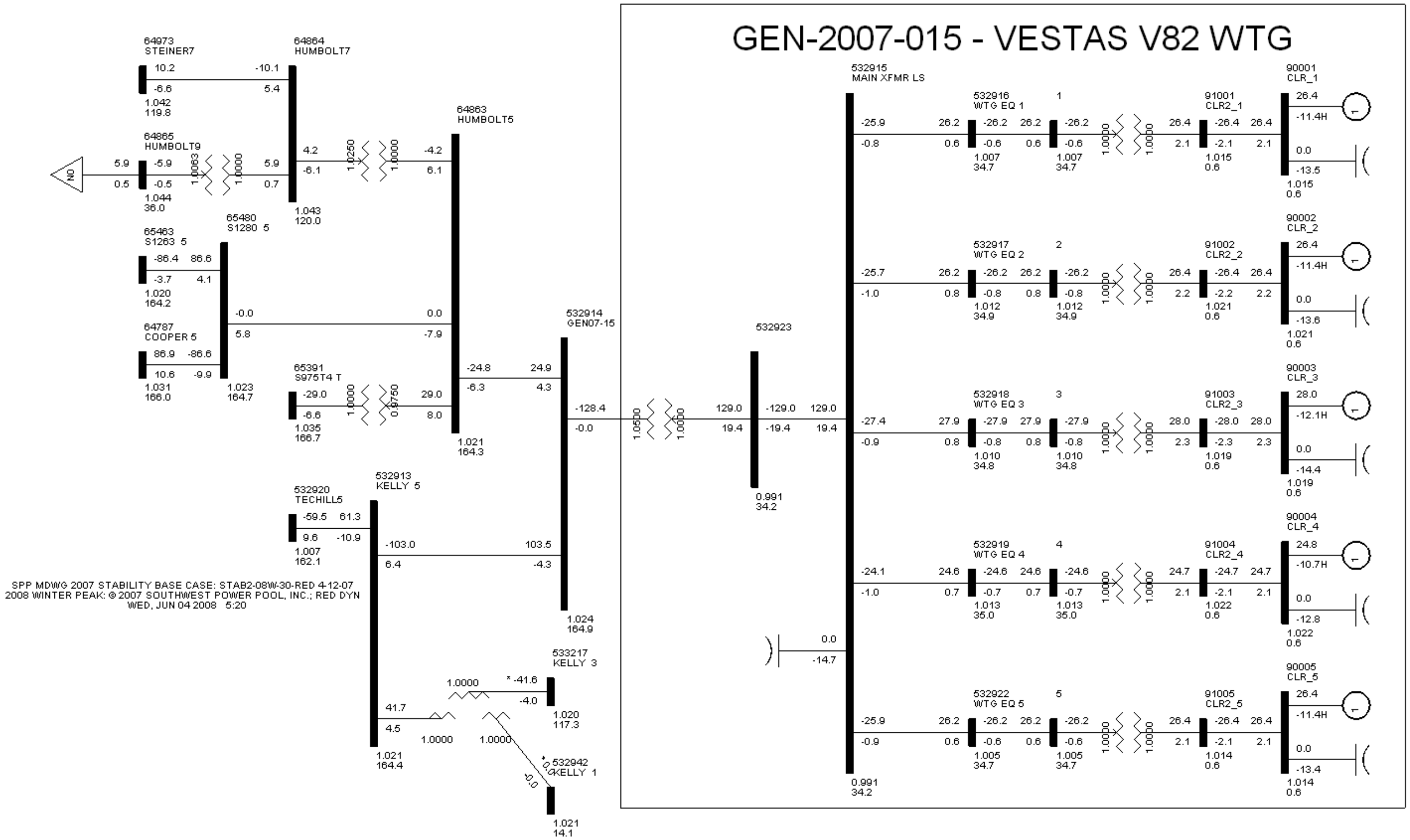

Figure 3: GEN-2007-015 and nearby buses for winter peak 2008 with Vestas V82 turbines

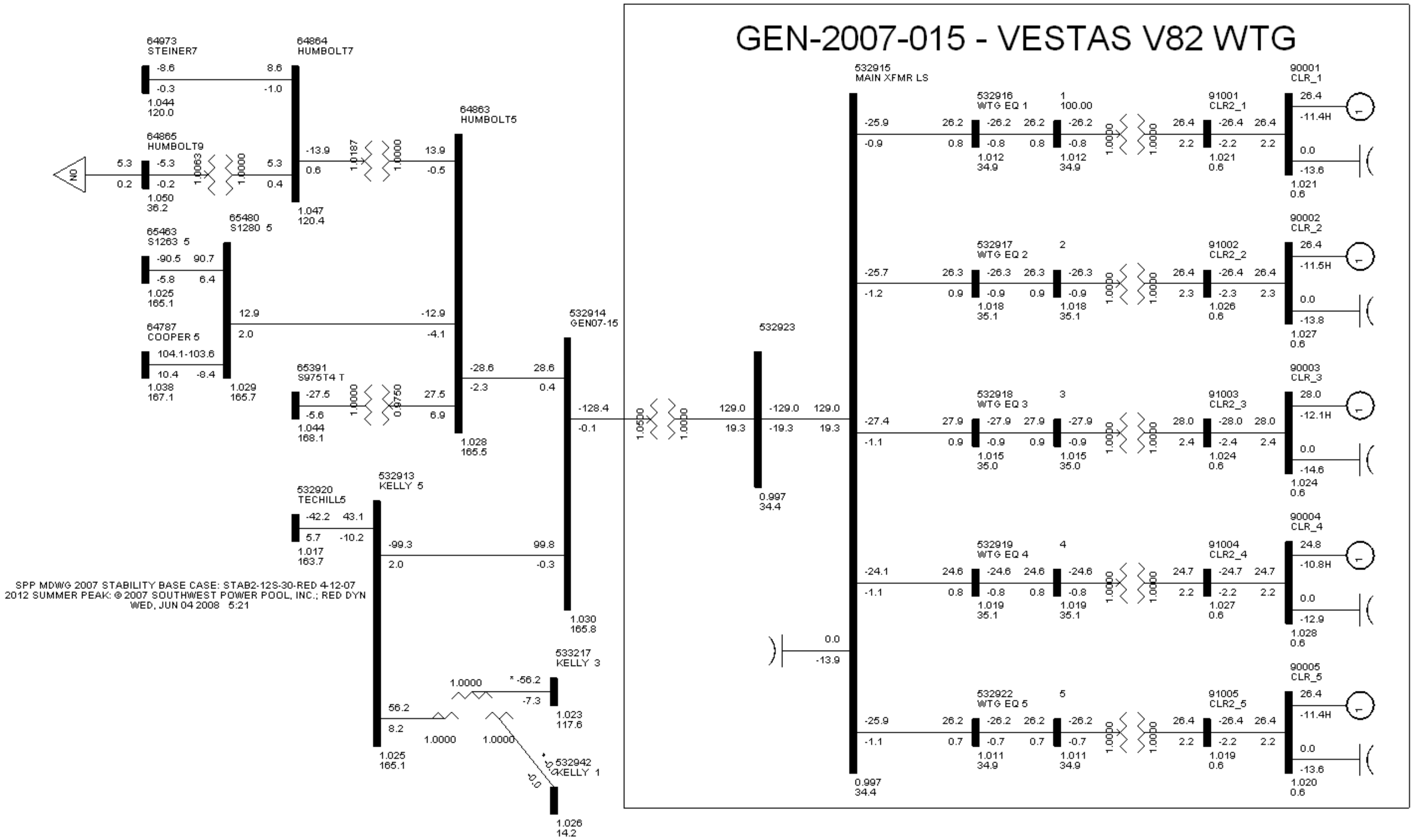

Figure 4: GEN-2007-015 and nearby buses for summer peak 2012 with Vestas V82 turbines

3. Dynamic Stability Analysis

Dynamic simulations were performed for fault contingencies in Table 3 with and without GEN-2007-015.

Table 3: Fault Contingencies Evaluated

Cont. No.	*Cont. Name*	*Description*
1	*FLT13PH*	3 phase fault on the Wind Farm (532914) to Kelley (532913) 161kV line, near the Wind Farm. a. Apply fault at the Wind Farm. b. Clear fault after 5 cycles by tripping the line from the Wind Farm to Kelley. 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 (532914) to Humboldt (64863) 161kV line, near the Wind Farm. a. Apply fault at the Wind Farm. b. Clear fault after 5 cycles by tripping the line from Wind Farm to Humboldt. 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 Kelley (532913) to Tec. Hill (532920) 161kV line, near the Kelley. a. Apply fault at the Kelley bus. b. Clear fault after 5 cycles by tripping the line from Kelley to Tec. Hill. 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*
9	FLT93PH	3 phase fault on the Kelley (532217) to Seneca (533337) 115kV line, near the Kelley bus. a. Apply fault at the Kelley bus. b. Clear fault after 5 cycles by tripping the line from Kelley to Seneca. 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.
10	FLT101PH	*Single phase fault and sequence like Cont. No.9*
11	FLT113PH	3 phase fault on the Kelley (532217) to King Hill (533331) 115kV line, near the Kelley bus. a. Apply fault at the Kelley bus. b. Clear fault after 5 cycles by tripping the line from Kelley to Seneca. 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 Kelley (532217) 115/161kV autotransformer. a. Apply fault at the Kelley bus. b. Clear fault after 5 cycles by taking the auto out of service c. No recluse
14	FLT141PH	*Single phase fault and sequence like Cont. No.13*

Cont. No.	*Cont. Name*	*Description*
15	FLT153PH	3 phase fault on the Humboldt (64863) 115/161kV autotransformer. a. Apply fault at the Humboldt. b. Clear fault after 5 cycles by taking the auto out of service c. No recluse
16	FLT161PH	*Single phase fault and sequence like Cont. No.15*
17	FLT173PH	3 phase fault on the Cooper (64787) to S1280 (65480) 161kV line, near the Cooper bus. a. Apply fault at the Cooper bus. b. Clear fault after 5 cycles by tripping the line from Cooper to S1280. c. . Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
18	FLT181PH	*Single phase fault and sequence like Cont. No.17*
19	FLT193PH	3 phase fault on the S1263 (65463) to S1280 (65480) 161kV line, near the S1263 bus. a. Apply fault at the S1263 bus. b. Clear fault after 5 cycles by tripping the line from S1263 to S1280. 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.
20	FLT201PH	*Single phase fault and sequence like Cont. No.19*
21	FLT121PH	3 phase fault on the Humboldt (64864) to Steinhauer (64973) 161kV line, near the Steinhauer bus. a. Apply fault at the Steinhauer bus. b. Clear fault after 5 cycles by tripping the line from Humboldt to Steinauer. 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.
22	FLT221PH	*Single phase fault and sequence like Cont. No.21*

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.

Areas monitored: NPPD, OPPD, WERE, WEPL, MIPU, KACP, AECI

Prior queued projects monitored:

a. AECI Wind Farm on the Fairport-Cooper 345kV line comprised of 400MW of GE turbines
b. AECI Wind Farm on the Fairport-Cooper 345kV line comprised of 400MW of Gamesa turbines
c. GEN-2003-006A; 200MW of Vestes V90 turbines on the Concordia – E Manhattan 230kV line
d. GEN-2006-033; 150MW of GE turbine at McDowell 115kV substation

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 in Dynamics

The GE 1.5 MW turbine is part of the PSS/E Wind standard library model. PSS/E Wind package issue 2.0.0 dated February 2006 was used for the dynamic stability analysis. Low voltage ride through was evaluated with the voltage and frequency protection settings summarized in Table 4.

Table 4: 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

The Vestas V82 – 1.65 MW wind turbine generator model was provided by PSS/E as a compiled library model which included the mechanical and electrical sub models associated with the turbine. Low voltage ride through was evaluated with the voltage and frequency protection settings summarized in Table 5.

Table 5: Vestas V82 – 1.65 MW wind turbine generator trip settings

Relay type	Description	Trip setting and time delay	Units
Undervoltage (27-1)	Relay trips if |Vbus|<	0.90	Pu
	for t =	60.0	S
Undervoltage (27-2)	Relay trips if |Vbus|<	0.85	Pu
	for t =	5.0	S
Overvoltage (59-1)	Relay trips if |Vbus|>	1.1	Pu
	for t =	60.0	S
Overvoltage (59-2)	Relay trips if |Vbus|>	1.125	Pu
	for t =	0.1	S
Underfrequency (81U-1)	Relay trips if Fbus <	57.0	Hz
	for t =	0.1	S
Overfrequency (81O-1)	Relay trips if Fbus >	61.0	Hz
	for t =	0.1	S

3.3. Pre-Project Dynamic Simulations

Non-disturbance runs of 10 seconds were carried out on Winter Peak 2008 and Summer Peak 2012 base cases to verify proper initialization of dynamic models and to check steady-state conditions.

PSS/E version 30.2.1 was used for dynamic stability studies.

Nearby areas are stable for the fault contingencies in Table 3 in winter 2008 and summer 2012 peak cases.

Pre-project study results are summarized in Table 6 and 7 for fault contingencies in Table 3.

3.4 Post-Project Dynamic Simulations

Non-disturbance runs of 10 seconds were carried out on Winter Peak 2008 and Summer Peak 2012 base cases to verify proper initialization of dynamic models and valid power flow cases after the addition of the project.

Winter Peak 2008

Nearby areas are stable for all fault contingencies in Table 3 with the GE 1.5 MW turbines. However, with the Vestas V82 wind turbine generators, the project will not satisfy the low voltage ride through provisions in FERC Order 661A. The project will disconnect for fault #3 on high voltage relay actuation (Figure 5). Furthermore, when the V82 voltage and frequency protection is removed and fault #3 is re-studied, simulations show that voltages in the wind farm and nearby connected buses will become unstable (Figure 6).

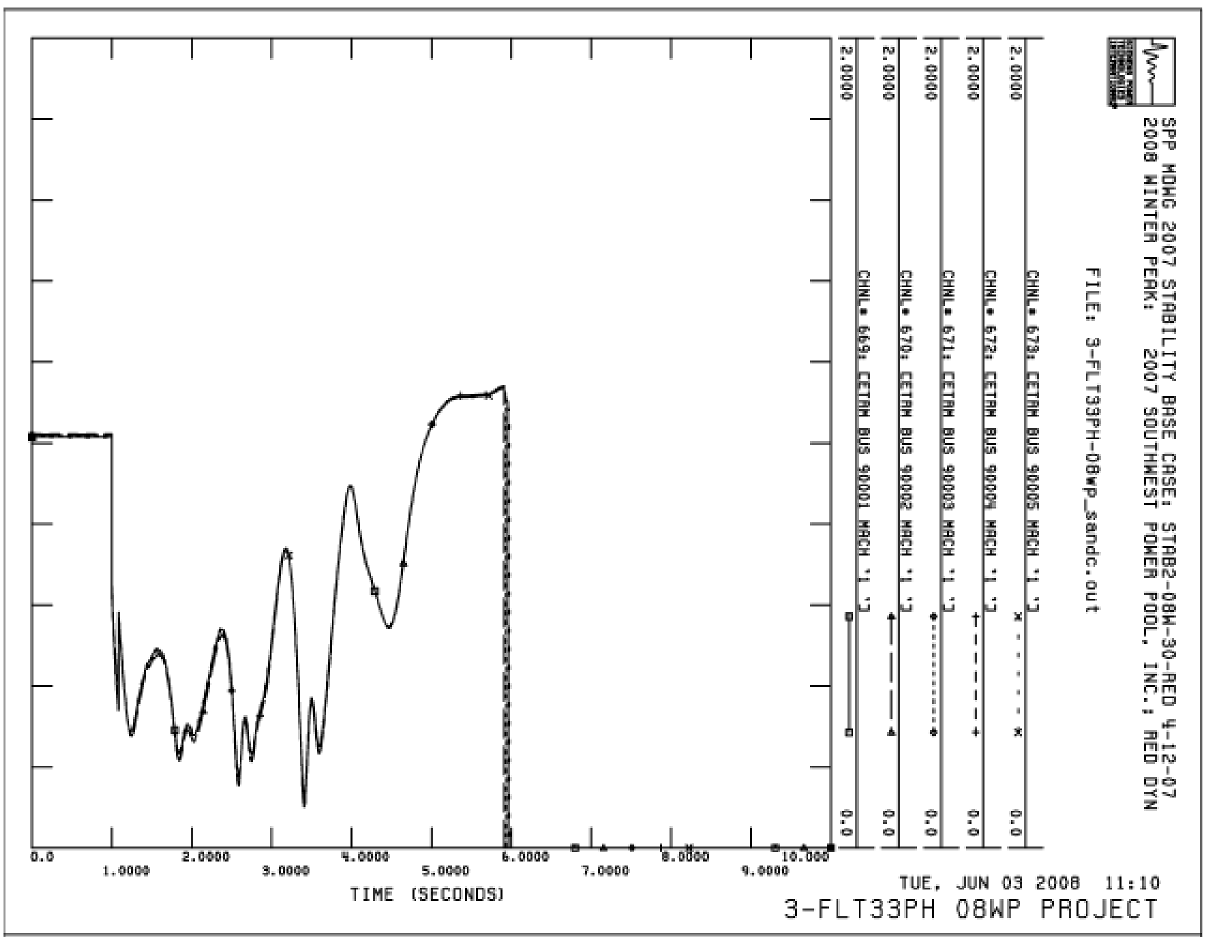

Figure 5: GEN-2007-015 Vestas V82 terminal voltages for fault #3 (Table 3)

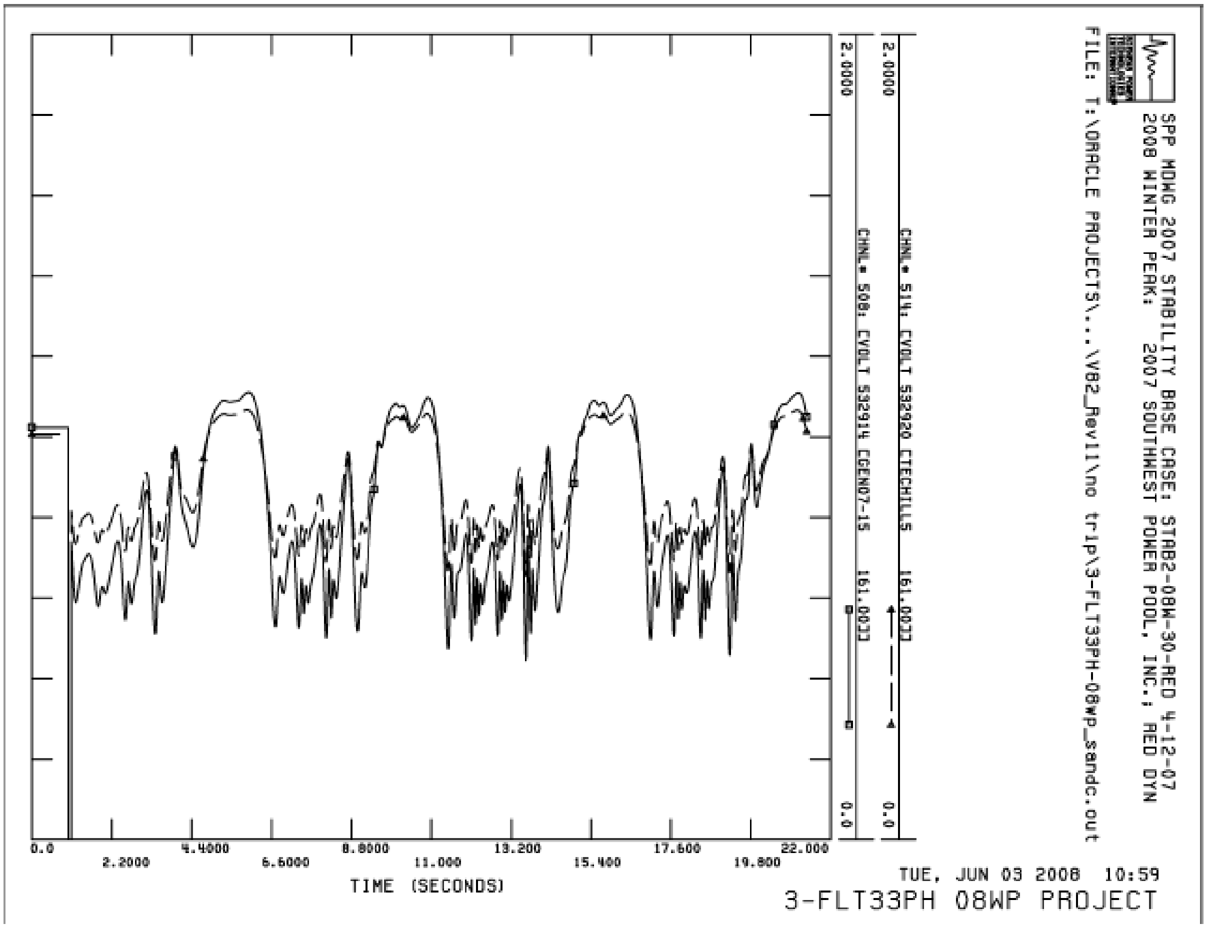

Figure 6: Voltage at GEN-2007-015 and Tec. Hill for fault #3 (Table 3)
with Vestas V82 voltage and frequency protection disabled

The transient analysis response of Figure 5 suggests that the system is weak when the 161 kV line from the POI to Humboldt is open. This weakening of the transmission system was verified through QV analysis at the POI. Figure 7 shows the pre-project and post-project QV curves. For the pre-project case, the reactive power margin is 116 MVAR (at 0.5 pu voltage). For the post-project case, the margin is 19 MVAR (at 0.96 pu) and additional reactive power injection at the POI causes the solution to diverge. The reactive power margin will decrease by 84% post-project. The steeper slope from the pre-project curve indicates that the system is stronger prior to the interconnection. For instance, 67 MVAR injection will increase the voltage to 1.11 in the pre-project case while 17 MVAR will increase the voltage to 1.11 pu post-project.

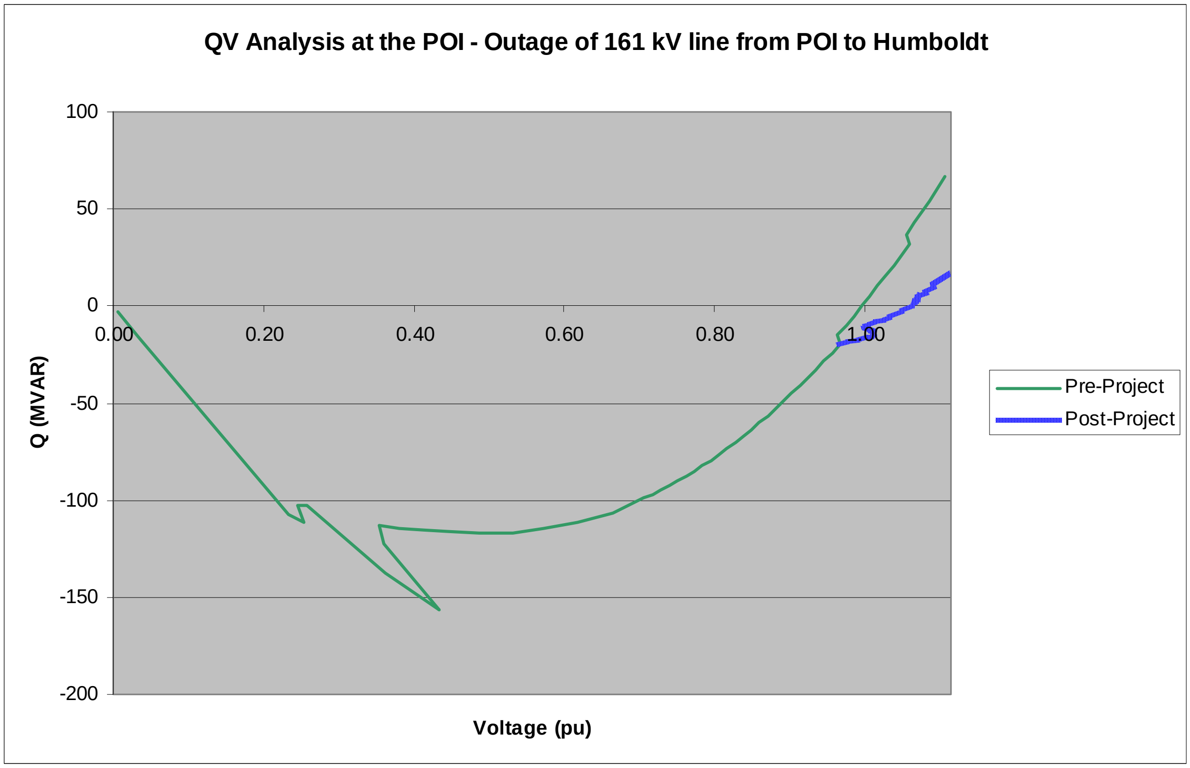

Figure 7: QV Analysis at the POI for outage of the 161 kV line from the POI to Humboldt

Simulation results indicate that a STATCON with 3.5-second minimum short-time rating of 13.75 MVA at the 34.5 kV collector bus will satisfy the requirements of keeping the project connected and maintain system stability. Furthermore, the STATCON needs to output between -3 MVAR to 4 MVAR over an extended period of time (within its continuous rating). A STATCON with short-time rating of 13.75 MVA will have a wide continuous range of ±5 MVAR or ±6 MVAR depending on the device. Figure 8 shows the net STATCON Q (MVAR) output (shown at rated voltage 1.0 p.u. voltage) for fault #3. Q injection is dependent on actual voltage at the 34.5 kV collector bus.

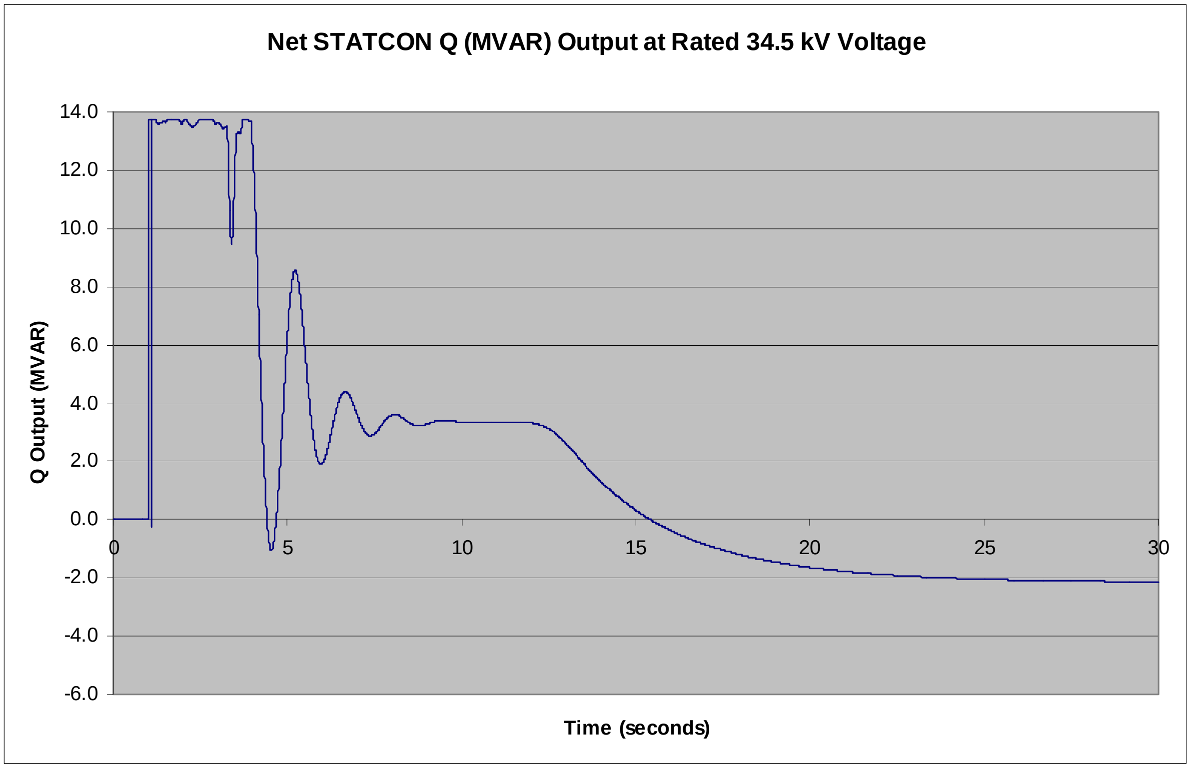

Figure 8: Net STATCON Q output at rated 34.5 kV voltage for fault #3 (Table 3) and GEN-2007-015 with Vestas V82 turbines

Post-project study results for Winter 2008 are summarized in Table 6 and 7 for fault contingencies in Table 3.

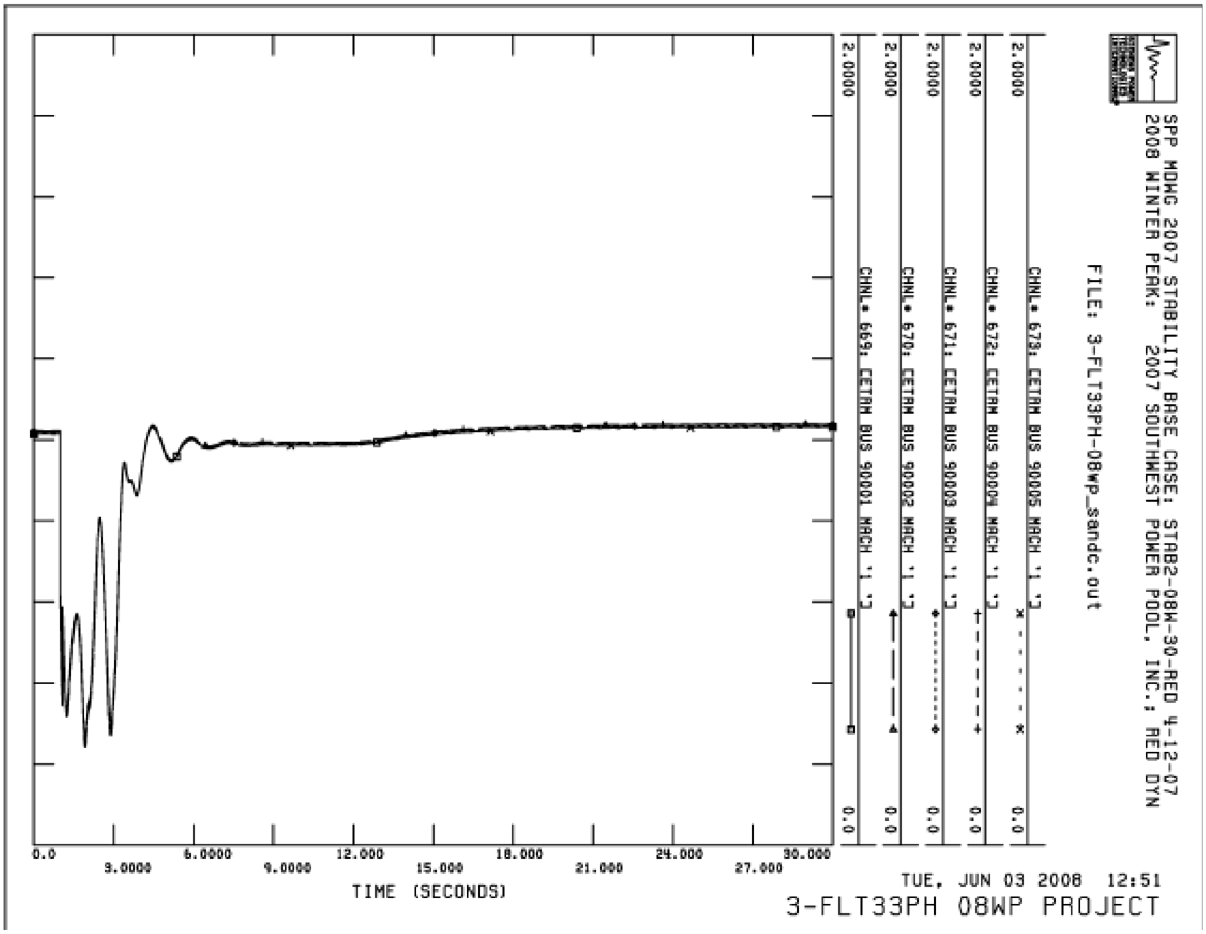

Figure 9: GEN-2007-015 Vestas V82 terminal voltages for fault #3 (Table 3) with STATCON at the 34.5 kV collector bus

Summer Peak 2012

Nearby areas will be stable for the fault contingencies in Table 3 for Summer peak 2012.

Pre-project study results are summarized in Table 6 and 7 for fault contingencies in Table 3.

Table 6: Summary of Fault Simulation Results with GE 1.5 MW wind turbine generators

Fault No.	*Description*	Winter Peak 2008		Summer Peak 2012	
		Pre-project	Post-project	Pre-project	Post-project
1	3 phase fault on the Wind Farm (532914) to Kelley (532913) 161kV line, near the Wind Farm.	STABLE	STABLE	STABLE	STABLE
2	*Single phase fault and sequence like Cont. No. 1*	STABLE	STABLE	STABLE	STABLE
3	3 phase fault on the Wind Farm (532914) to Humboldt (64863) 161kV line, near the Wind Farm.	STABLE	STABLE	STABLE	STABLE
4	*Single phase fault and sequence like Cont. No. 3*	STABLE	STABLE	STABLE	STABLE
5	3 phase fault on the Kelley (532913) to Tec. Hill (532920) 161kV line, near the Kelley.	STABLE	STABLE	STABLE	STABLE
6	*Single phase fault and sequence like Cont. No. 5*	STABLE	STABLE	STABLE	STABLE
9	3 phase fault on the Kelley (532217) to Seneca (533337) 115kV line, near the Kelley bus.	STABLE	STABLE	STABLE	STABLE

Fault No.	*Description*	Winter Peak 2008		Summer Peak 2012	
		Pre-project	Post-project	Pre-project	Post-project
10	*Single phase fault and sequence like Cont. No.9*	STABLE	STABLE	STABLE	STABLE
11	3 phase fault on the Kelley (532217) to King Hill (533331) 115kV line, near the Kelley bus.	STABLE	STABLE	STABLE	STABLE
12	*Single phase fault and sequence like Cont. No.11*	STABLE	STABLE	STABLE	STABLE
13	3 phase fault on the Kelley (532217) 115/161kV autotransformer.	STABLE	STABLE	STABLE	STABLE
14	*Single phase fault and sequence like Cont. No.13*	STABLE	STABLE	STABLE	STABLE

Fault No.	*Description*	Winter Peak 2008		Summer Peak 2012	
		Pre-project	Post-project	Pre-project	Post-project
15	3 phase fault on the Humboldt (64863) 115/161kV autotransformer.	STABLE	STABLE	STABLE	STABLE
16	*Single phase fault and sequence like Cont. No.15*	STABLE	STABLE	STABLE	STABLE
17	3 phase fault on the Cooper (64787) to S1280 (65480) 161kV line, near the Cooper bus.	STABLE	STABLE	STABLE	STABLE
18	*Single phase fault and sequence like Cont. No.17*	STABLE	STABLE	STABLE	STABLE
19	3 phase fault on the S1263 (65463) to S1280 (65480) 161kV line, near the S1263 bus.	STABLE	STABLE	STABLE	STABLE
20	*Single phase fault and sequence like Cont. No.19*	STABLE	STABLE	STABLE	STABLE
21	3 phase fault on the Humboldt (64864) to Steinhauer (64973) 161kV line, near the Steinhauer bus.	STABLE	STABLE	STABLE	STABLE
22	*Single phase fault and sequence like Cont. No.21*	STABLE	STABLE	STABLE	STABLE

Table 7: Summary of Fault Simulation Results with Vestas V82 - 1.65 MW wind turbine generators

Fault No.	*Description*	Winter Peak 2008			Summer Peak 2012		
		Pre-project	Post-project		Pre-project	Post-project	
				With STATCON			With STATCON
1	3 phase fault on the Wind Farm (532914) to Kelley (532913) 161kV line, near the Wind Farm.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
2	*Single phase fault and sequence like Cont. No. 1*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
3	3 phase fault on the Wind Farm (532914) to Humboldt (64863) 161kV line, near the Wind Farm.	STABLE	STABLE GEN-2007-015 trips off on overvoltage*	STABLE	STABLE	STABLE	STABLE
4	*Single phase fault and sequence like Cont. No. 3*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
5	3 phase fault on the Kelley (532913) to Tec. Hill (532920) 161kV line, near the Kelley.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
6	*Single phase fault and sequence like Cont. No. 5*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
9	3 phase fault on the Kelley (532217) to Seneca (533337) 115kV line, near the Kelley bus.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

Fault No.	Description	Winter Peak 2008			Summer Peak 2012		
		Pre-project	Post-project		Pre-project	Post-project	
				With STATCON			With STATCON
10	*Single phase fault and sequence like Cont. No.9*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
11	3 phase fault on the Kelley (532217) to King Hill (533331) 115kV line, near the Kelley bus.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
12	*Single phase fault and sequence like Cont. No.11*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
13	3 phase fault on the Kelley (532217) 115/161kV autotransformer.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
14	*Single phase fault and sequence like Cont. No.13*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

Fault No.	*Description*	Winter Peak 2008			Summer Peak 2012		
		Pre-project	Post-project		Pre-project	Post-project	
				With STATCON			With STATCON
15	3 phase fault on the Humboldt (64863) 115/161kV autotransformer.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
16	*Single phase fault and sequence like Cont. No.15*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
17	3 phase fault on the Cooper (64787) to S1280 (65480) 161kV line, near the Cooper bus.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
18	*Single phase fault and sequence like Cont. No.17*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
19	3 phase fault on the S1263 (65463) to S1280 (65480) 161kV line, near the S1263 bus.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
20	*Single phase fault and sequence like Cont. No.19*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
21	3 phase fault on the Humboldt (64864) to Steinhauer (64973) 161kV line, near the Steinhauer bus.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
22	*Single phase fault and sequence like Cont. No.21*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

* Voltage instability was observed at the project and nearby connected buses with Vestas V82 protection elements disabled

APPENDIX A

COLLECTOR IMPEDANCE CALCULATIONS

APPENDIX B

STATCON MODEL PARAMETERS

APPENDIX C

DYNAMIC STABILITY PLOTS - GE 1.5 MW TURBINES

Winter Peak 2008: Fault contingencies #1 thru #22

Summer Peak 2012: Fault contingencies #1 thru #22

WINTER PEAK 2008

Fault contingencies #1 thru #22

SUMMER PEAK 2012

Fault contingencies #1 thru #22

APPENDIX D

DYNAMIC STABILITY PLOTS - VESTAS V82 TURBINES

Winter Peak 2008:	Fault contingencies #1 thru #22 (without STATCON)
Winter Peak 2008:	Fault contingency #3 with Vestas V82 voltage and frequency protection elements disabled (without STATCON)
Winter Peak 2008:	Fault contingency #3 with STATCON at the 34.5 kV collector bus
Summer Peak 2012:	Fault contingencies #1 thru #22 (without STATCON)

WINTER PEAK 2008

Fault contingencies #1 thru #22
(without STATCON)

WINTER PEAK 2008

Fault contingency #3 with Vestas V82 voltage and frequency protection elements disabled (without STATCON)

WINTER PEAK 2008

Fault contingency #3 with STATCON
at the 34.5 kV collector bus

SUMMER PEAK 2012

Fault contingencies #1 thru #22
(without STATCON)